Citizen Science

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A Path to Democratic and Sociopolitically Conscious Science

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Abstract

In this chapter we explore the idea of citizen science in science education and its value in broadening student science participation, building greater science engagement, and expanding the usefulness of science in broader life events and actions. The focus of the chapter is to explore how citizen science provides a space and context for teachers and students to engage in science content and activities that bring greater personal and community meanings in learning and doing science. The chapter seeks to explore the following questions framed by critical pedagogy and critical theories: What is citizen science and how does it raise critical consciousness in students from underrepresented groups? How is citizen science a space for equitable science teaching and learning space for all students? In what ways does citizen help students make sense of science learning and provides a context to challenge the dominant view of learning and doing science? How does citizen science make doing science a democratic practice for sociopolitical consciousness? As we answer these questions, we draw from critical theories and pedagogies where sociocultural contexts take a central space in understanding affordances of citizen science as a sociopolitical consciousness raising framework for teaching and learning.

Keywords

Citizen science · Sociopolitical consciousness · Democracy · Critical pedagogy · Culture · Science teaching · Learning · Marginalized

Introduction

Citizen science (CS) has been recognized as a distinct scientific method for data collection and analysis by the professional field (Silvertown 2009). CS is founded in the relationship between the public (volunteers, students, or activists) who collect data in partnership with professional researchers from universities, nongovernmental organizations (NGOs), government entities, and nonprofits (Silvertown 2009; Ruiz-Mallén et al. 2016). Wiggins and Crowston (2015) liken the difference between scientist and citizen as that between expert and non-expert, with formal training and credentials distinguishing the scientist. CS facilitates communication between scientists and the public, providing an educational opportunity for both parties involved and a method for collecting large-scale data that may not be possible with other techniques. CS projects allow for intensive surveys across larger areas, such as continents, and in longer temporal windows, which would be costly and time consuming if carried out solely by professional scientists. CS also allows localized data to be collected at higher resolutions where more direct action can take place (Hochachka et al. 2012; Bonney et al. 2014; Theobald et al. 2015). Yet, most research in CS has not focused on in what ways CS could help the public – including students, teachers, caregivers, activists, and those from underrepresented groups – understand and value the power of science for sociopolitical and sociocultural action. We are specifically questioning the value and voice given to local knowledge given that CS relies on expertise situated in, and originating from, knowledge that local communities openly share. Additionally, we question the value and voice given to the local community's ways of knowing because CS requires non-science participants to collect data based on the values of Western Modern Science (WMS). We further question how the local knowledge created by using centuries of observational and experiential data gets co-opted by scientists and institutions for their benefit and the promotion of WMS as the only legitimate and reliable way of generating knowledge. These issues, for us, raise much deeper moral questions about the purposes and goals of CS in making science accessible and meaningful for individuals and communities from underrepresented and indigenous groups. Finally, we wonder if participation in CS encourages and supports sociopolitical consciousness-oriented actions and discourses. In other words, does CS allow local communities and their members to critically examine both the epistemology and value of CS for sociopolitical consciousness-oriented discussions and actions?

The importance of the public's understanding of science is becoming necessary with increasing changes in our natural environments due to human activities and natural disasters. In the past decade, efforts to reform science education have been made, with movements toward informal science education inside and outside of the classroom. Informal environments such as museums became important spaces to attract the public to engage in science for the purposes of both educating them about science and its developments and critically examining human interactions with science. In this space, the types of science knowledge and the ways of understanding science were decided mostly by majority privileged White individuals. This inadvertently excluded most of the groups from underrepresented communities such as Blacks, Hispanics, Native Americans, and Hmong (people from Southeast Asia) in both the nature of museums and its contents. Therefore, CS became a logical space to broaden participation specifically from underrepresented groups. CS is often viewed as a form of informal science education (Brossard et al. 2005; Burgess et al. 2017; Bonney et al. 2016), but can be further viewed as a way of connecting science education to local place (Silvertown 2009; Riesch and Potter 2014; Wiggins and Crowston 2011; Mueller and Tippins 2012; Adams et al. 2012). Thus, citizen science creates a space for science engagement and learning to be more place-based rather than traditional secluded lab-based environments. There exists a tension between science, place, and one's acquired knowledge (Lim et al. 2013). Science education has historically ignored its connection with place and local communities. Kissling and Calabrese Barton (2013) and Upadhyay et al. (2017, 2019) argue that marginalizing place-based science knowledge in science education ignores cultural and historical realms, minimizing youth's unique sociocultural, political, and geographic backgrounds that shape the way they learn, engage, and give value to education. Place-based inquiry through CS can successfully motivate students to become active members of the community and investigate the ecology (Switzer 2014).

CS can be seen as an abstract concept to many, as there is a wide range of projects with varying objectives. CS projects typically are not withheld to the same hypothesis testing model as other academic research in the field; therefore, research in this area has been underrepresented in peer-reviewed science and science education literature. Furthermore, the limited number of studies on CS within science education has focused mostly on the engagement and outreach aspect of it, with less emphasis on the sociopolitical and sociocultural influence of CS on individuals and communities from underrepresented groups. In this chapter we first explore the current status of CS and its typologies based on Wiggins and Crowston (2011) and Bonney et al. (2009). Typologies allow us to explore how and why CS projects are conceptualized, goals are set, outcomes are communicated, and community and public are involved. Second, we explore the value of CS projects in engaging underrepresented groups through a critical framework by questioning social, cultural, and institutional powers that are embedded in CS projects and then linking the potential value of CS in making science engagement and learning as a sociopolitical act. Finally, we present our CS project on attempting to create citizen science curriculum for personal and community wellness and engagement in science among underrepresented groups.

What Is in a Name: Citizen Science and Its Meaning

Citizen science (CS) projects are most common in the fields of ecological and environmental sciences but are also implemented in other disciplines. The earliest examples of CS projects are from the early 1900s, such as the Christmas Bird Count, run by the National Audubon Society (2018). The UK began one of the longest running CS projects in 1932 through the UK National Biodiversity Network (NBN), which keeps records of observed plant and animal species. The NBN's project has collected over 38 million observations to this day and recorded over 71,980 different species (NBN 2018). The success in collecting so many data on so many avian species is possible only because ordinary people engaged in the process who valued the knowledge that could come out of their small but valuable contributions. However, the critical examination of questions such as what citizen science is, who counts as a "citizen," and what is science is needed to ensure that this kind of "science is for all" and everyone has equal voice in the knowledge CS will create. From critical theory's point of view, we believe, the benefits of CS cannot be just for elite groups of people and institutions. CS has to benefit all who participated in its success.

According to Oxford English Dictionary (2018), "Citizen Science is scientific work undertaken by members of the general public, often in collaboration with or under the direction of professional scientists and scientific institutions" (n.p.). On the other hand, Cambridge University Dictionary (2018) defines citizen science as "science done by ordinary people, often for or with the help of scientists" (n.p.). These two definitions beg several questions, including: Who is a "citizen"? Who decides who is not a citizen or belongs to "citizen science"? How is "citizen" and "general public" different? Which activities and actions count as citizen science and who decides the legitimacy of such activities? Who decides who is a "professional scientist and scientific institution"? What role or voice do ordinary people have in making the decisions of what science to be done under CS? Who decides and controls the processes of collaboration and the outcomes of it? How, if at all, does science done by indigenous and other nonscientist groups during CS become valued and attributed as *science* knowledge contributions of those communities? What are the public responsibilities of scientific institutions in research and who benefits from that research?

These questions about CS make us wonder if a unitary definition of CS is possible (Eitzel et al. 2017). On the other hand, if we believe that the meaning of CS is shaped by individual sociopolitical, sociocultural, and local experiences and local worldviews, then how should CS community work with a community of ordinary people? From the action point of view, CS community members seem to use the idea of "ordinary people" and "public" as a way to collect large swaths of data through participation. However, these words only go so far to capture the idea of CS as a participatory science because the participants are without much agency and direct voice in the overall processes of CS. Many scientific institutions tend to use CS to improve community engagement and hope to increase numerical equity in STEM disciplines (e.g., Annie E. Casey Foundation 2014; Maruyama et al. 2014; Upadhyay et al. 2017). Our understanding of equity also involves the value of racial equity in science education. From these perspectives, CS is more than just data gathering, temporal and geographical coverage, scientific knowledge, and opportunities for participation by "ordinary people." We assert that CS has to be viewed and practiced as a sociopolitical and sociohistorical issue in science education to achieve equity, agency, and participation.

Defining Citizen Science and Public Participation

Citizen science (CS) was first labeled as a term in the mid-1990s by Rick Bonney (1996) in the USA and Alan Irwin (1995) in the UK. Both researchers have different definitions of CS, which leads to the first major divide in CS projects. Bonney (1996) defines citizen science as the successful combination of public engagement in professional scientific projects that include both outreach and research objectives. He saw the movement as scientific projects in which nonscientists (amateurs) provide observational data for scientists and ultimately gain scientific skills through their participation (Bonney 1996). Through this, the democratization of science and scientific research allowed a "give-and-take," bidirectional nature of learning within CS. Bonney advocated CS as a method to collect large quantities of data to be submitted and analyzed by professional scientists and their respective institutions. This perspective is distinct from how CS was envisioned in the UK context. Alan Irwin saw CS a method to engage citizens in a form of scientific democracy, where participants are involved in all steps of the inquiry process, from question development to policy-level action. According to Irwin (1995), "'Citizen Science' . . . conveys both senses of the relationship between science and citizens" (p. xi). For him, both senses meant science by and for the people, making science more "democratic" while addressing people's "concerns" and helping them better “understand” science (pp. 69–80). Irwin’s goal for CS is to bring the public and science closer together through deeper dialogue and decision-making processes (Bonney et al. 2016; Riesch and Potter 2014). Based on the level of participation and voice a public citizen holds in a given project, CS could be categorized in three ways – “contributory,” “collaborative,” and “co-created” (Bonney et al. 2009, p. 5).

The above typology shows promise to improve diversity in CS projects where participants are engaged in collecting observational data (Wiggins and Crowston 2015). Additionally, the typology holds strong potential for broader participation in CS when projects are more collaborative and co-designed. Yet, there are many CS projects in which nonscientist citizens are passive participants (Jordan et al. 2011), meaning that much of the project is tightly controlled and initiated by scientists and institutions rather than citizens who may be amateurs.

In the past two decades, CS projects have multiplied and are being used in a variety of settings. CS projects have become more widespread due to development of the Internet and other mass technologies. Increased functionality of the technologies such as the Internet allows data to be gathered and disseminated more easily and efficiently, facilitating data sharing across interested communities of amateurs and scientists. CS projects are also more visible and accessible online, which has led to a greater awareness of the CS potential and uses in science, government, and education communities. CS projects are now easily searchable by citizens and agencies who may have an interest in specific scientific topics. Information technologies are used in greater extents to create functional interfaces to increase participant diversities so those who may not have numerical or literacy skills can still participate (Bonney et al. 2015). Some CS projects can be completed solely online, where participants are required to classify or interpret files, videos, pictures, and sounds, such as in Galaxy Zoo (Zooniverse 2018). Increased Internet and smartphone use supports CS projects that emphasize data collection over educational aims. CS projects that are mediated by information and communication technologies have been seen as a form of crowdsourcing: a participation model that makes an open call for contributions from large unidentified networks (Wiggins and Crowston 2015).

Many CS projects share data but do not make all processes publicly available online. This can limit the transparency of the projects and strain the relationship between scientist and partners, creating a dichotomy in leadership (Wiggins and Crowston 2015). Although computational resources have helped the growth of CS projects, there are still subsets of the population who do not have access to technologies, perpetuating disparities in science participation and literacy. Another limitation of computer-based CS projects is the constant development of technology, makes it difficult for the management of CS projects to keep up with rapid changes. Additionally, the need for cyber infrastructure and security can become costly (Silvertown 2009) for both the participants and the institutions that depend on them. Therefore, we view CS projects increasingly needing ways to promote ethics and rigor in scientific projects. Finally, some of the most pressing and challenging questions in front of CS works include the myriad ways in which citizens participate in projects, who has the power to decide the nature and scope of projects, and what metrics are used to assess the effectiveness of projects, particularly with respect to meeting educational, emancipatory, and social goals.

Citizen Science Typologies and Nature of Public Participation

The public deficit in science knowledge is becoming more apparent, begging the question: If an individual understands how scientific investigations are carried out – from observation to analysis – would they better understand and evaluate scientific claims in their daily life? If so, could CS serve as a method to empower communities and improve their well-being? What differentiates CS from other forms of public participation in science is active engagement in scientific work, though this engagement may be superficial (i.e., simply data collection) or intensive (i.e., co-creating scientific research) (Wiggins and Crowston 2011). Many researchers (e.g., Howe 2006; Irwin 1995; Muller and Tippins 2012) have written on and conducted CS research in broad areas of interests, which in turn requires different levels of public participation. In this chapter, we critically explore the typologies of CS as proposed by Wiggins and Crowston (2011) and Bonney et al. (2016) to explore the need for situating CS projects in a sociocultural theoretical lens. Additionally, examine how CS projects suppress or enhance issues of equity, social justice, race, gender, power, sociocultural, and sociopolitical issues and interrogate the ways that recent CS projects have marginalized or supported the participation of people from underrepresented groups. We draw on critical theories to explore CS and the nature of underrepresented group participation in each case.

Wiggins and Crowston's (2011) Citizen Science Typologies and Nature of Participation

Drawing from a sample of 30 citizen science projects pursued in North American, Wiggins and Crowston (2011) constructed five typologies. They defined the typologies based on the nature of public involvement in various stages of scientific inquiry, project goals, and use of technology. The typology was developed by evaluating the 30 projects across 80 different facets, using a clustering method to narrow to 5 mutually exclusive groups or typologies. When clustering the CS projects, Wiggins and Crowston based the clustering on self-defined goals of those who initiated each of the projects. The five typologies Wiggins and Crowston came up with are action, conservation, investigation, virtual, and education.

Action Citizen Science

Action CS projects (e.g., urban pollination project at University of Washington at Seattle, "Globe at Night" at National Geographic, etc.) have local concerns at the forefront, with scientific research used as a tool to enhance engagement. These projects usually have citizens serving as project initiators, with professional researchers serving more as consultants, a bottom-up approach to research. Activities are usually linked to the physical world and provide long-term environmental monitoring in the community. The data collected are typically used to show reasons for intervention on environmental issues, not with the goal of publication. Action projects are not dependent on the use of technology, because often it is hard to find volunteers who understand information technology and maintain infrastructure.

Action CS is one of the key ways in which K-12 schools, universities, and nonprofit organizations, such as National Geographic, engage ordinary public in science and scientific research. Action citizen science projects have potential to take up sociopolitical and sociocultural issues of interest to a community while receiving guidance from scientific research. Based on research done in the areas of sociopolitical consciousness across many disciplines, including science (e.g., Seider et al. 2017; Sleeter 2012; Szostkowski and Upadhyay 2019; Upadhyay et al. 2017), public engagement, broad participation, and strong personal connections to local issues are key factors in the successes of any action-oriented activities to a community. Therefore, we argue that for CS to be more action-oriented and have meaningful impact on people's lives, action CS has to appeal to the broad groups of individuals and bring them in its fold through localized, issue-focused CS activities.

Conservation Citizen Science

Conservation CS projects have natural resource and stewardship as primary goals. As such, conservation CS can be a potent and powerful tool for confronting numerous challenges facing local and global conservation, including in the areas of conservation biology. For example, a 2-year CS study exploring the impact of cattle grazing on frequency and types of wild mammals and birds visiting fruiting trees in Brazilian Pantanal showed that citizen participation enhanced Pantanal conservation and land management for cattle farmers (Eaton et al. 2017). Conservation CS projects are rooted in local environmental conservation matters. These projects generally emphasize data collection and contain a stronger affiliation with local governments and government agencies that CS initiatives from the other four typologies. In most cases conservation projects tend to be initiated by academics and require volunteers with more specific capabilities, a top-down approach to scientific research. The data generated by these CS projects are publicly available but often in inaccessible formats or with different sets of data collection criteria. Additionally, there is a greater demand for access to data from these projects. Therefore, the need for appropriate and – at times – sophisticated technologies to access complicated data tends to put extra burden on technology resources (Wiggins and Crowston 2011).

Since the research related to conservation CS project are mostly on local conservation issues, the ideas of place-based education could help researchers and public better engage and add value to conservation CS projects for better and deeper understanding of conservation science and its links to local cultural practices.

Additionally, place-based ideas associated with conservation CS further engages the public as democratic and engaged citizens who cherish better environment, social quality, and cultural preservation in their communities (Gruenewald and Smith 2008; Smith and Sobel 2010). Extending conservation CS with place-based ideas into K-12 teaching and learning would encourage students to invest in participating in science and scientific research as professional scientists and citizens. Conservation CS projects in the classrooms could draw from critical pedagogy aspects of place-based paradigm to explore ways to have greater and varied voices of the local people in these citizen science projects. Place-based ideas could enhance dominant conservation CS norms and values by preserving and sustaining sociocultural values and knowledge of the local community while also ensuring sound scientific outcomes through distributed powers in a democratic scientific engagement.

Investigation Citizen Science

Investigation CS projects emerged as projects requiring data collection from the physical environment, with an emphasis on providing valid scientific results and generating formal science knowledge. Investigation CS project is carefully designed with research goals as a priority over education. These projects are usually led by academics or nongovernmental organizations (NGOs), thus following a top-down approach to scientific research. For example, the river otter demographic study initiated by Wildlife faculty at Humboldt State University, CA, recruited public from the Humboldt Bay area to collect observational data on the number of otters and scat samples to better understand how to save river otter populations using DNA information (Brzeski et al. 2013). The goal for public participation was to benefit investigators rather than the public, though arguably the results could benefit river otters. The researchers and public used a specialized data collection method called the Program Mark for this study. Program Mark, also known as include capture-recapture, capture-mark-recapture, and mark-recapture, is a method commonly used in ecology to estimate population size of an animal group (e.g., Lukacs and Burnham 2005; Pradel 1996; Paetkau 2005). In this method a portion of an animal population is captured, marked, and released in its habitat. At a later time, depending on the nature of the exploration, a sample of the animal is captured from the same group and habitat, and the number of marked animals is counted. The ratio of total number of marked animals to the total number of marked animals captured in the second sample gives an estimate of the total population size of the animal under study. This method allows for estimating an animal's population size when counting each individual in a population is impossible or costly. Through this example we see how investigation CS projects encourage the public to use a wide range of technology tools to collect data of benefit to researchers. One of the major constraints of investigation CS seems to be restrictive data access policies pertaining to the larger public from different walks of lives (Wiggins and Crowston 2011).

From critical theory perspectives (e.g., hooks 1994; Friere 1970; Giroux 1992; Gramsci 1971; Ladson-Billings 1994), public participation in education must focus on how power, privilege, and voice are controlled so only certain kinds of knowledge are legitimized. Through this lens, the nature and focus of investigation citizen science projects would present great concern with respect to how the public is allowed to participate in scientific research and access (or not) privileged information (i.e., data). If the power of what gets investigated resides solely among researchers and institutions, the potential for finding meaning in public's participation is greatly diminished. Therefore, we believe that for investigation citizen science to make meaningful contribution to the public, it has to find ways to involve the public in more intimately with the research design and interpretation.

Virtual Citizen Science

Virtual CS projects are generally information- and communication-technology based. These projects are designed to produce valuable contributions to science while maintaining volunteer interest. Virtual CS projects tend to follow the top-down approach of conservation and investigation projects, with the original development made by academics or other organizations with the capability to build complex web platforms (Wiggins and Crowston 2011). The requirement of technology for virtual CS projects create a digital divide that plagues much of science causing those without access to certain technologies to be continuously disenfranchised (Mueller and Tippins 2012). Yet, with the greater public connected to technology through mobile and other devices, a deluge of data could be collected through virtual CS projects. For example, *Search for Extraterrestrial Intelligence (SETI)@home* was the first virtual CS project that used Internet-connected personal computers to process data generated by radio telescope looking for extraterrestrial intelligence (Anderson 2004). Now, with greater access to mobile technology, there is more opportunity to bring in diverse groups of the public from far-flung areas and those historically left out from participating in meaningful scientific research. For example, in a virtual citizen science project called "Foldit" (http://www.bakerlab.org/index/), researchers recruited online game players to use problem-solving skills in the search for unknown three-dimensional protein structures (Cooper 2011). The value of this virtual CS project is that scientists included game players (i.e., the public) as co-authors in their publications, thereby formally recognizing the public's efforts and skills (Eiben et al. 2012). However, the challenge of this particular project was that scientists could only recruit individuals who were very fluent in complex problem-solving skills in virtual gaming contexts. On the other hand, virtual CS project Zooniverse required less technologically skilled citizens than Foldit. In the case of Zooniverse, the public became "Planet Hunters" without needing highly complex skills, but they still had opportunities to engage in scientific research and could help locate new planets and other undiscovered astronomical objects (Raddick et al. 2010). Furthermore, virtual CS projects mostly include individuals from upper- and middle-class families (Raddick et al. 2010; Riesch and Potter 2013). Research shows that citizens from these groups are more willing to participate in virtual and other CS projects across the board because they have both access and skills to participate in virtual CS projects (Riesch and Potter 2013).

From critical theory and critical consciousness perspectives (e.g., Giroux 1992; Ladson-Billings 1995a, b, 2006, 2014), virtual CS projects need to focus on equity issues and inclusion of participants from underrepresented groups. Technological developments have created greater opportunities to participate in scientific research and discourses, but the distribution of the technology required for participation is skewed toward more affluent communities (Riesch and Potter 2013). Additionally, gender participation in most virtual CS projects is similarly tilted in favor of men. For example, in virtual CS projects such as SETI @home (93% male) (SETI@home team 2006), World Community Grid (90% male) (World Community Grid member study 2013), Zooniverse (67% male) (Reed et al. 2013), and Galaxy Zoo (82% male) (Raddick et al. 2013) show clear underrepresentation of women. Virtual CS projects and the researchers and institutions promoting them should work toward broadening the participation of women and non-science degree holders to ensure that citizen science lives up to its promise of equity and inclusion. Virtual CS projects have to look into "threshold fear" (Gurian 2005, p. 203). "Threshold fear" is when people perceive constraints to participation in activities that are actually intended for them (Gurian 2005; Simon 2012). In the case of virtual CS projects, individuals and communities from underrepresented groups are reluctant to participate because of their sociocultural, historical, gender, racial, and personal historical experiences with institutions and locations (Dawson and Jensen 2011). Therefore, virtual CS projects should look into how to make public participation more inclusive and attainable, specifically with respect to underrepresented groups. The meaningful engagement in virtual CS projects should look into making them sociopolitically relevant to the communities and participants for greater participation and motivating factor for growth.

Education Citizen Science

Of all five typologies, only Education CS has as its central goals outreach and engagement. Education CS projects are designed to promote, among school-going public, cumulative learning experiences and inquiry skills focused on scientific research question development and data analysis. These projects are considered CS because of the involvement of professional researchers in a classroom setting whose analysis and engagement contribute to larger research efforts. The cost of doing education CS projects is generally higher because professional development in scientific research skills is required for teachers to directly participate in the research endeavor, a key goal of education CS (Wiggins and Crowston 2011).

An example of a project that fits in Wiggins and Crowston's education CS typology is described in a study conducted by Ruiz-Mallén et al. (2016) in a classroom setting in the Catalan region of Spain. The study focuses on a project developed by researchers through questions formulated by secondary students on the effects of wall colors on educational performance. The authors were interested in the potential of CS to empower and increase students' capacity to think as independent learners. Students expressed an increase in scientific learning beyond what is normally expected in K-12 school settings. Students learned through interactions with professional scientists on subject matters not otherwise taught, such as research methodologies, processes of data analysis, and other scientific skills. One of Ruiz-Mallén and colleagues' most noteworthy findings was that – through meeting the actual scientists and collaborating with them – students became more motivated to go into science careers and viewed scientists as kind and friendly people. This study emphasized the power of education CS projects on students' connection with the scientific community and the potential of CS to benefit students and researchers alike. Another key practice for education CS projects to maintain and teach to students is transparency among various stakeholders (Ruiz-Mallén et al. 2016).

Education CS projects are powerful ways to provide students with opportunities to engage with science content and scientific research of relevance to their lives and communities. Furthermore, education CS also could encourage historically marginalized students and communities to carve out spaces to bring locally generated knowledge and skills into scientific research. This aids in mitigating barriers between underrepresented groups and the science community with respect to science knowledge. Critical consciousness could be raised through education CS more efficiently and effectively as students and schools are engaged in co-creating and co-researching school-based and local problems in collaboration with the scientists. Therefore, showing greater promise for more empowering and transformative experiences for people from the underrepresented groups (e.g., Ottinger 2010; Ryan and Deci 2009; Upadhyay et al. 2017, 2019).

The typologies of Wiggins and Crowston (2011) provide us with a framework to explore ways in which issues of equity, discrimination, race, marginalization, power, and institutional disparities in science and scientific research could be interrogated. Wiggins and Crowston's typologies mostly focus on researchers rather than the public. Bonney et al.'s (2016) citizen science typologies (which they call "nature of activities," p. 4) answer the questions on how the public participates in citizen science projects, i.e., the role of public in CS projects, and how the community participation and participants engage in CS projects. Additionally, Bonney et al.'s typologies consider school-researcher connections more directly than Wiggins and Crowston's typologies, thus broadening public understanding of science. We now discuss the Bonney et al. typologies of CS and how they intersect with sociopolitical, sociohistorical, and cultural diversities to promote greater participation and voice from public participants.

Bonney et al.'s (2016) Citizen Science Typologies and Nature of Participation

In 2016, Bonney and colleagues proposed four categories of CS projects that reflect aspects of Wiggins and Crowston's (2011) typologies but focus more on types of activities the public would be involved in a particular CS project. Since their focus was on the nature of public activities within CS projects, they defined four categories in which all CS projects would fall based on their potential impact on the public's understanding of science. One of the key questions for us in this chapter is to critically examine if CS projects are successful in empowering the public through meaningful scientific inquiry leading to improvement in community well-being. Additionally, we also critically examine if sociocultural and sociohistorical theories would further help enhance our understanding of citizen science's impact on PUS and participation of the public from underrepresented groups. We examine each of the four categories of CS as proposed by Bonney et al. below: data collection CS, data processing CS, curriculum-based CS, and community science CS (p. 4).

Data Collection Citizen Science

Data collection is an integral part of any scientific endeavor, and science has specific practices that govern data collection as well as what would count as data to answer specific research questions. This means that the scientific knowledge generated very much depends on the data collected. Therefore, data collection is central to any CS project. All CS projects use public, who may or may not have formal training in scientific data collection, as volunteers to collect data for use in organized scientific research (Bonney et al. 2016). Most data collection projects are often hypothesis-driven and generally focus on environmental monitoring. The projects categorized as data collection CS are mostly based on top-down approaches to public participation where scientists control all aspects of research including which and how the data should be collected. Data collection CS projects are similar to those of Wiggins and Crowston's (2011) investigation and conservation typologies that take a top-down approach.

Many CS projects falling under "data collection" tend to be large in scale, cover broad geographic regions, and be long term (several decades) (Shirk and Bonney 2015). Data collection projects also tend to produce a higher number of publications that are purely for scientific knowledge development purposes; thus, they tend to make less of an impact on the general public's understanding of science (Bonney et al. 2009). This may be due to the fact that there has been less research done on the social impacts of data collection, and also the projects tend to exclude measurements of educational outcomes (Mueller and Tippins 2012). Data collection projects often include direct participation from the public, but do not actually involve interactions with scientist and citizen, or incorporate citizen-generated questions into the research design (Mueller and Tippins 2012). Therefore if CS projects seek to pursue long-term success as their primary goal, then these projects need to develop simple to follow data collection protocols and show clear benefits of the projects to the participating public (Hochachka et al. 2012)

Most CS projects in the field of ecology are data collection CS projects. These projects are conducted at scales that are relevant to range shifts, migration patterns, disease spread, national policy changes, and climate change (Tulloch et al. 2013). One of the longest running data collection CS projects is the eBird project (http://ebird.org) conducted by the Cornell Lab of Ornithology, which has collected over five million observation data from across the globe and various public groups (Theobald et al. 2015).

With the widespread use of smartphones and other personal technology devices, data collection CS projects have become more common as well. A study done by Snik et al. (2014) was initiated because current measurements of ground-level aerosols in the UK were not sufficient to permit mitigation efforts. A lack of temporal monitoring and low-resolution data from satellites prompted Snik and colleagues to develop a low-cost smartphone add-on – called the ISPEX – that allowed citizens to use phone as a spectropolarimetric instrument, enabling the direct and effective collection of atmospheric data. The ISPEX allows for crowdsourced measurements that reduces polarimetric error by averaging thousands of entries (Snik et al. 2014). The data can then be used to better understand ground-level air pollution, lobby for change, and create air quality awareness. Bonney et al. (2009), Haklay (2013), and Shirk and Bonney (2015) have all argued that data collection CS projects could be made more engaging by improving collaborative and co-creation of design with the public's input and interests. Yet the current system of data collection CS projects is more interested in getting new discoveries of unexpected ecological events and patterns, but less on creating strong bonds within communities through many shared activities, such as bird watching or water quality monitoring (Tulloch et al. 2013). The challenges to bring more collaborative approach to data collection CS projects reside in institutional and corporate structures of how science research is carried and who benefits from these outcomes. If we were to interrogate power structures and systems of scientific enterprise, we find a system that views science and its practices from an "end supports the means" perspective. We believe this kind of results-oriented attitude encourages a kind of science that is exclusive and controlling rather than a science that is focused on generating new knowledge for the public good. Furthermore, we also don't believe that citizen science could provide solutions to every social problem because in most data collection CS projects, the goal of CS is for the researchers rather than for the community and community goals (Shirk et al. 2012).

The goals of data collection CS projects tend to focus on new scientific understanding for policy changes and actions (Pocock et al. 2014) which tend to give overwhelming power to scientists and institutions rather than the public participants. According to Bonney and colleagues (2009b), citizen science could be a path for scientific literacy among a large swath of public that is less inclined to be interested in science. However, the question remains as to how CS shift its contribution from literacy to sociopolitical consciousness actions and local empowerment to influence policy for the larger community good. Many scholars in education (e.g., Apple 1993; Freire 1990; Giroux 1992; Ladson-Billings 2014; McLaren 2005) and science education (e.g., Pierotti 2011; Upadhyay and Albrecht 2011; Weinstein 2016) have suggested that the field of education and science education as well has to be explored and challenged through critical lens so that communities and people who are historically put in the margins get voice and opportunities just like the ones in power. Therefore, data collection CS projects have to be viewed, challenged, and questioned so that public at the margins get greater voice and input to benefit the communities in need of scientific solutions which respects local sociocultural values.

Data Processing CS Projects

Bonney et al. (2016) define data processing projects as another typology for CS. These CS projects are made possible by the Internet and sometimes referred to as crowdsourcing projects. Activities include data transcription, categorization, management, and interpretation. Participants do not physically collect data but examine and analyze it, much like the virtual CS projects categorized by Wiggins and Crowston (2011). Similar to CS data collection projects, data processing projects have education as a side objective that occurs through the research process. Shirk and Bonney (2015) suggest that data processing CS projects involve the public to "manage, transcribe, or interpret large quantities of data, for example, photographs of animals and their behaviors taken by cams around the world" (p. 2). There is an extensive demand on the public who participate in data processing CS to do more than just process data. Therefore, only 10% of the public make majority of the contributions (80%) in data processing CS projects (Bonney et al. 2016). Hence data processing projects have limited impact on the public's understanding of science. Yet, these projects could help improve public's awareness of new scientific research that are taking place at various scientific institutions and may also encourage the public to take up hobbies that are more closely connected to science (Bonney et al. 2016).

The data processing CS seems to focus more on the skills that are specific to certain kinds of science – analyzing photographs rather than numerical data. The narrowness of the skills results in fewer people from the public to engage with the questions a CS project is exploring. On the other hand, these members of the public are highly motivated and committed to engaging with a CS project. The concentration of narrow band of the public in a CS project could leave out many from underrepresented groups because many from these groups generally tend not to drop out of science courses lacking many scientific skills (Plunk et al. 2014). Plunk et al.'s (2014) study shows that the dropout rate in high school increased by 11.4% when students were required to take more mathematics and science courses; but when students were required to take fewer than six mathematics and science courses, the dropout rate was closer to 8.6%. A more concerning finding of the study was when ethnicity, gender, and race were accounted, the dropout rate for among women and many racial and ethnic minority groups increased by almost 5%. Thus, the power and privilege to participate in data processing CS projects were mostly among the White men. The current education system doesn't provide access and power to the public from underrepresented groups to participate and influence CS projects.

Curriculum-Based Citizen Science

The third category that Bonney et al. (2016) propose for the CS typology is curriculum-based CS projects. These CS projects typically take place in K-12 classrooms or as after-school programs. These CS projects involve supervised youths who are taught by school teachers or larger parent organizations such as the Parent-Teacher Association of a school to collect data and analyze data. Some curriculum-based CS projects are targeted at specific scientific research questions, and students collect scientific data; but the key distinguishing factor in this kind of CS is that it is designed to achieve specific educational goals. Curriculum-based projects demand significant number of hours and resources to educate and support K-12 teachers, causing them to be reluctant in adopting CS projects especially if they do not align with State Standards. Trautmann et al. (2013) found that the success of many curriculum-based projects lay in shared data visualization platforms that allow participants to explore and manipulate data, allowing further inquisition in the context and validity of data collected by others.

Curriculum-based CS projects have been found to increase science understanding and evoke interest in students, who previously were skeptical of the science field, to pursue science (Bonney et al. 2016). However, some science educators (Calabrese Barton 2012; Mueller et al. 2012; Weinstein 2012) have questioned how much contribution would CS add to school curriculum and student learning who are historically at the margins of science. Furthermore, citizen science curriculum needs to be place-based for some possibility of including underrepresented groups both in design and implementation (Calabrese Barton 2012; Mueller et al. 2012). Similarly, Michael Apple (1995, 2006) argues that all curriculum where the people in power have the control to justify and require what students need to learn should be viewed more critically. He encourages us to ask not only what students learned but more importantly whose knowledge the curriculum is covering. How did this knowledge become official? What is the relationship between this knowledge and the ways in which it is taught/evaluated? Therefore curriculum-based CS has to be looked at from the perspectives of educational and social inequalities for a better future.

Community Citizen Science

Community CS projects are those projects that are often developed by community members first, and afterward scientists are solicited for help (Bonney et al. 2009). Community CS is much more like the bottom-up action CS projects as suggested by Wiggins and Crowston (2011). In addition to data collection, community-based projects are distinguished by active participation in the formulation of research questions and design of the project. The goal of data collection, in community projects, is more oriented toward policy change and decision-making surrounding public health and environmental concerns. Community projects can also engage a wider range of volunteers because of the flexibility of the design to meet citizens geographically and have multiple entry levels equipped to accommodate varying degrees of interest and availability (Bonney et al. 2016). Issues arise in community-oriented CS projects when the professional scientist and citizens have varying research agendas. In this kind of research project, the power dynamics between the professional scientists and the community citizens are very skewed or misunderstood. This could create conflicts and disagreements on the goals and the purposes of the community CS projects between the two groups. Sometimes the expectations of the scientists and the public on time commitment for the project could be unrealistic, and this could generate tensions between these groups. Therefore, scientists should lower their expectation on community participants to show up regularly and stay with the project long term (Mueller et al. 2012; Riesch and Potter 2014). If scientists and institutions design community CS projects, they should know why and how members of the community want to be involved (Adams 2012; Bonney et al. 2014; Mueller et al. 2012).

An example of community-initiated CS project is related to growing asthma cases in socially and economically disadvantaged communities (Eiffert et al. 2016). Citizens from two neighborhoods in the City of Atlanta, Georgia, USA, experienced higher than average asthma rates, prompting the communities to collect accurate data on housing conditions (environment and economy) and asthma (Eiffert et al. 2016). The community hoped to share the results with community-based organizations, universities, and government agencies to influence health and related policies. A team of scientists (Eiffert and his team) conducted a neighborhood wide study that documented prevalence of asthma and environmental conditions of homes that might have influenced the high rate of asthma. Eiffert and his team found high rate of the presence of mold in the homes of the neighborhoods than the national average. The documentation of environmental hazards and assessment of asthma severity was presented to residents and local officials. Subsequently community-based organizations took actions in response. Eiffert et al.'s (2016) study can be used as a successful model for other community-oriented CS projects. Another successful model of community CS project that positively shaped policy and resource management in a local community was about air quality study in West Oakland, California, USA (Fisher et al. 2006). This community CS study on air pollution in West Oakland community led to policy change related to heavy diesel trucking in low income and minority neighborhoods. The project was initiated due to health concerns raised by community members and the need to demonstrate correlation between emissions and racial and immigrant community demographics. The results of the project provided scientific clarity to environmental justice issue the EPA had not shown interest in exploring (Fisher et al. 2006). This project shows the power of community CS project that explored local-level concerns that were not evident in large-scale monitoring projects. This brought policy change in trucking routes in this community. Both of these community-based CS projects were mostly locally initiated. Sometimes the community-based CS could be top-down but with more community support.

In the case of Bangladesh, a top-down community-based co-management of fisheries is an example of community-based CS that brought economic, social, and environmental successes in the Bengali fisheries community (Sultana and Abeyasekera 2008). In this case the top-down community-based CS brought better results for poorer community compared to other top-down CS projects. However, we need to be cautious that many top-down community-based CS projects give greater benefits and voice to richer and more powerful community people than the ones that are bottom-up community CS projects.

Community-based CS projects seemed to show great promise for the good of the local communities and communities and people from underrepresented groups. Yet there are many cautionary steps that need attention in these kinds of CS projects. Conard and Hilchey (2011) list several ways community-based CS projects could marginalize the local people or run into problems. Some of those missteps could be organizational turf battles, improper data collection and data use, focus on scientific knowledge rather than solving community issues, greater control and voice to people from dominant groups and marginalized and poor people being left out, poor communication of the findings so a lay person from the community doesn't understand, and policymakers ignoring the findings from the CS projects. Similar concerns are brought up by many critical researchers in education and science education in particular because when underrepresented communities and individuals are involved in scientific research for the good of these communities, they tend to lose their voice and influence over the more powerful outsider scientists and institutions (e.g., Calabrese Barton 2012; Freire 1990; Giroux 1992; Maruyama et al. 2014; Upadhyay et al. 2019).

Bonney et al. (2016) argue that citizen science has become as large of a field as science itself with greater participation of the public across geographical and community groups throughout the world. The breadth of CS projects also demands clear need for differentiated goals, research methodologies and methods, data collection and analysis, outreach strategies, inclusion of diverse communities, and supporting local needs to solve problems that matters to a community. Therefore making the use of typologies allows for better citizen science projects.

With so much potential for good and also for exploitation of the public, specifically from underrepresented groups, the researchers and other stakeholders have to protect and give power to people who come from underrepresented groups. A much more equity and social justice-oriented frameworks are necessary within the citizen science projects, so the marginalized communities get promised benefits from their involvement in CS projects including, but not limited to, access to the scientists and increased scientific literacy. Below we critically examine for who and for what purposes does citizen science exist and how CS could be further enhanced to be socially just space for underrepresented groups.

Democratizing Citizen Science with and for Underrepresented Communities

In our attempt to understand and explore different typologies of citizen science projects and their goals and purposes, several important aspects and actors (scientists, community, citizen, etc.) become very salient to us in connection to CS. Additionally when we seek to find relationships between citizen science projects and communities, we discover challenges for communities to gain equal voice and power to influence the processes, solutions, and the nature of understanding expected out of CS projects. Democratization of science and democratic participation of the public in exploring are one the major advocacy slogans of citizen science.

However, most scholars of CS projects haven't critically examined the idea of democracy or democratic public participation in science or in their own projects. Furthermore many of these projects have labeled "democratization of science" in a very simplistic and narrow manner. We also believe that the majority of CS projects anemically lack in framing citizen science as democratic. Therefore we find value in briefly discussing about the ideas of democracy that are prevalent in social and political sciences and why CS projects need to rethink the complexities of democracy and why democratizing of science needs to be more than just participation in collecting data for the benefit of science and scientists. We now briefly discuss what democracy is based on different theorists and how CS projects need to rethink democratic participation more critically if the purposes of CS projects are to help communities find answers to their persisting problems and engage them in science in general.

Democracy for us is not only about participation of diverse groups of people for a common cause but also about whose values and goals are promoted through these participation. Therefore we believe that if the ideas of democracy are practiced in citizen science, then equity and voice and agency of minorities have to be central and protected. Social and political sciences have proposed multiple theories of democracy such as liberal democracy, deliberative democracy, participatory democracy, minority democracy, etc., each having its own meanings and goals. However, there are several crosscutting foundational practices of democracies that each of the theories broadly agree upon, and they are public participation in a shared decision-making; upholding equality and liberty; respect and value for each other's diverse ideas; upholding mutual respect; economic growth for all; open communication; decentralizing political, cultural, and educational power centers; and respectful deliberation of and cooperation for the good of the larger public (e.g., Benhabib 1996; Cohen 1997; Dewey 1927; Habermas 1996; Keane 2009; Lippmann 1993; Pateman 1970; Putnam 1993; Schumpeter 1962). However, in many cases, "in a democracy the cultural standards of the majority [tend to] be the dominant ones and that these standards [are mostly] be culturally debased" (Cunningham 2002, p. 25). In other cases, organizations and groups band together to promote for a common cause or purpose that multiple groups hold as valuable. Thus democracy in this case promoted common interests and multiple groups have to band together to be successful (Dahl 1959). This idea of group interest is countered by neoliberal idea of democracy where efficiency is the root cause of success and that's what democracy is about (Buchanan and Tullock 1965; Hursh 2007), but neoliberal idea of democracy displaces common good and social justice as inefficient goals of democracy (Apple 2009) because large organizations like governments are less efficient than open markets giving choice to the public to make the best decisions. Varying ideas and theories about democracy make us ask why citizen science projects and scientists need to conceptualize democratic participation in citizen science contexts.

In a study of elementary students in a science class, Upadhyay and Albrecht (2011) argue that democratization of science is more sustainable and productive in encouraging students from underrepresented groups to like science and science becomes more inclusive. In another study of after-school program, Fleming et al.

(2015) show that democratizing science values local sociocultural knowledge. In both the studies, agency that students gained to shape the direction of science they wanted to learn was key to democratic nature of the class. Even though these studies are not CS projects, they show how democratized science could benefit underrepresented groups.

In our currently on going CS project, which is a part of a larger National Science Foundation funded project, we are developing a CS curriculum that intends to improve middle and high school students' understanding of the linkages between wellness and environmental factors and their understanding of related science contents. We have envisioned this curriculum to provide tools and experiences to K-12 teachers and students that would allow them to make decisions about what they wanted to explore about their environment that helped them understand and consider potential actions to improve familial and community wellness. In our teacher professional development workshop last summer a teacher noted:

> This CS curriculum is so closely connected to local issues on health, infrastructure, environment, and access to things like food and health [hospitals, air pollution, etc.] that I feel very powerful to students. There are so many opportunities for students and also for us [teachers] to come together to decide what is important for us and explore those ideas and issues... My students in the Northside will be able to decide what and how they want to learn in [conjunction] with [university educators] and us [teachers] in this curriculum. The great thing is that they can use ArcGIS to explore different local problems for their benefit which they [students] decided, not me [teacher] or the [university] experts...The university experts gave the framework but the actual actions were decided by students in each class and most importantly [minority and immigrant] students could explore their own experiences.

In this CS curriculum the agency and the power to make choices in the types of issues to be explored and learned rested mostly on the students and teachers rather than the university experts. The control over the nature and scope of the CS curriculum was on a continuum where the university experts had the least voice and power but the students and teachers had the greatest power and voice. During our teacher PD another CS project teacher participant mentioned:

> This CS curriculum seems to put more value on the local issues rather than global issues. To me it seems that students from diverse communities and specifically the ones from poorer communities, where mostly racial and immigrant minorities live, will find their ideas represented and their problems explored like [food deserts], asthma, air quality, roads, and community gardens...This becomes their [science and their solution].

The CS curriculum is being seen as the place for the teachers to bring students' local knowledge into play and determining what happens through the CS curriculum. When we consider the major tenants of the theories of democracy, we view this CS curriculum on wellness and environment to be based on the democratic values of deliberation among different stakeholders, importance of minority experiences, and the willingness to compromise on an issue, consensus building among the stakeholders, and recognizing the dignity of all the people involved. If CS projects advocate for democratization of science, then they should also strongly focus on how the democratic values of participation and partnering align with individual and community agency and power to influence what gets explored and for what purposes. Just focusing on neoliberal democratic ideas of efficiency and efficacy for economic and knowledge growth in CS projects may only help put power in a few already powerful people and institutions and may end up alienate the rest of the public. The democratization of science through CS projects raises the question: For who is the science for and to who it belongs?

In most CS projects that we have looked at through Wiggins and Crowston (2011) and Bonney et al. (2009) typologies, we found that they mostly ignore place-based needs, culture, and values of the concerned communities. These concerns become afterthoughts rather than parts of the CS projects. These typologies have also shown that the projects have given greater importance to getting the "science right" and "getting increasingly large amount of data" through all modes of technologies and from diverse groups of the public. These projects also seem to ignore the fact that science is filled with errors and most scientific discoveries came out of errors and failures. Therefore demanding "correctness" and "accuracy" from the public clearly indicates that CS projects don't seem to value the fundamental aspects of engaging in science. How would CS projects be successful in democratization of science if the premium is placed on "getting the answer right" rather than exposing and encouraging the public to engage with science despite "not getting the answer" for a CS project. During our engagement with the teachers in CS curriculum professional development, we were encouraged to learn that they valued the "messiness and uncertainty" that were allowed in the CS curriculum and also "not getting the right answer" was "acceptable" and as "scientific [as] getting the right answer." How do we then consider citizen science for sociopolitically conscious actions if the focus is on the right science? How do we find place for underrepresented groups in CS projects that is for them?

Sociopolitical Consciousness in Citizen Science

Citizen science has the purpose of brining diverse communities and individuals to participate in science, but the activities in which the public participates in seem less directed toward their community. The social, political, and cultural complexities of a community are mostly left out from the CS projects except in few that intersected with the scientists. We believe sociopolitical conscious actions through CS projects are very organically connected. When a community decides to propose and engage with a CS projects, the community is looking for actionable outcomes that then they can use to enlighten the larger public and policies for change. What troubles us about citizen science is when does a citizen gets to decide which science they want to pursue. We take note of Calabrese Barton (2012) and Weinstein's (2012) idea that citizen science leaves out "citizen's science" and marginalizes what citizens of a place want to explore and learn for the local purposes. In this sense we find citizen science in the current framing can't promote the ideas of equity, social justice, and sociopolitical consciousness particularly in the citizens from the margins of the society.

We believe equity, social justice, and sociopolitical consciousness go hand-in-hand in citizen science if the goals of CS are to both promote participation from the public in science and focus on place-based problem-solving (Smith 2002; Powers 2004) that is meaningful to a concerned community. Drawing from the equity ideas in education (e.g., Banks 2008; Friere 1970; McLaren 1995, 2005), social justice ideas (e.g., Young 1990; Greene 1986), and sociopolitical consciousness (Ladson-Billings 2012), we argue that CS has to be both the context for a CS project and also science contents that are for the community. Furthermore equity, social justice, and sociopolitical consciousness ideas are based on critical theories; therefore CS advocates have to figure out how power, agency, and equal participation with equal voices from the public are respected and valued in CS.

Implementing citizen science in school contexts are worthy efforts as it allows families and students part of science. In our mind CS curriculum that we are working with K-12 teachers allows students and their families to be citizens of citizen science. Students make help our CS curriculum citizens' science where the science comes out of student and their experiences in their local communities. As we further look into national science initiatives advocated by American Association for the Advancement of Science (1989) and The National Academy of Sciences (2010), Lieberman and Hoody (1998) we continuously find the push for broader participation in science and increasing scientific literacy. In these and other works in science education, including our CS curriculum project, we take the stance that making science relevant and meaningful to students are the key factors that could make CS successful in schools.

We are optimistic that citizen science through CS curriculum, with support from K-12 teachers, could be successful in making citizen science a part of regular science and other disciplines where local community problems could be explored. We also feel optimistic in the success of CS if CS projects could be designed to gather data through community participation. We also envision that students could be encouraged to expand CS curriculum to global problems. For example, our CS curriculum could expand into eBird and the Audubon's Christmas Bird Count involving people from all walks of life or anyone who is interested in the local birds and the local environment, therefore encouraging the students and their families (public) and the scientists to explore varieties of questions about connections between a local bird population and local environments.

On the other hand, CS projects like Zooniverse and Foldit, which are more exclusionary to the public through high skills demands, are less open to the public. Therefore we wonder if such CS projects are helping to democratize science through greater public participation. For example, the Zooniverse project (2019) on its web description (https://www.zooniverse.org/about) clearly puts value on volunteers (public) as "assisting professional researchers" so that the results gained from volunteers' labor benefits "the wider research community, and [produces] *many publications*" (n.p.). In this CS project, we believe that the public is taken as free labor on whose backs the "professional scientists" deliver products for their benefits rather than for the lager public. We struggle to find democratizing effects of science in this kind of CS project where the goal is more on the production of science related "things and knowledge" that benefit the people in power and makes science less accessible to the public. Historically science has acted as a place for those who are in power – mostly White men – and this trend is still true in science (e.g., Ceci et al. 2014). So, the question is how CS becomes more democratic and supports democratic values within science disciplines. We are not advocating for democratic science where anything goes, but we are advocating for science that values voice and agency of the larger public like our students and their families who have always been outside of science.

Finally, we believe that citizen science has tremendous potential in benefitting the students, families, and communities that are at the margins. We ought to consider citizen science as a part of the K-12 curriculum where teachers could bring plethora of opportunities to make meaningful difference in their students' lives and their interest in science. In citizen science our citizens are students and their families where the science that happens comes from students and their needs. Therefore, for CS projects to be inclusive, socially, politically, and culturally impactful, CS projects have to let student citizens to take control of the science and problems they want to understand, explore, and find solutions to. We continuously wonder when and how we can make citizen science for the student citizens and their families. A democratic citizen science is one that which works to protect minority values, ideas, and power, along with, placing greater value to science that is generated from the local community participation rather than just the scientists in power.

Finally, looking forward, we encourage CS scholars to explore several valuable questions about CS projects and the participants. We propose some important research areas that scholars and policymakers could explore through qualitative and quantitative methodologies:

1. How does citizen science promote advocacy and participation in community issues among the public? Specifically who participated and why? In this we push CS scholars to carry out ethnographic studies to understand the processes of participation by the public in different contexts or locales and also of the CS projects and scientists.
2. What are ways through which CS projects could disseminate science knowledge generated for the public based on community needs and how communication of science knowledge build better citizen scientists? In this we are pushing the CS project leaders to find communication means to share knowledge that could be used by a community in useful ways. We want to encourage CS scholars and scientists in particular to explore ways to make new knowledge available to the public for free.
3. How does CS help build a more scientifically literate and scientifically engaged citizens across the globe? In this we seek to push CS scholars to critically examine the questions what does participating in CS project mean to a non-scientist public? How does science literacy mean in the context of CS project?
4. How does CS project support doing science and participating in science more socially just and inclusive? In this we seek to challenge CS scholars to question their

own personal and institutional practices that may be promoting science as an objective and meritocratic discipline rather than a socially and politically mediated space. Also how CS could narrow the gap in gender participation in science?

5. How does race and racism influence CS projects both in the kind of community issues taken up for exploration and the nature of participation from marginalized groups? In this we seek the CS scholars to ask uncomfortable questions around race and racism and its effects on who participates in science and CS projects.
6. What factors and initiatives could make CS projects more collaborative between the public and the scientists? Specifically what barriers exist to make CS projects more collaborative in (a) problems to be explored, (b) data to be collected, (c) analysis and meaning making, and (d) authorship in publications?
7. Native communities across globe have vast amounts of experiences with the environment and have accumulated large amounts of knowledge based on these experiences. How should CS projects be more respectful, inclusive, and recognizing of these knowledge as legitimate science knowledge?
8. How should policy and funding around CS projects be designed and applied so local communities and the participating public also have greater stake in the success of these projects? In this our aim is to research policy and funding documents and their impact on CS projects and the outcomes of these projects on local community and people.
9. In what ways place-based and community-led CS projects could promote greater participation between scientists and community? How do these CS projects promote agency and empowerment in communities and nonscientist participants?
10. How does democratic citizen science look like? A qualitative study would shed light on the nature of democratic science and what the public and the scientists value about democratic science.

Conclusion

In conclusion, citizen science (CS) has much to offer to both broadening participation of groups and individuals who have believed that science is not for them. A similar sentiment exists in many students in school and higher education settings that they are not intelligent enough or good enough to do science or participate in science. These myths exist in science because science has traditionally been promoted as an area of study for those who are academically and intellectually good. Yet, we have known the contributions of native communities to scientific fields in much to the surprise of many scientists who received their training in science in academic institutions. The knowledge about nature and its inhabitants are very well documented and understood by many native communities around the world; but the dominant science education system that delegitimizes other ways of knowing has held these knowledge as "untrustworthy." Most native knowledge is based on observations and activities done over decades and centuries with many tweaks and adjustments along the way. Therefore, their knowledge is more comprehensive and durable unlike knowledge produced by many practitioners of modern science in their labs. Yet, indigenous knowledge gets relegated to less rigorous and less legitimate. Similarly, local communities and individuals know a lot about their local environments and could aid science to learn more from their knowledge too. CS has been working to attract more and more communities and scientists to participate in doing science as close synergistic partners to learn about the nature. These partnerships are essential if the goal is to both build support for science in an era of climate change and skepticism and broaden participation in science. The appeal of CS is its potential to influence ordinary citizens to see science as a part of their everyday lives. However, CS has to also critically examine social, economic, and political issues of the time. Researchers involved in CS have to also work against the political and social forces that use science as a legitimizing tool for discrimination and oppressions for the benefit of the dominant class. CS can play a central part in disrupting the narrative of oppression and injustices whereby privileging all ways of knowing and making science more accessible to all groups. Since CS is dependent on local participation, CS can help disrupt systematic discrimination by allowing people to gain agency to influence a kind of science that gets done. For example, if the CS is only focused on ideas and issues of the affluent nations and societies, then CS is no different from other sciences that were done on the poor or the less fortunate such as the Tuskegee syphilis study on African Americans or sexually transmitted disease study in Guatemala and many others around the world. Therefore, we advocate for CS to continuously focus on building capacities that allow everyday people to critically examine science and through that their own social and personal change and transformation issues. We strongly believe that CS has the potential to help people to be sociopolitically aware through science because the science everyday people participate in through CS is about their local place and connected to their local issues. There can be a strong buy-in by these communities in the science that gets produced by engaging in CS because it is based on events that happen in their own communities. Thus, we find great value in leveraging CS as a participatory science where community members have voice and power to dictate and play a positive part. CS has to consider social justice and equity issues so that it can be a partner in making the society more just and equitable for many marginalized groups.

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