The Future of Citizen Science

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ABSTRACT
There is an emerging trend of democratizing science and schooling within science education that can be characterized as citizen science. We explore the roots of this movement and some current projects to underscore the meaning of citizen science in science and schooling. We show that citizen science, as it is currently conceptualized, does not go far enough to resolve the concerns of communities and environments when considered holistically and when compared with more dynamic and multidimensional ideas for characterizing science. We use the examples of colony collapse disorder (CCD) and emerging trends of nanotechnology as cases in point. Then we justify three dialogical spheres of influence for future citizen science. As citizen science becomes more holistic, it embodies the responsibility of youths who are prepared to engage real concerns in their community.

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In the second decade of the 21st century, science education reform is occurring in a context of decreasing budgets for education, increased accountability, and an emphasis on achievement that minimizes students' and teachers' diversity of experiences, voices, traditions, and histories. Reform documents and corresponding initiatives such as Science, Technology, Engineering and Mathematics (STEM) education and Race to the Top (American Recovery and Reinvestment Act of 2009 [ARRA], Section 14005-6, Title XIV [Public Law 111-5]) reflect societal expectations for schools to provide "a trained workforce and only incidentally with enlightened citizens" (Curtis, 1993, p. 134). Amid this rhetoric of reform there is an implicit recognition that democratizing science education is vital to fostering students' understanding of how science can be relevant to their lives and communities. Yet many efforts for science education reform continue to operate on the assumption that knowledge is a body of isolated facts with little connection to other disciplines or the larger community. In contrast to this narrative of isolation, our vision of science education, and by extension schooling, is one

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predicated on the notion of participatory democracy—one in which citizens actively take part in collaborative efforts to make the world a better place. At the nexus of science education and participatory democracy is a commitment to educating students to make more informed choices, think critically, and believe they can make a difference. Giroux (1993) suggested that at the very least this means that "educators need to affirm the voices, histories and stories that provide students with a sense of place, identity and meaning" (p. 280). At the core of science education, students' identities influence everything from how they view ecojustice issues to whether they offer agency and advocacy for affected parties of their choices.

Admittedly, there are many challenges to democratizing science education. There are scholars within the field of science education who try to constrain science to a very narrow view. The very notion of democracy has a concomitant history of contested meaning. Within the realm of public education, as Westheimer and Kahne (1998) point out, "the policies and practices of teachers, schools, and districts can promote or constrain the degree to which students acquire the knowledge, skills, and attitudes necessary to function effectively as citizens in a democracy" (p. 19). Consider a group of middle-school students with the desire and capacity to respond to the pollution of a nearby stream by a local business. The very characteristics essential to a participatory democracy rest in the students' desire to understand the ways in which the stream is vulnerable to human impact and then to take action. As the students gather information and decide on a course of action with respect to the stream, they may encounter school administrators who work to avoid any perception of controversy. School administrators may justify their knee-jerk reaction with assumptions about how the controversy will be perceived by the school board or district, policymakers, and business partners. In many ways, it is hard to understand this without noting that corporations now significantly influence school administrators' decisions. Likewise, the specifics of curriculum and pedagogy that support democratic participation may also be a source of contention, particularly when teachers feel bound by the authority of the professional discourses in which they work. Democratizing science education requires a school and its overseers to take seriously their role as part of the community and to act within it.

Kincheloe, Steinberg, and Tippins (1999) emphasize that teachers, students, and parents come to view the "community as a mini-laboratory for democratic participation" (p. 223). In this sense, the community becomes a microcosm through which scientific events and their effects can be analyzed. Similar to Dewey's (1916) conception of democracy as a way of life, a vision of participatory democracy for science education calls for students, teachers, and communities to counter the culture of inaction or passivity that often characterizes what it means to teach or learn science. Today's teachers face a significant tension of whether to teach students for science competency or whether science competency is the secondary purpose of engaging them in scientific literacy. It is the transformative nature of participatory democracy that may ultimately enable students, teachers, and parents to reclaim a new purpose for science education.

A Roadmap for this Study

In order to make the point clear that education is one where competency is secondary to literacy, through citizen science, we provide a brief history of citizen science and discuss some of the educational research findings that have surfaced from analyzing citizen engagement. We demonstrate some of the shortfalls of citizen science as it is currently popularized and so on. We connect with a theory of citizen science that was designed to guide science education, and modify it such that citizen science can be defended for any subject within societal education. To avoid the presumption that citizen science accurately embodies the sciences, we provide two highly relevant examples: colony collapse disorder (CCD) and the emerging field of nanoscience and technology. We show in each example that despite how citizen science is often separated from ethics, politics, and spirituality, it cannot continue to be separated from these aspects in science if we are to truly understand these issues. We theorize a conceptual model that may be used to guide the development of citizen science projects as well as to broaden the purview of where our educational studies interests lie. To articulate the model, we connect with other scholars who have explored similar theoretical ideas: street science, technical democracy, and zones of civil disruption and emergencies. The purpose is to develop a theory that recognizes problems of access and social disparities in light of our discussion of participatory democracy and the transformative view of citizen science.

Citizen Science

When the community becomes a minilaboratory for democratic participation, for citizen science as a tool for, say, conservation in a residential neighborhood (Cooper, Dickinson, Phillips, & Bonney, 2007), the more likely it is to be conceived as the culmination of diverse actions of inquiry. The outcomes are iterative of the experiences and needs of a community, where collaboration in research activities leads to common knowledge and community awareness and dissolves the residential or inherent cultural, environmental, and virtual tensions. Tensions affect those who have power to choose but also those who are affected by choice. The problem, however, is many of the popular citizen science projects are not guided by this idea.

Citizen Science Example: Audubon's Christmas Bird Count

Consider the longest running citizen science project, the Audubon Society's Christmas Bird Count, which is one of hundreds of science projects in which everyday citizens participate. (See those featured in Cornell University's Citizen Science Toolkit, http://www.birds.cornell.edu/citscitoolkit). The Christmas Bird Count has for 112 years provided a protocol for surveying birds and collected extensive data on the numbers of bird species. For example, in Athens, Georgia, 37 participants spent 102.5 hours on December 18, 2010, noting 516 Northern Cardinals, 50 Purple Finches, and 283 Carolina Chickadees, among thousands of other birds surveyed. The data were recorded on a world-wide distribution map. Data may also be displayed in many other different formats, such as charts and graphs. The Audubon website notes that data collected by volunteers have allowed researchers, conservation biologists, and others (i.e., professional scientists) to study the long-term status and health of bird populations and species movements with respect to ecological issues. Similar to the calls of Carson (1962), based on her scientific inquiries, regarding bird declines associated with DDT (dichlorodiphenyltrichloroethane), the Audubon website claims that the Christmas Bird Count, by identifying habitat fragmentation and ecological threats such as groundwater contamination, is essential for the protection of birds and their habitats. By cross-referencing several science-search engines for literature, there appears to be a growing acceptance of the reliability of Audubon citizen science data. This point is based on the increasing number of ornithology articles that consider Christmas Bird Count data in relation to scientists' own studies. Thus, a conversation within science about how to increase the scientific value of citizen science for doing larger scale ornithology ensues (cf. Dunn et al., 2005). While the conversation, initiated for the most part by Cornell University ornithologists, seems to have popularized citizen science so that it is being taken more seriously within the scientific enterprise, the vast majority of scientists still consider volunteer-generated data to be much less rigorous and the margin of error significantly higher than that collected by professional scientists. Therefore, citizen science has a much different meaning within science than in education. Unless the protocols are designed by scientists with error-proofing methods such as digital photography and global positioning technologies, it is rejected as scientific work. See, for example, the protocol assigned to most projects. Much of the research literature for the Christmas Bird Count emphasizes its teaching and learning (or pedagogical) values rather than its value in enhancing scientific studies. In other words, citizen science is useful for teaching about science rather than engaging in issues. Unfortunately, teaching about rather than engaging in is a widely known problem in schools, and citizen science offers very little that the textbooks or teacher lectures do not already disguise.

THE RESIDUAL OF SCIENTISM AND POSITIVISM IN CITIZEN SCIENCE

The teaching-about-science conception embraced in schools can be traced back to the underpinning of science and science education, which has been associated with the ideology of positivism. Part of the reason that positivism has been the prevailing ideology for science and has had a deep residual (despite the changing philosophy of science over the 20th century) within science education is that it offers a simplistic assertion that scientific knowledge is best derived through standardized protocol (the scientific method) and that science serves as the only true authentic source of knowledge in our lives today. The scientific method does not suggest that investigators take into account ethical, political, and social studies but rather reinforce the assumptions of objectivity in our very ways of knowing. It is not surprising then most people think that science has a higher status and produces the best evidence for making informed decisions and taking useful action. Indeed, many people place their entire faith in science and technology to solve the concerns of modern society. This faith is equated with scientism, which also leaves a deeply embedded residue.

Additionally, the sources of best practices within science have traditionally and historically been generated by male scientists or androcentric philosophical science perspectives. Consider how Barbara McClintock, Rachel Carson, and other women of science were treated by their male colleagues. These women considered a different philosophical tradition of how science should be approached—that is, relationally. McClintock established relationships with her plants and Carson emphasized ecological understandings that are best developed in relation. Equally important, both women serve as examples of how difficult it is to enter a field where the rules of how to do science have been largely dictated by men, stemming all the way back to the ancient Greeks—a two-thousand-year legacy. Being an outsider and establishing one's own or shared rules for participating in science constitutes accessibility and is difficult, at best, to accomplish. Later we discuss how these ideologies continue to influence citizen science projects.

TOP-DOWN CITIZEN SCIENCE

The key point is that it does not matter whether or not individuals engage in citizen science projects focused on mammals, birds, weather, climate change, flora, or invasive species. The participants primarily serve to collect data for scientists rather than to collaborate with scientists, democratize protocol and equipment, assess ideas, and work in relation to others. We call the residual of positivism and androcentric view for citizen science a top-down approach. Many citizen science projects (e.g., the Christmas Bird Count) claim to involve participants in scientific research, yet very seldom do citizens actually witness a scientist in action, plausibly because they are not actually involved in collaborating with the scientists who developed citizen science projects to do larger scale scientific studies. Nor do they ask their own questions, develop protocol, use the data to construct their own models and analyses, and publish findings with only their names. We were challenged to find a single paper published by *citizen scientists* explicitly using that label for their roles collecting data for the Audubon count.

What Have We Learned from the Citizen Science Research?

Two science education studies (Trumbull, Bonney, Bascom, & Cabral, 2000; Trumbull, Bonney, & Grudens-Schuck, 2005) discuss volunteer participation in citizen science activities and the associated citizen science curriculum that was designed to promote science-inquiry learning. While these studies did not significantly increase understandings of the nature of science or lead to more positive attitudes toward science and the environment, they did promote increased science content knowledge about bird anatomy and biology—that's the least that is to be expected, right? What is more interesting is that these science educators found that volunteers who participated in citizen science activities for longer periods of time already had increased motivation for participating in science and ethical orientations for birds and ecosystems. In other words, the reason why citizen scientists participate in bird studies for longer periods of time is because they perceive their contributions worthwhile. They already love birds, in most cases, and believe that they are making a difference toward protecting birds and their habitats. But this is the same situation as the top-down manager or employer who does not afford employees a voice in decisions that affect their longer term participation and yet these employees are involved in what they love to do. A remaining question is whether those who are not ethically inclined toward birds and their habitats would stay active?

Ethics Have a Lot to Do with Longer Term Engagement

We know that when an individual asks questions that matter to one's self or the community, and designs and carries out investigations in order to resolve environmental concerns, they are more likely to learn everything they need to know in order to resolve bioregional issues (Corburn, 2005; Rheingold, Seaman, & Berger, in press). This learning includes collaboration with community professionals, teachers, scientists, and so forth to perform investigations and collect and analyze evidence to support conversations of a range of choices. Even youths, when guided by adults, have demonstrated that they can be trusted for the data collected, and in some cases the quality of the data collected by students could exceed that of scientists (Fogleman & Curran, 2008; Fore, Paulsen, & O'Laughlin, 2001). Watershed volunteers who monitor the health of stream systems for the Environmental Protection Agency (EPA) have also demonstrated how local concerns coupled with democratized methods increase degrees of confidence associated with making the most informed choices and advocating for those who need it (Ely, 2008; Engel & Voshell, 2002). Civic responsibility is generally higher for citizens who are motivated by the welfare of their local community (Jones & Colby, 2001). However, a significant problem exists for those who want to participate in ways that are of their own design. There are pitfalls associated with community-based learning when power dynamics limit levels of participation such that the guidance of adults or community professionals is overly biased or people's agendas are being compromised (Hogan, 2002). Power dynamics will affect citizen science projects at any level (top-down or bottom-up), but less when community driven.

Original Theory of Citizen Science for Science Education

We now know that there is a spectrum along which citizens participate in citizen science, and their projects may be closer to either top-down, often scientist driven, or bottom-up, such as EPA's watershed network. Somewhere in the middle of the spectrum is where citizens mediate citizen science so that it may be used initially as a top-down program to generate data for scientists but mediated later in such a way that a group of students and their teachers may ask new questions that involve different protocols, equipment, research designs, and so forth. Approached this way, Mueller and Tippins (in press) initially theorized a participatory democratic approach to citizen science where science is something that all citizens can contribute to. This premise is based first on the idea that scientific understandings of the natural world have not come from any single group of people on Earth. Science has been sustained by many people and across time—by the ancient Greeks, Chinese, Arabs, and so forth. Likewise, it has taken many diverse participants with different views of the world to increase the confidence in findings that have occurred from investigations of natural phenomena. Second is that multiple stakeholders (that is, people with an invested interest in an issue or who might be affected by an issue) with diverse views increase degrees of confidence (particularly as it relates to ecological theory; cf. Aslaksen & Myhr, 2007; Code, 2006; Thayer-Bacon, 2003). Generally, there will be higher degrees of confidence around decisions if people with different aspirations, norms, beliefs, and cultural ceremonies are represented fully. Aslaksen and Myhr provide a great example around the economic worth of a wildflower. Based on that premise, we add that youths are part of the community and not often involved in stakeholders' decisions (e.g., adults rarely think of children specifically in relation to water rights), but they are naturally attracted to exploring ecosystems and may even be more attuned or sensitive to changes that occur within environments. Anyone who has children can testify to this point, and it has also been justified in the literature (Louv, 2008). Therefore, youths may serve as appropriate and significant advocates for affected parties not limited to humans but also flora, fauna, and physical environments. According to Kozol (2005), young people can be trusted for the quality of their data because so often they approach issues without the longer lived experiences of adults who may be jaded or biased, tainted or torn. We shared in the previous section that young people can be trusted for the quality of their data when scientists and teachers play an active role guiding inquiry. We now add to this premise the idea that we also make use of the knowledge and understanding of the world that have been previously devalued or excluded (Kincheloe, Steinberg, & Tippins, 1999) and, concomitantly, be aware of power dynamics that exclude individuals' participation.

What follows is that diverse geographic knowledge (Mueller & Tippins, in press) needs to be emphasized or it is more likely to be eroded away—think tools, languages, and ceremonies. With diverse geographic knowledge, citizens are more likely to be consulted for what they know—such is the case still with tribal communities or for a shaman whose knowledge is sought even though it is not the knowledge of institutionalized education (Abram, 1996). This knowledge is no different from that of the teacher who becomes an expert in a local fauna species, or the student who finds a centipede and learns everything he or she can about it (Wilson, 2006). Without geographic knowledge, citizens are not likely to know their surroundings well enough that they will also know when those surroundings are being degraded or when they as citizen scientists need to consider other appropriate actions. Consider the serious situation of most Americans who do not know where their food comes from and how animals used for meat were treated before and during slaughter (Singer & Mason, 2006). When the matter of data acquisition is explained in such a way that regular citizens gain meaningful involvement in science or environmental inquiry, they begin to ask further questions that lead to democratizing science such that they can solve local issues. We used these principles of citizen science to initiate the conversation (Mueller & Tippins, in press), about the previous dilemma of citizen science emerging as a predominately top-down project. However, there are now new challenges for citizen science as we advance this conceptualization. Whereas citizen science gets its power from basking in the sun of science, there is much more to science that is often not acknowledged as part of the endeavor, such as cultural, ethical, political, and spiritual (and virtual) studies. The next two sections help make this point clear.

Colony Collapse or Cultural Lapse

Consider bee research. The National Research Council (NRC, 2007) report on the North American pollinator decline suggests citizen science where science teachers and students are recognized for the contributions they can provide for the scientific community. The NRC calls for high-intensity biodiversity surveys and notes, "the assessment should include monitoring of pollinator status and function that integrates the work of professional scientists and citizen-scientists to maximize the depth and breadth of effort" (p. 10). The NRC also calls for the conservation and restoration of pollinator-friendly habitats, such as wildflower gardens, as well as the public outreach and education needed "to raise awareness of pollinator's ecological and economic contributions and to encourage public participation in conservation" (p. 11). The NRC notes "as part of their outreach, federal granting agencies should make an effort to enhance pollinator awareness in the broader community through citizen-scientist monitoring programs, teacher education, and K–12 and general public education that center on pollination" (p. 11). Pollinator citizen science projects have emerged in response to colony collapse disorder (CCD), which is devastating for honeybee populations across the United States (Phillips, 2008). Despite the popularity of these projects and emphasis on environmental monitoring and habitat restoration, bee researchers have had to become more expansive in their approaches to collecting poignant information about why honeybees, in particular, have declined in North America.

When the science of bee decline is compared with the science embodied within citizen science, the differences are remarkable. Scientists' approaches to assess the situation do not nearly capture work by the citizen science projects. Most of these projects provide very basic standardized protocol that draw attention to scientists and their studies of bee declines, or CCD. They seldom go far enough to emphasize the ways that people are more than superficially participating in bee studies. Interestingly, citizen science studies focused on CCD do not acknowledge the lack of scientific data to support CCD. Consider the following: "Regrettably, despite increasing claims of global pollinator declines, the data needed to assess global changes in the abundance and diversity of wild pollinators are not currently available" (Aizen & Harder, 2009, p. 1). In this report, which is being taken very seriously by bee researchers, Aizen and Harder assert that cultural, political, and economic factors are responsible for declines. They note:

> *Although the mysterious colony collapse disorder has recently had an impact on American honey bees, the half-century decline in their numbers may partly reflect decisions by honey producers to leave the industry in the face of competition from cheaper imported honey, given that the USA became increasingly reliant on imported honey beginning in the late 1960s. (p. 2)*

Aizen and Harder show that solutions for CCD may lie with local cultural and economic inquiries: "The rapid increase in the fraction of pollinator-dependent agricultural production greatly exceeds that of the global stock of domesticated honey bees, especially since 1991" (p. 3). This increase in agricultural demand without an increase in the numbers of hives kept that would otherwise provide for the demand is particularly true of the United States, where the number of people keeping honeybees has significantly decreased over the last half century. While other types of pollinators (e.g., solitary bees) have taken over pollinating the current agricultural demand, more lands are cleared for urban and agricultural development and there is increasing vulnerability for pollinator habitats.

CCD has more to do with historical, cultural, and community factors; it involves agricultural, political, and conservation policies rather than focusing squarely on simple biological ones. Barnes (1982) noted how Aristotle recognized this aspect of what is today called scientific inquiry two thousand years ago when he consulted beekeepers to learn about the nature of their work and the biological understandings they intimately knew. Sometimes Aristotle is called the father of science, but we have lost many of the ways of learning and inquiring that Aristotle used so many years ago. He regularly talked with people who kept animals, fishermen, and indigenous peoples to understand the deeply embedded contexts from which biological knowledge is inseparable.

Almost all of the citizen projects focused on pollinators have to do with environmental monitoring or counting the numbers of bees (and other insects) that visit flowering flora during a specified period of time. Very few (Mueller & Pickering, 2010) citizen science projects emphasize cultural vulnerabilities such as what might be gained from monitoring how many people keep bees locally, or local political, agricultural, and conservation policies in relation to the environmental monitoring protocol that accompanies widesweeping citizen science. Indeed, this evidence signifies that citizen science projects superficially focused on environmental monitoring miss the mark with regards to the larger problems scientists are now focusing on to understand CCD and pollination. Other sources support the same conclusion (Benjamin & McCallum, 2009), which begs the question of what citizen science data help scientists to do and whether citizen science data are being collected to generate awareness around scientist-generated agenda. In other words, it may be the case that scientist-driven citizen science projects merely serve to create apparent panoptic crisis situations to help increase support for expert-research, when the general public does not understand that spatial and temporal scales play a role in the ways in which biological conditions are contextually embedded with sociocultural, historical, ethical, political, spiritual, and virtual spheres of influence for them.

We are making a bold claim here, so this claim deserves some explanation. Philosophers such as Kuhn (1962) note the powerful role that constructed crises play in paradigm shifts for the scientific community. Constructed crises also play powerful roles in European and North American societies for moving public interests one way or another (Mueller, 2009; Mitchell & Mueller, 2010). The sense of urgency that is captured with global climate change is also extensively focused on in CCD awareness; it is used to hamper the ways that laypersons might gain meaningful participation (as we demonstrate later). Thus, it seems highly suspect that citizen science projects such as the Great Sunflower Project (http://www.greatsunflowerproject.org), which has hundreds of thousands of volunteers, are not purposely recruiting participants to draw attention to a body of work and then elicit funding because of this increased awareness. Unfortunately, many citizen science projects share the miseducation associated with drawing participants into thinking they are doing something scientific when what they are doing does not nearly capture the integrated nature of science, culture, and consequences. There are at least three dialectic spheres of influence at work here (environmental, cultural, and virtual) that are invisible in citizen science projects. Before discussing these spheres in more depth, let's turn to nanotechnology for another example of an emerging trend within the sciences, where thinking across scale has significant implications for nearly every area of science and other cultural modes of society. We want to draw attention to the virtual or futuristic characteristics of nanotechnology in particular.

New Trend in Science: Nanotechnology

In the last few decades, scientists have begun to measure and control the synthesis of matter on the nanoscale. What is significant about the nanoscale is that some of the most fundamental principles governing form and function of matter depend on size in a way that is unlike any other scale (Di Ventra, Evoy, & Heflin, 2004; Ratner & Ratner, 2003). Scientists and engineers working at the nanoscale level exploit the novel physical, chemical, mechanical, and optical properties of materials that naturally occur at this scale. It is estimated that the worldwide workforce necessary to support the field of nanoscale science, engineering, and technology (NSET) will be close to two million people by 2015 (National Nanotechnology Initiative, 2005), and that more than 10% of all manufacturing jobs will relate to nanotechnology (Hullmann, 2006; Roco, 2003). Since the inception of the National Nanotechnology Initiative (NNI) more than a decade ago, the U.S. federal government has provided sustained funding for NSET research and development to the sum of more than $14 billion. Our investment is based on nanotechnology's "potential to vastly improve our fundamental understanding and control of matter, ultimately leading to a revolution in technology and industry for the benefit of society" (National Science and Technology Council Committee on Technology Subcommittee on Nanoscale Science, Engineering, and Technology, 2011, p. 7)

Much of the intrigue of nanotechnology, in particular, lies in its unprecedented promise. Many of these technologies represent major advances that enhance our lives in ways that only decades ago were the imaginings of scientists, engineers, business people, and even science-fiction writers. For example, researchers are now using nanoparticles as a treatment and diagnostic tool for cancer. With the promise of replacing caustic treatments such as chemotherapy or radiation, new cancer therapies employ nanoparticle-based drug delivery systems to carry chemotherapeutic drugs into target tumor cells, leaving healthy cells untouched (Choi et al., 2007). Nanometer-sized semiconductor crystals called quantum dots are being studied as ways to improve clinical diagnostic tests for earlier, quicker, and less evasive detection of cancer (Liu, Lau, Varma, Kairdolf, & Nie, 2010). Electronics applications involving nanotechnologies are providing smaller, faster, and more powerful systems that can manage and store increasingly greater amounts of information. Imagine a single-molecule electrical transistor. Computers and other technology based on newly developed nanotechnologies will require much less energy to power, produce much less heat, and run much faster (University of Liverpool, 2005). Finally, in the post-9/11 era of heightened security, nanoparticle biosensors will revolutionize much of the effort for protecting human health and the environment because of their remarkably simple and accurate ability to detect biotoxins such as anthrax at fewer than ten molecules (Mirkin, 2000).

While many of the advances in nanotechnology are seemingly visionary, they are the prospects of future generations, being first investigated in the minds and laboratories of physicists, chemists, material scientists, and biochemists today. It is hard to find someone who has not heard of nano, given the bombardment of media attention and myriad of consumer products that purport to include some aspect of nanotechnology. Students may own a Babolat NS Drive OS tennis racquet that boasts of "nano strength material technology" (http://midwesttennis-tennis.blogspot.com/2010/07/babolat-ns-drive-os-tennis-racquet-1374.html). Their Eddie Bauer khakis may resist spills, stains, and static thanks to Nano-Tex technology. A school bathroom may be painted with Behr Premium Plus bath paint that claims improved adhesion and antimildew properties because of nanotechnology. Teachers may not even realize they are wearing cosmetics (concealers, foundations, and sunscreens) that incorporate nanoparticles for their promise to disguise wrinkles and their highly beneficial effects in blocking the sun's ultraviolet light.

Nanotechnology has been touted as the next industrial revolution (Center for Responsible Nanotechnology, 2011), one that will have a greater impact on society than the first industrial leap. History has taught us, however, that with the promise of science and technology come potential perils. Mnyusiwalla, Daar, and Singer (2003) assert that progress in nanotechnology is far out-pacing the study of its ethical, environmental, economic, legal, and social implications. Take the case of silver (Ag) nanoparticles (NPs). With the increasing resistance of pathogenic bacteria to traditional antibiotics, AgNPs have become a valued antimicrobial alternative. AgNPs are being used as antimicrobial agents for surgical tools, water purification, aseptic food packaging, refrigerator surfaces, and even odor-resistant socks. Recently, however, concerns are mounting about possible unforeseen environmental and health consequences of using AgNPs in consumer products.

Specifically, researchers have found that when commercial clothing coated with AgNPs is washed, the AgNPs are released and may travel through a wastewater treatment system, entering our natural waterways and compromising aquatic ecosystems (Benn & Westerhoff, 2008) and perhaps even humans.

While nanotechnology could lead the way toward more effective drug delivery systems, feeding more of the world's people, and significantly reducing waste, the cultural, ethical, social, and virtual aspects of the science are being deemphasized or ignored in deference to the aspirations of entire industries or investors. Like so many genetically modified foods that become part of the products people eat every day, nanotechnologies are also emerging into the market with great zeal. But they are arriving without the proper guidance and oversight that comes from engaging diverse individuals as stakeholders, from decision makers to those who advocate or represent people who are affected but do not have a voice in decision making. For example, there are no requirements for manufacturers to label consumer products containing nanoparticles (although as a marketing strategy, many manufacturers tout the use of nanoparticles in their products). If citizens knew of the potential risks, would they still purchase such products? How aware is the general public that there are unknown risks associated with products coated in AgNPs? How many consumers who purchase sunblocks and sunscreens containing titanium dioxide or zinc oxide nanoparticles are aware of the ongoing debates about the potential risk (i.e., cancer) of these nanosize particles? Would the general public be supportive of nanotechnologies that dramatically improve our national security (e.g., improved surveillance devices) if individuals were aware that this same technology (i.e., near-invisible tracking devices, cameras, or microphones) would compromise their privacy? How many readers of this article are familiar with current uses of Radio Frequency ID (RFID) tags and the fact that no laws currently exist mandating that a label indicate the use of an RFID chip in a product? Similar to CCD, nanotechnologies are loaded with cultural and ethical choices. Virtually, these ethical choices have much to do with the decisions that people make today, evaluated against their forecasting scenarios or aspirations for the prospects of future generations.

Obviously there can be benefits that outweigh the risks. However, the key point we are making is that the lack of dialogue between various stakeholders (e.g., scientists/researchers, investors, regulators, policymakers, and the general public) could have negative consequences on the future of new science and technologies like those offered in the field of nanoscience. One of the most egregious consequences could be a layperson's suspicion or complete rejection of any nanotechnologies—developed out of fear that has been fostered by the inadequate study of environmental, ethical, cultural, and societal implications of the new technology.

Advancing Citizen Science: Democratizing Democracy

Written to address the question of how science and technology might democratize democracy, Callon, Lascoumes, and Barthe's *Acting in an Uncertain World: An Essay on Technical Democracy* (2009) explores why we are content with few generally accepted scientific understandings in light of culturally diverse knowledge. We connect with Callon et al. because they write that laypersons, or citizen scientists, have always been involved in progressing science and technology. Callon et al. point to the ways in which science has always been mediated and, when democratized, serves to include others who are marginalized in the community in more meaningful ways. For example, imagine a dialogical sphere of relationships that influence the guidance and future of citizen science in terms of nanotechnologies. There are scientific aspects, certainly, but the cultural aspects engulf and elicit the ethics that weave research agendas and community concerns with the virtual aspiration of action (ethics with creativity, for example).

Callon et al. (2009) acknowledge the importance of all aspects of culture: "When the expert abandons the investigation, powerless, the layperson bravely continues with it" (p. 78). They note the particular significance of spirituality, witchcraft, and folklore as part of the science. Laypersons are never separate from the contexts where science and technology are investigated and applied as agenda. Science is never separate from the values of those who have a stake in it. Despite science's long history of being secluded, citizen science is a way for laypersons to gain meaningful involvement; it doesn't take long before laypersons become more fully involved. Callon et al. state: "Anyone who silences those who should speak is condemned to organize ways for them to express their views" (p. 109)! In terms of citizen science, there may even be times when collaborating with scientists will not be in the best interest or even possible for those who want to organize to express their views, which necessitates a greater emphasis now on the dialogical spheres of historical, indigenous, archival, community, or virtual relationships.

Consider Mueller and Zeidler's (2010) analysis of the genetically modified pet GloFish. Most Walmart and pet stores carry the popular genetically modified zebra danio. On the website (http://www.glofish.com) of patent holder Yorktown Technologies, its ethical principles mislead the general public with scientific claims of no harm for environments (which, after an extensive analysis of their lesson plans for teachers, means the contiguous United States). Despite that a closed-door review of patents is used by the Federal Drug Administration (FDA) for new drugs, including genetically modified organisms, and the FDA determined that GloFish proved no greater threat for the environment than its wild counterpart, zebra danio, the heart of the issue serves to guide the preparation of a different consumer. Through citizen science, teachers can play a role in helping students to mediate the conflicting scientific reports regarding GloFish. For example, lesson plans designed by Yorktown Technologies and being distributed by Carolina Biological with their GloFish Kits suggest that it is too cold outside for GloFish to live in U.S. waterways. However, temperature has not been an issue as these fish are bred in live tanks in Florida, and California has banned the sale of GloFish as a preventative measure against invasive populations. There are also cultural factors that were overlooked by the rush to patent life. For example, since genetically modified fish do make their way back into the wild, what threats might they impose on aboriginal peoples who rely on wild populations to initiate cultural ceremonies, traditions, language, or beliefs and value systems that protect the prospects of how they treat environments?

There are also Yorktown's stated ethical principles on its website. The company maintains that fish are treated humanely throughout their life cycle. However, since Yorktown pressure-treats the tanks to sterilize GloFish prior to entering the market and to protect patent rights, the fish are not likely to reproduce or to enjoy parts of their life cycle that wild organisms do. Interestingly, Carolina Biological's website (http://www.carolina.com/product/145260.do) notes: "Reproduction (breeding) of GloFish® is permitted only for educational use by teachers and students in bona fide educational institutions; however, any sale, barter, or trade of the offspring from such reproduction is strictly prohibited." Could teachers and students access nonpressure-treated fish, such that they could participate more fully in citizen science? School laypersons (from "bona fide educational institutions") may perhaps be provided something that a much larger community of stakeholders outside of schools (e.g., aquarium hobbyists) may be excluded from. This example clearly demonstrates how teachers and their students may have access in citizen science where others have been denied and, thus, should be well-prepared to serve as advocates.

Without much thought, new doors may be opened as a result of efforts to patent a genetically modified ornamental pet. Citizen scientists guided by their teachers, Mueller and Zeidler (2010) suggest, could challenge the no-labeling policy for genetically modified organisms such as GloFish that currently exist in pet stores where people may not know what they are buying. Citizen science takes the form of participatory influence and dialogical expression where the mediation of policies concerning labeling and patent practices are the outcome of teachers invested with students in relational spheres of advanced citizen science.

Callon et al. (2009) would support the effectiveness of what they call throughout their book "technical democracy," whereby citizens collaborate with others to fully explore multidimensional uncertainties that are implicit within science. Their book also repeatedly notes the "hybrid forum," and we connect this forum to Corburn's (2005) participatory community action research, or space where people of heterogeneous groups come together to mediate possible and desired worlds. By Corburn's account, street scientists are equated with citizens who use what they know, derived from their everyday lived experiences in realms such as fishing, graffiti, and food practice, to mediate possible and desired worlds. Citizen science influenced dialogically is expressed in actions rather than with exclusive emphasis on sacrificing scale, data gathering merely for science professionals' interpretations, and management's one-way guidance.

Having a say in community decisions by becoming involved is one way to solve current issues surrounding climate change, overpopulation, or the vulnerability of resources and disease. But the true test of an enriched democratic science is one where conversations of citizen science not only serve present-day scientific agendas, such as management and the coercion of nature, but also consider the (virtual) prospects of future generations. For future generations to enjoy some of the qualities of cultural and environmental life present in today's world, citizen science conversations have to take on relations where pluralism in participatory democracy is measured by care, preponderance, and commitment to ecojustice and the welfare of future people.

The Issue of Accessibility

For today's qualities of life to be considered prospects for future people, participatory democracy must be interwoven with accessibility. Consider, for example, the dialogical relationship between modern-day scientists and those who value and rely on longer lived traditions of endorsing the ecological pursuits of previous generations? Some aboriginal communities worldwide do not embrace the European and North American organizational structures and accountability systems implicit within liberal democracy (Thayer-Bacon, 2008) and, ultimately, meet with collaborators to actively participate in democratizing sciences and other education.

Similarly, we recognize there is an access issue that plagues any science or technology impregnated with the digital divide—that is, people who lack access to these technologies because of their lack of knowledge or finances (e.g., about or for computers and by extension the Internet). Who has access to these new technologies? Who will be economically disenfranchised or disadvantaged? Who stands to benefit from advances in nanoscience and nanotechnology? If we have learned anything from the past with advances in technology, it is that with technological advances there are initial costs for those who may benefit the most from the new technologies. This point is inseparable from the great responsibility that educators share with their students for learning in order to participate more fully for those who may not be able to.

Concerns with Speaking for Others

In Chiapas, Mexico, anthropologists (Berlin & Berlin, 2004) and scientists envisioned training community collaborators, indigenous and not, to research botanical knowledge implicit within native medicinal technologies for the purposes of developing pharmaceuticals to patent. In the same way that citizen scientists might map out the flora of a particular region, one of the goals of the Chiapas project was to develop an ethnoflora of the Chiapas highlands. The development of these ethnobotanical gardens (containing 324 species in 103 botanical families) allowed the researcher collaborators to begin to identify a viable substitute for chemical pesticides that were being used to control a cabbage-worm infestation. Berlin and Berlin note that the Maya community collaborators recommended providing information about ethnobotany through theatrical performances.

> *[The] skit included an introduction about our overall goals and each component of the project's activities: demonstrations of our ethnobotanical collecting procedures, work on Maya medical anthropology and enthnopharmacology, establishment of ethnobotanical community gardens, agroecological use of medicinal plant species in traditional agriculture, laboratory procedures, benefit sharing, and our plans to produce illustrated bilingual materials on herbal medicine. (p. 477)*

They included intellectual property arrangements:

> *To develop home and market-oriented community herbal gardens, community cooperatives, establishment of scholarships to be awarded to qualified Maya students, or other significant activities that might lead to the improvement of the social and cultural well-being of Maya communities in the region. (p. 478)*

Still, the project failed, according to Berlin and Berlin. The legacy of biopiracy and the general misunderstandings of bioprospecting were sorely misrepresented by individuals who spoke for the Maya because the Maya have a cultural lack of autonomous institutional governance. The key point is that there were significant cultural misunderstandings as a result of ignored collaboration, according to the authors, which would have alleviated the marginalization of the Maya.

Participatory Democracy during States of Exception

During times of protest, street medics become a good example of participatory democracy. The street medic's communities (Weinstein, 2010, 2011) come together to support antiglobalization and antimilitarization demonstrators. At the core of this group's exceptionality lie technical democratic details of iteration and influence for spheres of street, or citizen, science where confluence rarely matters, where groups are misrepresented (intentionally or not) for the ways that they help foster choices. Street medics, Weinstein notes, are creatures of the state of exception because they are aware of crisis narratives used by governments and corporations for profit and they mobilize. In other words, they are lay doctors, nurses, emergency medical technicians, and other medical practitioners who collaborate to provide medicine during emergency riots and peaceful demonstrations, protected only by state laws such as Good Samaritan laws. They monitor medicine in response to new technologies, such as gear and tear gas used to disperse protesters, that enable an organized cultural sphere of politics to protect riots. Weinstein writes that today's street medics are organized by their principles and ethics, which serve to stimulate internal debates among them. The evolving ways of knowing, embodied by those who provide action medicine, serves to mitigate even police violence. The science of action medicine (e.g., manage shock, identify drug and diabetic reactions) is inseparable from the cultural (political) sphere and technical democracy, thereby they represent scientific literacy through skin treatments and application methods. Weinstein (2011) notes that street medics provide a better understanding of the state of schools:

> *Many of our students (or students' students) are actually living one foot outside the tangled network of civil society, social welfare, and strong state that serve as the foundations of reliable science and, the other foot in schools, zones in which stability, law, and civil society tenuously persist. (pp. 19–20)*

But these youths clearly embody science education, if schooling is the smaller part of a more encompassing education. Clearly, diverse educators should rally during states of exception in the ways Weinstein describes to overcome the guards at the gates, those who believe they are "protecting" teachers from reaching out of their constrained forms.

Guidance for the Development of Future Citizen Science Projects

Youths are vulnerable to the types of risks facing the Maya or the teachers who are constrained by tests. They are not often organized by institutional governance, nor do they have the right to vote, in the United States at least. They form the basis of many citizen science projects that might otherwise be used to deemphasize or subjugate their (educational) participation and gained outcomes—too often those in authority "speaking" for youths and so forth. There is a need to prepare teachers and students for the new roles that they must play to ensure the technical democracies of future teachers and students: culturally, virtually, and environmentally.

How might we think differently about the development of future citizen science projects? An example from the Philippines (Tippins & Handa, 2010) serves to illustrate the kind of citizen science that could become possible in the context of preparing future teachers. At West Visayas State University on the island of Panay, all prospective teachers enroll in the course Community Immersion. Dubbed a "dialogue of life," this course provides opportunities for prospective teachers to experience citizen science on relational grounds by living in rural fishing or farming villages where they might someday teach. They are organized in interdisciplinary cohorts of 8–10 students (i.e., biology, physics, chemistry, mathematics, English, social science majors) and placed in rural villages where they work with community members to find suitable housing for their community stay—typically the local school or church facilities. During their stay in the community, the prospective teachers participate in action research, service-learning, community assessment surveys, focus group discussions, cultural memory banking,[3] and other activities that serve as the context for an authentic and emergent experience with citizen science. Community immersion as envisioned in the Philippines seeks to blur the historical tensions and distance between schools and communities and the fragmentation of education from the complexities of everyday life, creating new roles for educators such as that of teacher–culturalist.

Using cultural memory banking (Handa & Tippins, in press; Nazarea, 2001; Nichols, Tippins, Morano, Bilboa, & Barcenal, 2006), the prospective teachers work together with community members to locate and understand cultural practices at the intersection of community life and science learning, with the inherent assumption that communities have much to offer these future teachers. In the process of locating and understanding the shared cultural practices of the community, the prospective teachers take on roles as proactive members of the community and movers of change, working with citizens to solve local problems. They conduct water-quality assessments of local wells and invite university scientists to join them in sharing simple, cost-effective water-purification technologies with the local school children. In the process of learning how some community members are weaving bracelets from a local plant and selling them to Taiwan, they came to understand the challenges citizens face in obtaining a fair price for their products—social science majors worked with the local weavers to develop an equitable marketing and pricing strategy. While collecting information on the hectares of community land planted with rice, sugarcane, and other crops, the prospective teachers came to understand the plight of marginalized members of the community living on the fringes of the town proper. These individuals had to walk on elevated rows of soil between the rice paddies, slippery during times of rain, to bring their crops to a road for transportation to the local market. The prospective teachers joined with these community members in collecting additional data to make a case to community officials regarding their need for equal access to transportation. The prospective teachers worked with community members to identify local herbs for soap making and, using soap- and ointment-making protocols, conducted trial tests with other ingredients, such as juices from guava leaves and ripe papaya. This led to the development of a seminar on soap making. Joining with community members to collect data to access the impact of erosion in a flood-prone area, physics majors designed a bamboo bridge to minimize the effects of the erosion. In these examples, and many more like them, the prospective teachers, as citizen scientists, located themselves in the history of the community and became empowered to act alongside community members as active agents of democracy. In the process they learn that the teaching and learning of science must move beyond the transmission of an isolated set of facts to acknowledge the diversity of experiences, voices, traditions, and histories of people. By having authentic citizen science experiences through community immersion, these future teachers ultimately begin to develop a system of ethics on which to ground their vision of citizenship and future teaching practice.

To what extent is the Philippine experience with community immersion relevant to our envisioning of the future of citizen science? The Philippine experience with citizen science points to a type of community-oriented schooling that may require new identities in the education of both students and teachers. As a starting point, intact school communities can be created with the capacity to extend the meaning of teaching and learning beyond the confines of the classroom. With the transience of young people in America, this sort of starting point for communities could be extended across places, blurring the boundaries created artificially by state lines and cities proper. Through participatory citizen-science education networks, teachers and their students could share the results of their investigations in relation to other school networks. See the distribution (Figure 1) of fire ants constructed using a database to which students and their teachers can upload photos of flora and fauna, use global positioning with other variables to filter results, and overlay multiple maps for interpreting data. Imagine the overlay of sociocultural systems, historical archives, analyses, and so forth for better interpreting the consequences of taking a particular action or set of actions in relation. Envision the ways that species' movements might be monitored in relation to climate changes, weather patterns, sociocultural demographics, historical records, and forecasts. These integrated epistemological analyses are within the purview of teachers and their students, and yet policymakers, parents, and other community members need to make them available now. As we noted, community immersion and the preparation of teacher culturalists and, perhaps, teacher naturalists (with the downplaying of naturalist skills development in science) cannot be understated as a way to shift toward embracing the responsibility of today's people to the future.

Figure 1. Using Global Mapper to show the species distribution of the tropical fire ant, which is swiftly moving into North American regions and continues to move in response to changes in climate and habitats. (http://www.discoverlife.org)

Conclusion

As community members and prospective teachers prepare to set out together to understand the complexity of issues such as the loss of mangroves, the decimation of coral reefs from dynamite blasting (associated with fishing practices), or the increase in dengue fever, a democratic dialogue must be heightened. There are many different directions in which one can open the dialogue more fully in citizen science and in science education as a field. There are hybridized directions that should not be separated from science education, such as connections with the humanities. Students might investigate the context of their lives through poetry, essays, or through the expressions of their cultural traditions. A rich type of public conversation, which provides the idealization and conceptualization of more citizen-centered citizen science, comprises the proving grounds of the theory we explore.

Citizen science may be best developed with preplanning or surveying of the systemic cultural, community, environmental, and virtual aspects of citizen science projects. Our vision of schooling, and by extension science education, is more aligned with participatory democracy, where citizens actively collaborate in relation to accounting for future generations. We demonstrate that science, particularly the way it is popularized in schools today, cannot lead us to the insights and environmental understandings that scientists and researchers are developing when they analyze cultural systems in relation. We demonstrate the promise of new technology vis-à-vis science and why the investigations of cultural systems associated with nanoscience lag behind the science itself. This is a dangerous predicament when youths are growing up in a world that accepts schooling for its uncritical bias toward science. Withstanding the transformative reform called for by followers of Dewey (1916) and others, the viability of teachers and their students in relation to their communities is hampered by a back-to-the-basics approach that has constrained educators to a depressed social imagination. Very few teachers envision the kinds of projects that might involve their students in the democratization of street-level knowledge that we have described in this paper. Teachers are not rewarded for going the extra distance required to make citizen science a reality in the everyday lives of students, with the exception of intrinsic factors. A pat on the back does not suffice for the teachers who invest in their communities with youths who want to make a difference—who do end up making a difference. This difference is manifest when students are involved in policy-making or become adults who adjust the mandates constraining educators. Lest we forget that progress in a democracy can always be measured in terms of its ethical, environmental, economic, legal, and social implications for the prospects of future peoples, we need to find ways to include youths not only in pedagogy that heightens epistemic development but also in schooling where they have opportunities to engage real issues through their activism. Thus we promote youth activism through citizen science as a pedagogy in which teachers and their students gather information to make the most informed decisions about potential consequences and collaborate with others to increase the degrees of confidence surrounding these choices. We want to heighten the freedoms of democratized people so that they recognize the limits of choice, so that the livelihoods of future generations are not compromised for the prospects of the present. We want to ensure the accessibility of participatory democracy underpinning citizen science as pedagogy, in which teachers and their students represent those who are also affected by our choices (whether they be people, flora, fauna, physical environments, or cultural or historical traditions). We need to take advantage of the niche where educators and their students have been given leeway to take advantage of vested authority, such as what we explored with the GloFish case.

To conclude, we should not be misunderstood as promoting a panacea of diversity so that in the end we become lost in translation, but rather as accepting the responsibility that comes with making space for diverse voices and the acknowledgement that youths have an appropriate and significant role to play in shaping the prospects of the future and present community. After all, there is a spectrum of consequences from those who are living today to those tomorrow that must be recognized, before these consequences become too large to deal with. We anticipate the difficulties of raising children in a citizen-science society as teacher culturalists and naturalists, or through community immersion, and how that might be wrestled against current priorities. But it is unlikely that a cost-benefit analysis, if situated in the science of schools (e.g., testing), will reveal the fruition that is envisioned through community immersion and citizen science. We hope this model of citizen science will better position educators to discuss their project needs and help access the niches where they can play an especially large part, with our youths, in choices.

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Notes

1. The term *citizen* is not without problems, but it is used here because of its external coherence in science. *Citizen science* is incisively conceptualized as community-centered science, community science, participatory community-action research, street science, traditional ecological knowledge, social justice, scientific literacy, and humanistic science education.

2. The point is that the current developments in science and other ways of knowing represent the social imagination of affected parties or those who advocate for those without a voice in the community decision-making process. The social imagination is the confluence of individuals who ask questions (Feynman, 1998) and seek resolutions to their inquiries by imagining possible or desired worlds for the future. We extend this idea to denote the ecodemocracy by which citizen scientists ought to live, where the prospects of future generations are considered just as important as the prospects of today and where a triad of iterative spheres influence citizen science theory.

3. Memory banking stems from the work of Virginia Nazarea (2001), an ecologist and cultural anthropologist who developed the idea as a botanical preservation tool to complement traditional practices of gene banking with respect to the collection and documentation of knowledge, social practices, and technologies associated with the cultivation, harvesting, and uses of heirloom seeds. As adapted by Nichols, Tippins, Morano, Bilboa, & Barcenal (2006), cultural memory banking is a transactional and meaning-making tool used to understand, without mining, the cultural practices of a community.