Designing citizen science projects

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Introduction

Citizen science and public participation in scientific research have emerged as powerful techniques to engage the public in the content and practices of science. However, citizen science approaches are wide ranging in terms of their models of public engagement, their commitment to learning goals, and particularly in the role of non-scientist participants in the overall processes of science. This presents a broad space for learning designers who wish to use citizen science to increase STEM interest, STEM literacy, STEM content learning, and contributions to professional science by amateurs (whether adult or youth).

The term 'citizen science' was proposed by Irwin in the context of locally focused, citizen-driven environmental research. "'Citizen Science' evokes a science which assists the needs and concerns of citizens—as the apologists of science so often claim. At the same time, 'Citizen Science' implies a form of science developed and enacted by citizens themselves—and one important strand of this book will deal with the 'contextual knowledges' which are generated outside of formal scientific institutions." (Irwin, 1995, p. xi) Later, Bonney et al. proposed a definition based on the role of citizens in data collection: ""Studying large-scale patterns in nature requires a vast amount of data to be collected across an array of locations and habitats over spans of years or even decades. One way to obtain such data is through citizen science, a research technique that enlists the public in gathering scientific information." (Bonney, Cooper, et al., 2009, p. 977) Later works have proposed definitions that draw distinctions between online and offline citizen science, or have attempted to use the more generic "public participation in scientific research". In all of these cases, the key concept is that science is not conducted solely by professional scientists, but that non-professionals (whether amateur scientists, students of science, or simply interested public stakeholders) play a role (and in some cases, the primary role) in the conduct of science. Especially in the Internet era, large, distributed networks of people can participate in theorizing, questioning, data collection, data analysis, and arguing conclusions to a striking degree. While public participation in science pre-dates electronic communication networks (e.g., postcard-based bird censuses), the Internet provides a platform for communication, data sharing, and joint scientific work that greatly increases the possibilities of using citizen science approaches to enhance the impact of professional science and to engage different publics in scientific inquiry.

The purpose of this paper is to explore aspects of the use of citizen science, and to present a framework for people considering the design of citizen science interventions, with special consideration to design of citizen science interventions for science learning or for engagement and interest in STEM. In the sections that follow, different goals for creating a citizen science intervention are considered; instructional and sociotechnical systems design process and their applicability to citizen science are discussed; different conceptual models for citizen science and how it can support different goals are listed and explained; and finally, some potential pitfalls of employing citizen science approaches are highlighted.

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Why support citizen science?

The definitions mentioned above help illustrate that there may be many goals involved in a citizen science endeavor. While Irwin's definition emphasizes science for and by the public, Bonney's defintion has the public 'enlisted', and the article emphasizes the scientific value of using (free) public labor to achieve scientific aims difficult to reach with only professional scientific staff. Accordingly, we break down the issue of "Why support citizen science?" into two sets of goals: goals of leaders/initiators (who typically include professional educators or scientists), and goals of participants.

Goals of project initiators

In this section, we examine typical goals of citizen science project initiators or organizers who are professional educators or scientists. These goals fall into two rough categories: scientific goals, and educational or outreach goals. Within the category of scientific goals, project initiators may have a wide range of preferred outcomes, from the very narrow (assistance in collecting or analyzing a type of data for a well scoped study led by professionals) to the very large (increasing the speed and robustness with which a scientific field progresses, making new discoveries, or making science more responsive to the needs of society). The scientific goals might be more applied (for instance, ensuring local communities have scientific data on local environmental systems to feed into planning or conservation processes), or more driven by pure scientific questions (such as a sky survey looking for evidence of particular astrophysical phenomena). These goals are as diverse as the goals of science generally, and initiators who work primarily as scientists are usually well-equipped to think of these types of goals.

On the other hand, professionals initiating citizen science projects may hold a variety of educational or outreach goals, and scientists may be less familiar with how these goals map on to the research literature on how people collaborate and learn. We examine the theoretical stances that may be useful in a later section, but for now we can list some of the major education and outreach goals that might be connected to a citizen science project. See Table 1.

Table 1: Education and Outreach Goals

Attitudinal.

- Improving attitudes about science, the particular domain of science (e.g., physics or geosciences), or the application area of science (e.g., space exploration or environmental conservation)
- Improving attitudes towards or enthusiasm for participation in science or STEM (e.g., increasing interest in STEM careers, increasing respect for what scientists do); developing an identity as a scientist or competent in science
- Changing dispositions or 'habits of mind' (Jordan, Singer, Vaughan, & Berkowitz, 2009) to use scientific ways of thinking (e.g., increasing people's likelihood to conduct systematic inquiry, modelling, data collection and analysis, etc. more generally) (Herodotou, Sharples, & Scanlon, 2017)

Cognitive.

- Improving participant knowledge about the scientific domain or skills associated with the science domain (e.g., identifying a plant, analyzing a dataset)
- Improving participant knowledge of the epistemology or methods of a particular science domain (e.g., how concepts are tested and proven in chemistry or climate science)
- Increasing basic familiarity with the findings or methods of science for general science literacy (e.g., being better able to participate in public discussion on or formulate informed policy stances about water quality or earthquake safety)

Social.

- Development or shifts of knowledge building communities (Christopher Hoadley & Kilner, 2005; Scardamalia & Bereiter, 1994), communities of practice (C. Hoadley, 2012; Lave & Wenger, 1991), communities of interest (Gee, 2003; Rheingold, 1994), or other new communities (e.g., establishing national network of gardener/naturalists from existing networks of gardeners)
- Helping people with an interest in a STEM topic locate and befriend others who might help them pursue that interest (Ching, 2016) (either with specific knowledge or hard resources, like a measurement device)
- Increasing equity and democracy in science, either by inclusion of previously missing groups, or by changing social norms, practices, and implicit biases to be more egalitarian, meritocratic, or democratic.

These goals can take on many forms in different projects, and most projects will necessarily address some of the education and outreach goals as primary and others as either instrumental or secondary goals. Two things are critical to recognize though. First, no project achieves all of these goals equally, and thus the initiators of citizen science activities need to know where their priorities lie. Second, these goals are not pursued in a vacuum. Due to the collaborative nature of citizen science (at minimum between the citizen scientist and the project), the goals of participants must also be taken into account.

Goals of non-scientist participants

There are many reasons non-scientists participate in citizen science projects. In some cases, there is an institutional or organizational mandate that requires it. Probably the biggest category of such goals would be the involvement of schoolchildren in citizen science as required by their teachers (e.g., the GLOBE program which links geoscience and environmental scientific data collection protocols to science education in over 100 countries worldwide, http://globe.gov). Some citizen science is paid, either by outsourcing scientific tasks as piecework through platforms like Amazon's Mechanical Turk, or more directly by hiring non-scientists to work on scientific data collection. By far the majority of participation in citizen science, however, is voluntary.

Voluntary participation in citizen science follows two kids of goals: altruistic (for instance, helping the field), or egotistic (such as learning a valuable skill). Curtis in her dissertation (Curtis, 2014) studied participants in three online citizen science projects, and found motivations varied from starting to work on a project to sustaining their work on that project. Motivations in the beginning included reasons such as contributing to research outcomes or worthy causes, intellectual challenge and interest in science, or the chance to make a discovery. Sustained participation was linked to reasons such as competition, community, interaction with others, or developing new skills, in addition to the altruistic sense of making a contribution.

Any initiator of a citizen science project should expect that participants will bring their own goals to any voluntary citizen science opportunity, and that not all participants will share the goals of the initiator. Furthermore, these goals are likely to change over time, and some participants will deepen their relationship to the project while others may remain static or drift away. The 'reader-to-leader' framework (Preece & Shneiderman, 2009) describes a dynamic equilibrium in online communities in which some, but not all, participants progress from reader, to contributor, to collaborator, to leader. Any vibrant community will have some leaders, but most communities will have a predominant membership of people who are less engaged. This process has been alternately described in the communities of practice literature as a process of enculturation through 'legitimate peripheral participation' (Lave & Wenger, 1991; Wenger, 1998) in which learning represents individuals gradually moving from more peripheral roles to ones in which they are central to the practices of expertise. One expectation is that communities emergently develop norms, values, and practices, and thus the goals the initiators of the citizen science project have will shape, but not determine, what expert practice and identity looks like in the project.

A final model of participant goals is when a participant merely consents, but then doesn't actually have to do anything active to be part of the citizen science project. For example, a user might agree to contribute logfile data on an app they already use for research purposes, or might allow their computer's processing power to be used when the computer would otherwise be idling. Here the goals might be as shallow as being inattentive enough to miss unchecking a check box on a terms-and-conditions clickthrough (so the goal is simply to get past a dialog box). Yet even in a project in which passively providing computational power seems to prohibit deep engagement, citizen scientists may have strong goals that allow them to participate much more fully. For instance, in the Folding@home project in which participants download and install a program to provide computation to chemistry research, some participants have gone so far as to design and build custom computational hardware configurations in order to excel at contributing (Curtis, 2014). Thus, the 'no goals' version of participation is likely to be rarer than some might think.

Roles of participants in citizen science

Within the context of the variety of goals participants and initiators have for citizen science projects, it is helpful to examine typical roles for participants in citizen science. Defining and designing roles for participants is a key aspect of designing collaborative learning systems (Christopher Hoadley, 2010). There are many ways to describe roles; in a 2009 report, citizen science roles were divided into contributory, collaborative, or co-created projects, based on the level of input and leadership exercised by the public as opposed to the scientists. (Bonney, Ballard, et al., 2009) Hetland, Mørch, and Ponti (2014) provide a slightly different classification, in which users are targetted for dissemination of science, for dialogue with science, or participation in science. In this section, I use a more granular list of types of roles to examine several paradigms of citizen science.

Participant as data gatherer

Bonney et al. (2009) identify one of the most common paradigms of participation; that of the participant as data gatherer. Their examples, drawn from the field of ornithology, build on pre-digital projects such as the Annual Christmas Bird Count from the early 20th century, to current work in which amateur birders are enlisted to help collect data. Some of their projects involve minimal expertise in participants, while others demand development of specific skills to acquire usable scientific data. (Dickinson, Zuckerberg, & Bonter, 2010).

Participant as data analyst

Another participation structure enlists members of the public to help in specific aspects of data analysis. For example, the galaxy zoo project was able to categorize the morphology of nearly a million galaxies in the Sloan sky survey dataset with online volunteers (Lintott, et al., 2011). While visual classification is not particularly difficult, the sheer number of galaxies to classify led the scientists to consider involving volunteers.

Participant as question poser

Some projects, following more from Irwin's conception of citizen science, engage participants primarily in question *asking* rather than collecting data to answer questions raised by others. For example, the WeatherBlur project (Kermish-Allen, 2016) allows fishermen, children, teachers, and other members of the public to explore local climate change through question asking and answering. The project explicitly uses a "non-hierarchical online learning community" framework to emphasize that control over the directions of the inquiry are driven by interested participants, without a hierarchy of professional expertise to limit who may ask questions.

Participant as stakeholder/partner

Many citizen science projects involve participation of the public either as drivers of, or apprentices to, scientific goals. But some citizen science projects involve partnerships between the science community and non-scientists whose goals either instrumentally involve science or overlap with those of scientists. For example, the Nature's Notebook project, run by the USA National Phenology Network, engages groups who have instrumental needs for phenology data or findings. They partner with amateur scientists, but also with professional natural resource managers who might need phenology data for their environmental management, or hiking clubs like the Appalachian Mountain Club whose members might need phenology data to help schedule long-distance treks (Schwartz, Betancourt, & Weltzin, 2012). Another example, the Science in the City project run by the organization Mapping for Change, aims to increase community awareness and advocacy for air quality; citizen science is driven by community organizing needs, and scientists serve to consult and support for the project. (Kloetzer, Jennett, Francis, & Haklay, 2017) Such projects fall into categories of "action" or "conservation" projects as defined by Wiggins and Crowston (Wiggins & Crowston, 2011) although other possible alliances can be imagined.

Participant as competitor or gamer

In some scientific areas, gamification (Deterding, Sicart, Nacke, O'Hara, & Dixon, 2011) can allow people to participate in scientific work as recreation or competition. One of the most famous examples is the foldit game in which players compete to find the lowest energy configuration of a folded protein (Khatib, et al., 2011). Foldit as a project has grown to encompass a wide variety of engagement models, and not just competitive gaming. In another project, Phylo, participants align gene sequences in a casual game–unlike foldit, the game is designed to excise the task from its scientific context (i.e., participants game only for the sake of gaming and are not exposed to the underlying scientific questions and answers) (Kawrykow, et al., 2012).

Participant as amateur or apprentice scientist

Another mode of citizen science is to support participants to act as amateur scientists, with a goal of helping people develop scientific skills and practices through participation in the overall activities of science, but not necessarily to develop scientific contributions of great value to the larger scientific community. For example, Kids Survey Network at TERC created a set of activities for youth in after school programs to ask and answer questions in social science by creating and taking surveys for each other. The project provided opportunities to learn some of the activities of scientific inquiry, but with considerable support, and without any assumption that the results would be publishable. Another mode of engagement is similar to treating people as amateur scientists, but with a different target: aiding or apprenticing to professional scientists. For example, teachers in the GLOBE (Global Learning and Observations to Benefit the Environment) "Learning to research" project worked with students to frame and study research questions related to climate change, while linking not only with other students but with expert scientists through the GLOBE network, extending GLOBE's prior focus on students doing primarily data collection (Malmberg & Maull, 2013). Interestingly, this project not only used scientists as scientific consultants, but also developed video webinars with expert scientists to help inform learners about STEM careers, including not only careers as scientists, but in other fields that utilized earth science (for instance, in emergency response planning).

Participants as cultural guides

Some projects engage participants not only as researchers or drivers of inquiry, but also reflexively as participants in a culture that is relevant to the science. One example is described by Charitonos (2017) in which heritage learners in a language school conducted projects to study language and cultural heritage. The research model was one of action research, in which the learners were simultaneously studying and participating in the cultures and practices being examined. While some might argue that this is just a different example of the 'participant as amateur scientist' paradigm, one important difference is that the participants have a critical role in not only conducting the research, but also interpeting it, and in bringing meaning-making (both personal and collective) to the work. As crisply pointed out by Medin, Lee, and Bang (2014, p. 34-34), "If participation in cultural practices is central to our development as humans, then these practices will influence how we learn and practice science." They argue for the importance of engaging diverse participants in science not only out of some sense of fairness or equity, but also because the diversity of cultural perspectives engaged in science improves the science itself. When conducting citizen science in a way that explicitly involves nontraditional groups as experts in their own culturally inflected perspectives, it allows a diversity of epistemologies, interpretations, and questions to be surfaced, thereby improving the quality of the research. Work by Bang and Medin illustrates how European-American and Native American learners interpret the relationship between self and nature differently, and how incorporating these differences can enhance ecological science work by students (Bang & Medin, 2010). Especially when dealing with scientific topics that have historically been used to colonize peoples, incorporating non-professional scientists in the work not only as consultants but also as participants in a more open form of research may help the scientific endeavor. Decolonizing science is a larger project than citizen science alone can tackle, but citizen science may be one important tool to help ensure science isn't biased towards one cultural group or gender and to increase the robustness of the findings.

Participants as passive resource providers

As mentioned in the goals section, some projects deemed citizen science actually only involve non-scientists in passively providing some resource. An example would be the SETI@home project in which users installed a screensaver that allowed spare computing power on their personal computers to be used as a form of distributed computing for processing data from the search for extraterrestrial intelligence (Anderson, Cobb, Korpela, Lebofsky, & Werthimer, 2002). More modern examples include passive collection of data by personal devices like phones or smartwatches for medical research (e.g., the mPower Parkinson disease study, Bot, et al., 2016).

These roles help illustrate a variety of conceptual models for how citizens can engage in science. The list is intended to be generative, rather than exhaustive. Many projects involve participants in multiple roles, so Such examples can help inspire those who intend to design citizen science initiatives to consider multiple possible types of interaction.

Designing citizen science projects

Designing citizen science projects is a messy business. Different conceptions of citizen science suggest utilizing techniques from different fields. In the area of interorganizational cooperation, the idea of 'collective impact' may be useful, which involves reaching consensus on shared goals, and then measuring progress towards those goals fastidiously. Within the field of sociotechnical systems research, the notion of 'ensembles' (constellations of people, practices, organizations, artifacts, and information flows) may be a useful metaphor. In the area of design and especially technology design, the human-centered design process might be useful. Within education, the various models used in the field of instructional design may help (typically going from needs analysis, to development, deployment, and evaluation of outcomes), as may the design processes associated with designing for collaborative learning.

Within citizen science itself, several models have been proposed. The US government's citizen-science.gov site proposes a five step process that presumes a scientific or operational goal by scientists or government agencies: Scope the problem, design a project, build a community, manage the data, and sustain and improve. Aristeidou et al. (2017) propose a set of 'requirements' for online citizen science projects that involve scientific inquiry. These requirements are based on features or processes documented to be helpful in maintaining other citizen science projects. These include features such as notifications, news feeds, top poster/leaderboards, real-time awareness of who is online, linkages to social networking sites, etc. Shirk et al. (Shirk, et al., 2012) describe a more elaborate model, represented below in Table 2.

Table 2: Shirk et al. 2012 Framework for Deliberate Design

- Consider degree and quality of participation
- Select one of five models of citizen participation: contractual, contributory, collaborative, co-created, or collegial
- Identify inputs, activities, outputs, outcomes, and impacts
- Link inputs through impacts to ensure a 'deliberate' design

In addition to these design models, there are a plethora of models for designing activities for learning science through inquiry, that are frequently relevant to the initiator of a citizen science project. Project- and problem-based learning approaches, inquiry cycles for science, and curricular frameworks such as the Next Generation Science Standards all contain ideas that can inspire the engagement models in a citizen science project. Two resources that help introduce these approaches are consensus reports from the National Academy of Sciences Board on Science Education (Center for Science Mathematics and Engineering Education. Committee on Development of an Addendum to the National Science Education Standards on Scientific Inquiry., 2000; National Research Council (U.S.). Committee on a Conceptual Framework for New K-12 Science Education Standards., 2012). Additionally, Quintana et al. (Quintana, et al., 2004) and Kim et al. (Kim, Hannafin, & Bryan, 2007) have proposed design frameworks specifically for software-supported inquiry learning. Kim et al. focus on designing for three layers of context: the classroom, the teacher community, and the educational systems in which the intervention is based. Quintana et al. list a series of strategies for scaffolding three aspects of scientific inquiry: sensemaking, process management, and articulation or reflection. Each strategy is illustrated by examples from technology-mediated science learning research.

Finally, many of the design models for sociotechnical systems design suggest aspects that need to be considered. Carayon (Carayon, 2006) advocates for a continuous improvement design model, with six activities. (See Table 3.) Alternate frameworks (Baxter & Sommerville, 2011; Clegg, 2000) also emphasize the interdisciplinary, collaborative, and ongoing nature of sociotechnical systems design, and the need to engage many stakeholders to address the complexities and indeterminacies introduced by large systems that have many complex interactions between people and tools.

Table 3. Carayon's 2006 Principles for Sociotechnical Systems Design and Adaptation (adapted from Carayon, 2006, p. 33-34)

- PARTICIPATE: active participation of participants in system design activities (e.g., participatory ergonomics),
- INTERACT: continuous interactions between participants and the project leadership organization,
- DESIGN: continuous system design and redesign,
- ADAPT: adaptive engagement model and long-run system adaptability,
- LEARN: activities and support for both individual and organizational learning (e.g., collaborative problem definition, analysis and modeling),
- MAKE SENSE: sense-making of on-going changes and their impact.

Pulling these models together, I propose the following steps for designing a citizen science project.

First, clarify the perceived opportunity for citizen science as a strategy. What problem will a citizen science project solve? Can you write a mission statement for the project? Once the opportunity is laid out, examine the goals people in the system will have, with particular attention to the *organizers'* goals and the *participants'* goals. The project intiators' goals are likely to include both 'selfish' goals about advancing science, fulfilling funders' requirements for outreach, etc., but should also include goals of the organizers for the participants (attitudinal, cognitive, social). Then, when considering participant goals, clarify the audience for the project and their likely motivations to participate (or not).

Secondly, identify ways to include necessary perspectives on the project. At some point, end users may also be involved in goal setting. Does the project organizing team have the right expertise? Key needs are likely to include expertise in the science domain, expertise in building and supporting the tools needed (typically online tools, but might also include research equipment), and expertise in the goals for the user. If the project initiator identifies increasing positive attitudes towards STEM careers among an underserved population as a key goal, the team will need someone who is an expert in the research on attitudes toward STEM careers in that underserved population.

Third, once necessary perspectives are identified, the project team should start considering the level of engagement of different groups. On the project team side, this may include questions of budgeting and staffing. On the citizen participant side, consider whether the participants will have input into the project goals, and if so, how much and when; will the participants be doing 'contractual' or 'collegial' engagement, or something in-between? Perhaps there are different tiers of participants, from the very casual participant to the leader (in Preece & Shneiderman's model), or from the very novice to the very expert. Or perhaps the participants come from different backgrounds with different engagement models (e.g., schoolchildren vs. adults).

Fourth, the project designers should consider what conceptual metaphor they prefer for the ways in which the participants will interact with each other and with the project. The list of roles I suggest above may be helpful, or the designer may wish to consider one of the many examples from science education or online communities. These core concepts will help determine a set of activities or tasks the various groups will do, and will further refine ideas about what tools and logistics are necessary to support those groups. At this point it is worth considering timelines. Knowing that communities take time to build, what might a bootstrapping process look like to get enough participation to get the system up and running? What types of onboarding needs will there be for each kind of participant? What will keep people engaged over time, or will each participant engage for a fixed set of activities and then 'graduate' out of the project? Are there trajectories for people to advance within the project?

Finally, the ongoing work of documenting, communicating, and refining this design must begin. A project might begin by recruiting prospective participants to advise on the project design, or might begin writing up the concept for a funding proposal. The first website and/or onboarding materials will need to be developed, and channels of communication among the various groups must be set up. Evaluation plans should be established, and mechanisms for adjusting the project in response to the evaluations or other new information should be identified. Ideally, a clear connection can be articulated between the opportunity provided by the project, the needs and goals of the various stakeholders, and the roles, practices and tools that form the sociotechnical system. Systems should be put in place to ensure that power structures, biases, and differences in perspective do not unjustly disadvantage either the scientific or human aims of the project. The literature on community-based participatory research may help in this regard. As the project stakeholders begin communicating more and more, tools are built or assembled, systems or practices are begun, and eventually the project 'launches' in a form that supports the desired level of participation.

In summary, this white paper has attempted to describe some of the design-relevant features of citizen science projects, with attention to the goals of and for participants as well as organizers; with a list of potential roles or paradigms of engagement for the participants in the project; and with a summary of related design methods or frameworks from education, sociotechnical systems, and from citizen science. I concluded with a suggested approach to design of citizen science projects. This document is by necessity incomplete, but should give some starting points to people considering using citizen science approaches to meet their needs.

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