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Perspective

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The Promise of Community Citizen Science

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In 2010, concerned citizens in the Gulf States responded to the Deepwater Horizon oil spill by developing low-cost, do-it-yourself technologies to monitor and map oil pollutants in the environment (Brownstone, 2014; McCormick, 2012; SkyTruth, 2016; Carmichael, 2015). Centralized platforms and crowdsourcing applications empowered the public to engage and contribute to disaster response efforts in ways they could not before.

In Flint, Michigan, in 2015, community members collaborated with scientific experts to collect tap water samples that demonstrated the existence of high lead levels in drinking water. The data forced state officials to acknowledge that a problem existed and to begin implementing mitigation actions (Hanna-Attisha et al., 2016).

In Sunset Park, New York, youth members of UPROSE, Brooklyn's oldest Latino community-based organization, gathered air quality samples and tracked vehicle activity in areas associated with sanitation truck traffic (UPROSE, 2017). The activities, carried out in 2016, informed a campaign to transform the commercial waste industry in New York City.

Across Pennsylvania, Save Our Streams PA, a small group of citizen activists, is currently enlisting the public to find and map the more than 150,000 abandoned oil and gas wells located on private and public lands (Save Our Streams PA, undated; Moskowitz, 2014). Because of methane leaks, abandoned wells are a potential source of environmental contamination. Given the natural gas drilling boom and construction of new wells, activists are concerned that the problem will only grow in the future.

These examples—diverse in topic, geography, and scope—all illustrate the emergence of citizen science into the decisionmaking sphere. Although multiple definitions abound, citizen science is, at its core, public participation in research and scientific endeavors. While the citizen as scientist is an old tradition dating back centuries (Cooper, 2016), new technological and societal developments are reshaping the phenomenon for current and future generations. Different models of citizen science are proliferating across various disciplines. Citizens volunteer as data collectors in science projects;

they collaborate with scientific experts on research design; and as exemplified by the participants in our four examples, they actively lead and carry out research. The last form of citizen science, community citizen science, tends to be action-oriented, highly collaborative, or independently led by citizen volunteers, with research conducted to support interventional activities or policy change. Community citizen science can, therefore, be of particular importance to those working at the nexus of science and decisionmaking.

To understand the promise of community citizen science, one must first understand what might motivate individuals without scientific expertise, hereafter referred to as volunteers, to pursue research as a means of action. In the cases shown earlier, the act of engaging in data collection and analysis may serve many different purposes. Beyond addressing research questions, community citizen science may represent a challenge to existing assumptions about the nature of scientific expertise. It can be a means of defining a scientific problem in terms of community interests. It may be a call for policy discussions to include citizens as experts in their own right, bringing a perspective not currently represented. And it may be born out of frustration that community voices often go unheard and a distrust of institutions and experts who have traditionally been called on to solve problems.

In today's political atmosphere, the role and very nature of expertise in all forms is being challenged and questioned (Norman, 2016; Pew Research Center, 2015a; Pew Research Center, 2015b). There is a growing trend toward public skepticism and mistrust of science itself as an objective input into decisionmaking. As both a scientific and social movement, community citizen science may hold transformative power to change this trend by disrupting scientific norms, the nature of data collection, and decisionmaking processes. Whether its disruptive nature will yield positive change for science and society or further harden discords felt across societal groups—or both—is a difficult question to answer. But it does point to the urgent need for citizens, scientists, and decisionmakers at all levels to work together to shepherd this evolution in the relationship between science and decisionmaking.

Purpose and Organization of This Perspective

This Perspective examines the transformative potential of community citizen science for communities, science, and decisionmaking. We, the authors, use citizen as a catchall term that includes any member of the public (i.e., irrespective of citizenship status). In addition, our conceptualization of decisionmaking captures all arenas and institutions in which decisions with broad-level community impacts may be made. Examples include government, industry, and academia.

The Perspective is based on the authors' experiences working in collaboration with community groups, extensive readings of the scientific literature, and numerous interviews with leading scholars and practitioners in the fields of citizen science and participatory research. The Perspective presents our synthesis of research findings to date; future publications will provide more in-depth assessments of literature topics and themes and interviewee perspectives on citizen science and decisionmaking.

In the following sections, we first discuss different models of citizen science to provide context for the specific model of community citizen science. We next present a brief history of the rise of community citizen science and then look at possible factors motivating its development, drawing from an exploration of the relationships between citizen, science, and decisionmaking. In the last section, we consider the areas in which community citizen science may hold promise in terms of outcomes and impacts, discuss concerns that may hinder its overall potential, and assess the roles different stakeholders may play in continuing to develop community citizen science into a positive force for science and society.

What Is Community Citizen Science?

Many scholars charting the modern citizen science movement have characterized activities according to the level of public involvement and the degree to which citizens exhibit control or ownership over the work. For example, Wilderman (2007) categorized citizen science based on answers to five questions: (1) Who defines the problem? (2) Who designs the study? (3) Who collects the samples? (4) Who analyzes the samples? (5) Who interprets the data? The answers to these questions have led Wilderman and others in the field, such as Shirk et al. (2012) and Bonney et al. (2009), to develop different models of citizen science. These models range from consulting or contractual, in which communities ask experts for help with a specific question (science for the people), to contributory, in which the public is involved in data collection and analyses under studies run by experts, to collaborative, in which the public is involved in or leads all aspects of research from problem definition to data interpretation (science by the people). Our discussion of community citizen science situates itself at the level at which citizens exert higher levels of control and ownership in scientific research processes, up to and including outright independence from established experts. These models have been given other names in the literature, including cocreated science, community science, civic science, collegial science, community-based participatory research, and street science. Given the lack of a standard nomenclature (Eitzel et al., 2017), we refer collectively to the models of citizen science in which citizens exert a high degree of control and ownership over scientific activities as community citizen science.

The production of scientific knowledge through citizens' self-motivated activity and personal time dates back centuries, and many of our greatest scientific achievements arose under a citizen scientist model.

The Rise of Community Citizen Science

The idea of volunteers—that is, people with no formal scientific credentials—conducting scientific research is not new. The production of scientific knowledge through citizens' self-motivated activity and personal time dates back centuries, and many of our greatest scientific achievements arose under a citizen scientist model. The seminal discoveries in 18th century biology were essentially self-financed activities, and many of these researchers lacked credentials in the object of their study (Nirenberg, 2010; van Wyhe, 2012; Browne, 1995). Gregor Mendel, Alfred Russel Wallace, and Charles Darwin all financed their work with their own funds or funds from their communities.

The current U.S. academic-governmental scientific system largely originated after World War II (WWII) with vast increases in government research spending originally related to the war effort

A History of Amateur Scientists

Gregor Mendel conducted his genetics experiments with financing from his abbey. His research ended when he was promoted to abbot, after which he no longer had sufficient personal time to conduct his studies (Nirenberg, 2010). Alfred Russel Wallace, who jointly published the theory of evolution by natural selection with Charles Darwin, self-financed his own work in the Amazon and Asia by selling animal specimens and, later, by selling his popular travel book *The Malay Archipelago* (van Wyhe, 2012). The choice of young Charles Darwin, based on his naturalist side pursuits, to voyage on the HMS *Beagle* was largely an idiosyncrasy of Captain Robert FitzRoy, who desired an educated companion and naturalist for the journey. More standard protocol would have called for a professional collector and Navy man (Browne, 1995).

and continued to be fueled by the Cold War (Mazuzan, 1995; Science Coalition, undated; Jahnke, 2015). The modern peer-review method dates to this time as well. Prior to WWII, manuscripts were reviewed by journal editors or informally by the author's own request to professional colleagues (Shema, 2014; Fyfe, 2015; Spier, 2002). Scientific truth was seen as adjudicated by the community's reading of the article and by replication of findings by other researchers, rather than by the assessment of two to five anonymous reviewers, as is the protocol today. WWII also saw the birth of "big science" involving large-scale institutions and collaborations, which reinforced the trend toward formal science (Hiltzik, 2015). The growth of science advisory committees and the increasing role of scientists in government affairs post-WWII led to public concern over the perception of a scientific "elite" influencing policies in secret to the benefit of their own interests. These fears were articulated by President Eisenhower in his farewell address:

> In this [technical] revolution, research has become central, it also becomes more formalized, complex, and costly. . . . Today, the solitary inventor, tinkering in his shop, has been overshadowed by task forces of scientists in laboratories and testing fields. In the same fashion, the free university, historically the fountainhead of free ideas and scientific discovery, has experienced a revolution in the conduct of research. . . . [In] holding scientific research and discovery in respect, as we should, we must also be alert to the equal and opposite danger that public policy could itself become the captive of a scientific-technological elite. (Eisenhower, 1961)

Eisenhower's concerns about public policy becoming captive of a scientific-technological elite persist, and these concerns contribute to the modern citizen science movement. Rather than see these concerns as de facto antiscience, scientists may instead view them as a call to renewal and reaffirmation of the fundamental values of questioning and antiauthoritarianism intrinsic to science. The scientific method, which at its root insists that there can be no arguments from authority and no evidence that is not open to public examination, may be radically at odds with the social institutions of the humans who employ it. Peer review, federal funding for research, or any other societal institution may be perpetually susceptible to public scrutiny. With the rise of citizen science, we hope that scientific debate can now motivate, as in Darwin's day, an educated and observant public to help renew the scientific enterprise for the production of greater knowledge.

Motivations for the Rise of Community Citizen Science

Compared to contributory and collaborative research models, the community citizen science model is sparsely represented in the scientific literature. Therefore, to explore possible motivating factors in the rise of community citizen science, we relied on interview findings and drew inferences from a broader set of literature that included research on science communication and issues related to public trust and understanding of science. In the following sections, we briefly discuss three potential motivators for community citizen science: (1) scientific uncertainty and complexity in decisionmaking; (2) a growing embrace of citizen science by the larger scientific community; and (3) the effects of new technologies in providing greater opportunities for public engagement in scientific activities.

Scientific Uncertainty and Complexity in Decisionmaking

Science plays a unique and essential role in many kinds of decisionmaking. The United States reaches decisions on social norms and policies through a representative democratic process, and scientific understanding provides the evidence and theory-based frameworks to guide their implementation. Science, however, is not a perfect guide for decisionmaking:

> Science is sufficiently rich, diverse, and Balkanized to provide comfort and support for a range of subjective, political positions on complex issues such as climate change, nuclear waste disposal, acid rain, or endangered species. . . . The problem is not one of good science versus bad, or "sound" science versus "junk" science. The problem is that nature can be viewed through many analytical lenses, and the resulting perspectives do not add up to a single, uniform image, but a spectrum that can illuminate a range of subjective positions. (Sarewitz, 2000)

That one can draw from science to find support for various positions is both a testament to the richness and inclusive nature of science and a cause for challenges to its credibility in decisionmaking. The issue lies in the scientific uncertainty that accompanies scientific evidence. Researchers accept or even embrace uncertainty and the trial-and-error nature of experimentation. For those less familiar with the scientific process, the publication of conflicting scientific findings may create an impression that science is not inherently better or worse than other, including subjective, decision inputs. Furthermore, when scientific uncertainty is actively exploited to seed doubt or confusion, as in the cases of tobacco harms or asbestos exposure, public trust in science as a valid process for solving problems is compromised (Oreskes and Conway, 2011; Michaels, 2008). The negative ramifications of these issues may be compounded by a growing public perception that scientific experts have failed to solve many societal problems. When it is community citizen scientists, and not local experts, who act to demonstrate against unsafe drinking water in Flint, Michigan, or identify the environmental impacts of an oil spill, faith in scientific experts starts to erode.

Another issue affecting scientific credibility is the use of science within policy debates. Controversy surrounding a myriad of issues, such as air quality, nuclear storage, biodiversity, healthcare, and biotechnology, may arise from economic concerns, ideology, ethics, equity, and local and regional politics. At the same time, the policy debates over these issues often draw from the language of science. Complex technical arguments can overshadow or even prevent discussion of stakeholders' values or preferences, which may well be at odds with each other (Cortner, 2000). In such cases, science can become a target of criticism from all sides of an issue. At worst,

Community Citizen Science in Action in Flint, Michigan

A mother concerned about the health of her family responded to changes in Flint's water quality by reaching out to a researcher (a professor of environmental and water engineering) at Virginia Polytechnic Institute and State University who previously had addressed water quality issues in Washington, D.C. (Edwards and Walters, 2017). The collaboration assured sound collection and testing of water samples by Flint residents, generating data that motivated responses at municipal, state, and federal policy levels. The situation illustrates how activism can be grounded in sound methods, how the results from such methods can influence public policy and government action, and how citizen-scientist partnerships can serve constructive ends. Flint's situation may be an anomaly, in that state officials were reportedly dismissive of the concerns raised by the community's citizens. Other state departments of environmental management have developed and used frameworks and guidance for making use of data contributed by volunteers, with the nature of that use dependent on the quality of the data contributed (see, for example, Indiana, undated, and Virginia Department of Environmental Quality, undated).

the underlying issues are never resolved, and successful democratic actions are stymied. When this happens, scientific institutions engaged in the technical debates can unwittingly reinforce a system that separates the public from science, and citizens from decision-making processes, with negative ramifications for democracy as a whole.

From the volunteer perspective, then, community citizen science may provide the means of allowing citizens to add their own perspectives to scientific and policy conversations, fill perceived credibility gaps in scientific expertise, and change the language and direction of policy debates to include a greater range of considerations (Edwards and Walters, 2017; Ottinger, 2009).

The Scientific Community's Embrace of Citizen Science

The view from the scientific community appears to be trending toward greater inclusion or, at the least, recognizing the value of citizen involvement in science for decisionmaking (Drahota et al., 2016; General Services Administration, 2016). Over the past 30 years, there has been a steady rise in participatory research approaches across scientific disciplines, with the public engaged alongside scientific experts as coproducers of knowledge (Drahota et al., 2016). This rise coincides with growing interest on the part of research funders and practitioners across public and private sectors in results-oriented research and translation of research to practice (National Center for Advancing Translational Sciences, 2017; National Institute for Occupational Safety and Health, 2015; National Institute of Environmental Health Sciences, 2016; Gebbie, Rosenstock, and Hernandez, 2003).

Researchers have a variety of reasons for engaging in participatory approaches, such as community citizen science. Reasons can range from a sympathetic desire to address community concerns, to a sincere belief in the value of a collaborative and democratic process, to the realization that, for science to be relevant, useful, and beneficial to society, research must be conducted with community input in some shape or form (Kennedy et al., 2009). Notwithstanding the trends, today's participatory research approaches still represent a tiny fraction of scientific research as a whole. And researchers note continued difficulties in obtaining funding for community engagement work within fields in which there is not a strong tradition or philosophy of public involvement and societal applications of research results. In addition, the nature of community engagement projects, with lengthy times to completion, metrics for success that are not widely accepted (e.g., strength of partnerships versus number of published papers), and lack of senior mentors to guide upcoming researchers all point to institutional challenges that will require sustained efforts to overcome (Teufel-Shone, 2011). Nevertheless, the more balanced the engagement of citizens and scientists, the more the potential for transformative change—where academic scientists, government scientists, industry scientists, and now citizen scientists have freedom to generate, cocreate, and pursue ideas for the betterment of all.

Greater Opportunities for Citizen Scientists to Engage Through Technology

Recent technological advances have lowered the barrier to entry for individuals to find and engage in citizen science (Newman et al., 2012; Bishop, 2014). New tools for data collection and other infrastructure are now inexpensive and available for broad use. Cellphones and other mobile technologies are capable of recording detailed image data collection in photographs and video; tracking location and position information via the Global Positioning System and accelerometers; and collecting other types of information, such as air or water quality, through integration with mobile sensors. These data, in turn, can be shared and pooled through the internet, increasingly engaging dedicated platforms as well as social media platforms. This has not only made participating in citizen science more accessible but, for many applications, can enhance the value of each individual's contribution by aggregating data into massive, crowdsourced databases. Sometimes engaging with modern computing tools and high-tech equipment can require a degree of expertise and specialized skills that may be unattainable for the average citizen scientist. The new platforms avoid that problem, facilitating public engagement and participation through their accessible and understandable user interfaces. Platform systems also enable online delivery of certain kinds of training. Therefore, with increasing access to the right tools and information, citizens

The Rise of Platforms for Increasing Public Engagement and Access to Science

Barriers to entry into citizen science are also lower because individuals need not sacrifice years of their lives to engage in research; rather, they can, for example, rapidly catalogue wildlife in their communities with such groups as iNaturalist. In a manner similar to how Darwin and Wallace were recognized experts in their own time, iNaturalist is building a collaborative citizen science model in which individuals' expertise as naturalists is recognized based on their contributions of work performed rather than on their academic credentials. Such groups as Public Lab are creating online platforms for individuals to collaborate and share research questions, data, and do-it-yourself tools addressing environmental issues in their communities. Safecast was founded in 2011, following the Fukushima Daiichi Nuclear Power Plant accident, and is dedicated to providing citizens around the globe with the tools they need to monitor and share environmental data. Organizing platforms, such as SciStarter and Zooniverse, are providing centralized spaces for projects to find matches with interested citizen scientists. And such sites as the American Geophysical Union's Thriving Earth Exchange offer mechanisms for coordinating community needs with experts who can help achieve those needs.

are expanding when and where scientific research takes place, with the effect of producing a more scientifically engaged and educated public, advancing different fields of science, and yielding evidence that could potentially be used to advance change.

Achieving the Promise of Community Citizen Science

A Promising Future for Community Citizen Science

Across the spectrum of citizen science, the promise of the entire enterprise for lowering the cost and increasing the reach of research, promoting public interest and education, and generating novel approaches for addressing research questions has generated excitement and optimism for the future of this budding field. A newly formed society for both scholars and practitioners, the Citizen Science Association, and the establishment of its journal are milestones in the formalization of citizen science as a field of inquiry, based on the belief that the success of public participation in research as a whole, "takes dedication not just from volunteers, but from organizers, educators, scientists, data managers, technology specialists, evaluators, and others" (Citizen Science Association, undated). By sharing insights across scientific disciplines, the association aims to accelerate continued growth of both research by citizen scientists and the scholarship of citizen science.

Recent government actions have also demonstrated an embrace of citizen science at the federal, state, and local levels. The American Innovation and Competitiveness Act, Public Law 114-329, was signed into law in January 2017. Section 402, the Crowdsourcing and Citizen Science Act, encourages federal science agencies to use crowdsourcing and citizen science to advance agency missions and stimulate public participation in scientific research. A federal community of practice with members across different agencies is working to improve and expand governmental use of crowdsourcing and citizen science (Citizenscience.gov, 2017). Meanwhile, reflecting the often local nature of community citizen science efforts, state and municipal government agencies have connected with citizen science, particularly around environmental monitoring issues (Indiana, undated; Virginia Department of Environmental Quality, undated).

The formalization of citizen science as a field unto itself has many benefits. Formalization provides a structure and mechanisms for sharing research, coordinating activities across researchers and citizen scientists, deriving best practices across research studies, evaluating activities, and promoting and disseminating work. It allows pooling of intellectual and social capital and, importantly, creates opportunities for growth and development. Community citizen science, in particular, can benefit greatly from integration with formal citizen science structures. When research activities are being led and carried out by volunteers, it is especially important to understand where such activities can integrate expert knowledge and what role, if any, scientific experts should play. When more collaborative ventures take place, researchers and citizen scientists can draw lessons about creating, maintaining, and sustaining effective partnerships through the experience of others.

In its ideal form, community citizen science is a field in which engaging people in knowledge generation, problem-solving, data interpretation, and research translation leads to more robust, open, and democratic decisionmaking processes (Ottinger, 2009). Through this type of science, communities may foster education and literacy, build social capital, create knowledge resources, and

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grow future leaders. There are many ways community citizen science may lead to the ideal future envisioned above; as we found in the literature and as came up in our interviews, there are plenty of examples of groups leading the charge. For instance, citizen science platforms, such as Public Lab, SciStarter, and others mentioned earlier, are building community capacity and infrastructure by providing access to information, tools, and online communities of practice. AIDS activists in the 1980s showed how the process of learning and becoming scientific experts in their own right upended existing research standards and led to real changes in clinical decisionmaking and treatment practices (Epstein, 1995). Meanwhile, since much citizen science addresses local concerns, the potential for place-based citizen science to affect local decisionmaking is only beginning to emerge (Newman et al., 2017). In the last five years, the RAND Corporation has begun collaborating on community citizen science projects with groups in Louisiana and New York. Our partner in Terrebonne Parish, Louisiana, Bayou Interfaith Shared Community Organizing, is promoting education and scientific literacy by training community members to monitor environmental pollution and become neighborhood citizen scientists (National Academies, 2017). In New York City, we collaborate with the New York City Environmental Justice Alliance and UPROSE, both of which are putting their own research on the unique vulnerabilities of urban industrial waterfront communities into practice and improving citywide policies (UPROSE, 2017; Bautista et al., 2014). By building community capacity, promoting education, strengthening community engagement, or influencing decisionmaking, these examples all demonstrate the value and potential of community citizen science for achieving transformative change.

Potential Concerns About Community Citizen Science

Alongside the promise and promotion of citizen science, a number of concerns have been raised about the credibility and use of citizen science outputs. Questions about data quality and citizen science expertise are still common sources of misgivings (Conrad and Hilchey, 2011; Gouveia et al., 2004), despite a body of work indicating that proper quality control, data validation, and training procedures will produce scientifically rigorous results for citizen science projects (Bautista et al., 2014; U.S. Environmental Protection Agency, 2017). Data quality may be a concern in any model of citizen science, although such concerns can be alleviated by addressing the fitness of the data for the intended use. Community citizen science, however, exhibits some unique characteristics that may cause additional scrutiny of its activities. The concerns noted in the following discussion may be highly relevant to the independent model of community citizen science—in which citizens lead and carry out their own research with little outside collaboration—but collaborative models may also be affected by virtue of their close associations with citizen scientists.

First, many community citizen science projects are carried out because of community concerns and thus walk a fine line between research and advocacy. Although advocacy has often made use of scientific findings (sometimes using the same findings on both sides of an issue), the perception of bias is a concern when scientists have a large stake in research outcomes (Conrad and Hilchey, 2011; Whitelaw et al., 2003). For instance, industry challenged a 2014 study showing high air concentrations of volatile compounds near hydraulic fracturing (or "fracking") sites both for its use of low-cost "bucket" air monitors and the underlying politics of the citizen scientists who participated in the study (Macey et al., 2014; Brown, 2014). While it is fair to consider the issue of bias, everyone, expert or amateur, citizen scientist or industry scientist, has conscious and unconscious biases; holds various moral and ethical values; and is influenced by social, cultural, and professional norms (Cortner, 2000; Haller and Gerrie, 2007). The best avenue for dealing with real or perceived bias is to ensure that scrutiny is placed on the research rather than the researcher. To that end, government organizations, such as the U.S. Environmental Protection Agency and state-level agencies, have established clear criteria for evaluating citizen science data that focus on the data contributed and not the contributors (U.S. Environmental Protection Agency, undated). At the same time, community citizen science, as with all forms of research, would benefit from transparently documenting project objectives, design, methods, and analyses to foster collaborative discussions around problem-solving and deter arguments centered on motivations and objectivity (Whitelaw et al., 2003).

A second concern about community citizen science arises when volunteer activities run counter to the prevailing scientific consensus. A prime example of this phenomenon is the current antivaccination movement. With roots that trace back to a (now-discredited) 1998 study (Wakefield et al., 1998) linking the measles, mumps, and rubella vaccine to onset of autism in children, the modern-day antivaccine movement in the United States has been slowly growing (Dube, Vivion, and MacDonald, 2015). Beyond vaccination, scientific consensus has emerged on many other topics on which public skepticism endures in pockets, such as the safety of genetically modified food and the causes and consequences of climate change. The persistence of controversies in these and other areas suggests

Community Citizen Science and Industry: A Complex and Evolving Relationship

What role does industry play in community citizen science? Growth in citizen science has been enabled by the proliferation of affordable and portable tools, such as sensors in cellphones, and platforms citizen scientists can use to communicate, such as Facebook and Twitter, as well as dedicated platforms fostered by nonprofits, such as SciStarter and Zooniverse. Some private companies whose businesses relate to science and technology also reach into their communities to assist with science, technology, engineering, and math education. In some industry segments, community citizen science is viewed warily as a vector for activism. This situation typically arises where local concerns about air or water quality are associated with industrial effluents. It can be complicated by differences in outlook about what is an appropriate way to measure and analyze a problem, differences that are intensified by the nature of standards linked to regulations imposed on companies. Understanding the landscape of interaction between industry and community citizen science and options for improving these interactions constitutes an area for further research.

the possibility that they could engender a kind of contrarian citizen science. At a minimum, such a development would reflect deficiencies and limitations in the way scientific experts communicate about their science and its results. Already, science communication scholars recommend a scientific dialogue that seeks to directly incorporate and address public fears versus one that operates under an assumption of public ignorance (Goldenberg, 2016; Pouliot and Godbout, 2014).

Finally, researchers and community groups note limitations in the translation and use of citizen science research. Successful translation is critical for demonstrating the value of community citizen science and ensuring accountability to those involved in the research. Yet in a review of the literature, Conrad and Hilchey found that one of the greatest challenges for community-based monitoring, or citizen monitoring of environmental systems, is the lack of dissemination and use of data collected (Conrad and Hilchey, 2011; Bonney et al., 2014). After the Deepwater Horizon oil spill, the Louisiana Bucket Brigade and Tulane University expressed regret that, due to limited resources, they could not package the data and results from their crowdsourced mapping application to present to relevant agencies for use in response activities (Ports, 2011). The "success" of Flint, Michigan—with success defined as recognition that a problem even existed—came about only after lengthy battles between community citizen scientists and professional scientists and state regulators (Hohn, 2016). Part of the problem may lie in the novel nature of citizen science research for decisionmaking and the lack of institutional procedures in place for incorporating citizen science data. There are promising signs that government agencies, industry, and other professional organizations are developing such mechanisms for the use of citizen science data, opening up doors for truly influential citizen research (Indiana, undated; National Advisory Council for Environmental Policy and Technology, 2016).

Shepherding the Future of Community Citizen Science

Citizen science as a formal field of scholarly inquiry is a recent development. Accordingly, the literature is only beginning to provide guidance on best practices for development of community citizen science, in particular to avoid potential pitfalls and attain its promise. This Perspective contains our reflections on the research we have conducted to date. While our work continues to determine major barriers to the success of community citizen science and to identify and evaluate actions that could be taken to enhance the chances for success, in this section we provide a snapshot of some potential actions that we have identified through the literature and our interviews. The table on p. 12 presents our categorization of actions by people, processes, and structures. Future work will explore such issues as priority-setting, feasibility, and implementation of actions.

Conclusions

Eisenhower lamented the loss of the "solitary inventor, tinkering in his shop" (Eisenhower, 1961). Today, he might be heartened to witness a rebirth of inventors, scientists, do-it-yourselfers, and makers at all levels of expertise. Instead of operating as solitary figures, many are taking advantage of new technologies for networking and coordination to work collaboratively; learn from each other; and share knowledge, insights, and findings. As the knowledge and mechanics of science become more accessible to citizens, people are acting to fill a void, redefining what it means to be an expert,

Potential Actions for Successful Development of Community Citizen Science

Category	Potential Actions
People	• **Scientists:** Consider ways to engage with stakeholders, communities, or research subjects that are central or peripheral to the research itself. If not conducting participatory research, make efforts to communicate and disseminate findings. • **Citizen scientists:** Take advantage of existing citizen science platforms to develop understanding of different projects and how scientific research is carried out and to find a community of practice for areas of interest. • **Government:** Continue public messaging about federal, state, and local citizen science initiatives and create guidance for integrating community citizen science research into policy. • **Industry:** Determine areas in which partnership and communication with citizen scientists would be of mutual interest and areas in which conflict is likely to occur. For areas of potential conflict, develop conflict-resolution measures and adjudication mechanisms.
Processes	• Enhance transparency of research through required disclosures of all assumptions inherent in study decisions and justifications for the assumptions. • Increase awareness of the benefits of citizen science across scientific disciplines. • Promote community-engaged research as a core competency in professional schools so scientists develop relevant skill sets in working with communities or stakeholder groups. • Develop citizen scientists through school- and university-based initiatives and programs through community-based organizations. • Incentivize work in community-engaged research within academic institutions. Performance metrics could be broadened (e.g., translational impacts, research dissemination) or softened to incorporate the realities of community involvement (e.g., longer study times, lower rates of peer-review publication). • Develop new or supplemental peer-review processes that allow greater public access to scientific research, open data, broader participation in peer reviews, more-open and -transparent critical reviews and response to reviews, and increased speed to publication.
Structures	• Develop data review structures or mechanisms for community citizen science data that assess not only overall data quality but also adequacy for intended uses and recommendations for improvement. • Create respected mechanisms for better communication and translation of scientific research to the public along with explanation of uncertainties and limitations (e.g., a WebMD for controversial science topics). • Develop structures that increase access to science education and collaborations at local levels. Examples include science shops, hack-a-thons, traveling science exhibitions, and university outreach programs. • Develop or expand existing communication and coordination structures for community citizen scientists and partners to share their research, form networks, and collaborate on translation and dissemination of work.

how to define a problem, and what outcomes are important to measure. Noveck has noted that "expertise rooted in lived experience or scientific fact is widely distributed in society" and that there has been "a shift away from credentialed experts to citizen experts in everything from restaurant reviews to medical advising" (Noveck, 2015). The democratization of science and the increasingly distributed nature of expertise are not without their concerns. Such a transformation would be difficult without some tension and conflict between current standards of practice and the changes required for citizen science to achieve its promising future. But the rise of community citizen science may, in part, be motivated by the perceived failure of the standard practices and established experts to solve the many problems the world faces today. Whether community citizen science will prove to be a transformative force—inspiring an engaged citizenry, promoting more open and democratic decisionmaking processes, and generating new solutions for intractable problems—depends on all of society playing a part to help the movement succeed. If its promise holds true, the relationship between science and society will be profoundly transformed for the betterment of all.

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About This Perspective

Citizen science is public participation in research and scientific endeavors. Different models are proliferating across various disciplines. Citizens volunteer as data collectors in science projects, collaborate with scientific experts on research design, and actively lead and carry out research. The last form of citizen science, in which citizens exert a high degree of control and ownership over scientific activities, tends to be action-oriented, with research conducted to support interventional activities or policy change. We call this form *community citizen science*, and it can be of particular importance to those working at the nexus of science and decisionmaking. This Perspective examines the transformative potential of community citizen science for communities, science, and decisionmaking. The Perspective is based on our experiences working in collaboration with community groups, extensive readings of the scientific literature, and numerous interviews with leading scholars and practitioners in the fields of citizen science and participatory research. It is intended to be a brief, high-level treatment; future publications will be more detailed about findings from the literature and interviews.

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