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Implementing an Environmental Citizen Science Project: Strategies and Concerns from Educators' Perspectives

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ABSTRACT

Citizen science seems to have a natural alignment with environmental and science education, but incorporating citizen science projects into education practices is still a challenge for educators from different education contexts. Based on participant observation and interview data, this paper describes the strategies educators identified for implementing an environmental citizen science project in different education contexts (i.e., classroom teaching, aquarium exhibits, and summer camp) and discusses the practical concerns influencing independent implementation by educators. The results revealed different implementation strategies that are shaped by four categories of constraints: 1) organizational and institutional policies, 2) educators' time and material resources, 3) learners' needs and abilities, and 4) aspects of citizen science project design that constitute a higher barrier to entry for educators managing student contributions. We developed a simple two-dimensional model to demonstrate the types of adaptations that educators made to citizen science projects and discussed the potential role of persuasive technologies to address some of the gaps and better facilitate educator and learner participation.

KEYWORDS
Citizen science; science educators; formal and non-formal education; practical concerns, implementation strategies

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Introduction

A variety of environmental education (EE) strategies have been developed and studied for improving people's awareness, attitudes, knowledge, and behaviors towards understanding and protecting the environment (Monroe, Andrews, & Biedenweg, 2008). Citizen science involves members of the public (i.e., non-professionals) as contributors to scientific research by facilitating opportunities to collect and process research data (Cohn, 2008; Silvertown, 2009). The majority of citizen science projects are environmental monitoring

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projects that document the status of natural phenomena, with common applications being establishing and observing changes in relative biodiversity, studying species abundance and distribution for specific populations or locations, and tracking environmental pollutants through air and water quality studies (Roy et al., 2012). In the past decade, EE and citizen science researchers have started to consider citizen science a type of EE strategy facilitating hands-on experience and learning through authentic inquiry practices (Monroe, Andrews, & Biedenweg, 2008).

The development of best practices for citizen science design and management has been concentrated on informal science education (ISE) contexts. ISE focuses on distributed and independent participation processes that can naturally support unstructured learning wherever and whenever volunteers choose (Eshach, 2007). For example, the eBird project allows birders to report observations of wild birds anywhere on earth at any hour (Sullivan et al., 2014) and the Zooniverse suite of projects engages people around the clock and around the world in processing image content into data structures for research in fields ranging from astronomy to ecology to the humanities (Tinati et al., 2015). While neither eBird nor Zooniverse were designed with education as a core goal, they provide a structure that can support learning through participation (Kelling et al., 2015; Masters et al. 2016).

A limited number of citizen science programs have been widely recognized for successful adoption in formal science education (FSE) and non-formal science education (NSE) contexts that support semi-structured or structured learning. FSE usually happens in classrooms at schools. NFE activities occur outside of schools, facilitated by such institutions as museums, zoos, and aquaria (Eshach, 2007). For example, the Global Learning and Observations to Benefit the Environment (GLOBE) program is best known for broad global adoption of its range of protocols specifically designed for classroom implementation (Malmberg & Maull, 2013; Penuel et al., 2006), the FrogWatch USA program is implemented by members of the Association of Zoos and Aquariums (Schwartz, Beaubien, Crimmins, & Weltzin, 2013), and the Long-term Monitoring Program and Experiential Training for Students (LiMPETS) program involves teachers and youth in scientific studies in both school and out-of-school contexts (Ballard, Dixon, & Harris, 2017). Unlike most citizen science projects where participants are self-selected adult volunteers and research outcomes are the primary goal, these programs recruit educators and students whose participation may be explicitly mediated by an authority, and they place more emphasis on learning outcomes.

Regardless of the type of education context, implementing citizen science reveals fundamental tensions between satisfying the needs of scientists and learners (Berkowitz, 1997; Zoellick, Nelson, & Schauffler, 2012). How these needs are weighted depends on which stakeholders are involved in decisions on implementing citizen science and what relationships are built between which stakeholders (Zoellick, Nelson, & Schauffler, 2012). In general, we observe that learners' needs are usually emphasized more than scientists' needs in FSE and NSE contexts than in ISE contexts, and vice versa. Combined with the structures and constraints of organizational environments, citizen science in FSE and NSE contexts may require more support to achieve the learning demands and expectations compared to ISE contexts. Although the terminology is used variably in the literature, throughout the rest of this paper, we use NSE to refer to education activities and programs occurring outside of traditional classrooms.

To examine the effectiveness of citizen science as an EE strategy, especially in FSE and NSE contexts, analytical case studies provide insights into the implementation ideas and issues for effectively meeting multiple stakeholders' needs. However, the number of such cases is limited and there has been little work examining how educators from different education contexts act as facilitators supporting learner participation in citizen science projects, and what factors influence their implementation choices.

In this study, we chose an environmental citizen science project (Biocubes) and investigated how it could be implemented across different education contexts from the educators' perspectives. We participated in and observed a Biocubes project training workshop developed for science educators on incorporating this project in their teaching and education programs. We then interviewed the workshop participants who were willing to implement Biocubes to address the following two research questions:

1. How do educators in different education contexts envision implementing the same citizen science project?
2. What are the practical concerns across different education contexts that would influence educators' strategies for implementing the citizen science project?

Answering these two research questions is intended to provide insight to support better design and adaptation of citizen science for EE in different education contexts. We begin with a brief review of related research and the methods for the study, and then report on the envisioned implementation strategies for the same citizen science project in different education contexts and the corresponding practical concerns, as well as a case study of an implementation. We then discuss a two dimensional model to provide guidance to educators for adapting citizen science to meet their requirements, and discuss persuasive technologies as a potential tool to encourage and reward data sharing that meets the needs of both scientists and the broader education community.

Background

We briefly review the literature on citizen science and similar models of collaborative research and learning that involve scientists, project coordinators, educators, and learners.

2.1. Citizen science

Supported by various information technologies, citizen science is gaining attention as a practical research approach across a range of sciences, such as astronomy, climatology, and biology. Scientists often adopt this approach to accomplish tasks that are otherwise infeasible, such as collecting large-scale and long-term monitoring data (Dickinson, Zuckerberg, & Bonter, 2010). The demographics of participants in many citizen science projects show that most are middle-aged whites with a comfortable income and bachelor or above education level, and they participate in citizen science voluntarily (e.g., Jordan et al., 2011; Brossard, Lewenstein, & Bonney, 2005).

However, the core values of modern citizen science focus on inclusivity: taking part in science is now potentially open to all, not just a privileged few (Silvertown, 2009). Understanding engagement with different populations and publics in citizen science is critical to designing projects that generate value for both participants and scientists (ECSA "Sharing Best Practice and Building Capacity" Working Group, 2015). Educators and students are important populations whose needs are distinct from those of other volunteers. Classrooms and various education institutions have the specific potential to engage a broader demographic in science and educators play a critical role in facilitating their own and students' engagement and involvement in science (Shah & Martinez, 2016).

2.2. Citizen science in schools

Although educators and students are not usually the primary participants in citizen science, previous research has examined initiatives similar to citizen science in FSE and NSE contexts. Since the 1980s, students, teachers, and scientists have developed classroom-based partnerships called Student-Teacher-Scientist Partnerships (STSP) in FSE contexts, such as primary school classes (Houseal, Abd-El-Khalick, & Destefano, 2014). Developed as a pedagogical tool, STSP programs involve school teachers and students in the fundamental work of generating scientific knowledge, typically through data collection and conducting their own analyses alongside professional uses of the data (Rahm et al., 2003; Sadler, Burgin, Mckinney, & Ponjuan, 2010). This differs from most citizen science projects mainly in the degree of direct collaboration between the scientists and classrooms and the focus of inquiry-based learning, which is considered fundamental in STSP programs. Such programs require substantial attention and effort on both scientist and teacher sides to develop and maintain working partnerships (Zoellick, Nelson, & Schauffler, 2012). The teachers who participate in STSP programs usually receive direct guidance and support from scientists and project coordinators (Wormstead, Becker, & Congalton, 2002), unlike citizen science more generally.

However, opportunity to participate in STSP programs is not widely available due to resource limitations for such intensive efforts (Gray, Nicosia, & Jordan, 2012). When STSPs are not available, we suggest that some citizen science projects can provide a viable option for more accessible hands-on science engagement, and some projects already provide supporting resources targeted to interested educators, such as curricular materials, lesson plans, and training workshops. For example, Silva et al. (2016) report how a cell biology citizen science project, the Cell Spotting project, is implemented in secondary school classrooms in Spain and Portugal. The aim of Cell Spotting is to search for new cancer treatments by asking volunteers to review large amount of images of cancer cells under the treatment of drugs (Lostal et al., 2013). Schools were invited to participate and designated teachers were sent to a training workshop. The project was well integrated with the biology curriculum and provides teachers with the necessary tools (e.g., a computer application developed by the project for data analysis) and other supporting resources for implementing the project in teaching (Silva et al., 2016). Teachers and students followed the project protocol to analyze the data via the Cell Spotting application and had opportunities to communicate directly with the scientist, the principal investigator of this project. The durations of project implementations in classrooms varied between a couple of hours, a few months, and a entire school year. In the evaluation of the implementation, teachers shared their concerns about implementation, which included lack of time, tight curricula, and need to prepare the students for exams at national level (Silva et al., 2016).

In the United States, several other citizen science projects have been implemented in classrooms with good results for both learners and scientists, such as the international GLOBE program (Bulter & MacGregor, 2003) and the Journey North project (Trautmann, Shirk, Fee, & Krasny, 2012). All of these projects have provided rich supporting materials to teachers in FSE contexts to implement the projects in their classrooms. However, in these examples, the degree of collaboration between teachers and research team members is not clear. Some citizen science projects initially collaborate closely with educators to develop a classroom-friendly project, but then move into a “production mode” where subsequent partnering educators are expected to operate largely independently using pilot tested protocols and supplementary materials.

2.3. Citizen science outside of schools

Citizen science is also used in various out-of-school education programs, such as summer and afterschool programs (Ballard, Dixon, & Harris, 2017). Like school teachers, educators in NSE organizations (e.g., such as science and nature centers, museums, zoos, and aquaria) have opportunities to adopt citizen science into their education programs, often in place of similar hands-on science activities like STSPs that require more intensive effort and resources. For example, the LiMPETS program, a coastal monitoring citizen science project, has been adopted by a natural history museum as part of its youth internship program (Ballard, Dixon, & Harris, 2017). LiMPETS program coordinators trained educators in an introductory workshop, provided various supporting materials, and also participated in and supported student training on field data collection methods and research question development. The program coordinators and educators supervised students’ data collection and the students spent more than 30 hours on the project, with 18 sessions over 6 months. One student was responsible for entering data online weekly, and a group of students analyzed the data and reported findings at scientific conferences. They also shared their results with the museum staff and program funders (Ballard, Dixon, & Harris, 2017).

Compared to other hands-on science activities, citizen science has substantial appeal based on authenticity of the science and potential for broader impact. Compared to STSPs, many citizen science projects are designed for “lightweight” participation that may be more feasible for a wider range of educators in both FSE and NSE contexts. However, citizen science projects that are successfully taken up and implemented in schools and out-of-school education programs still appear very similar to STSP programs. In order to meet educators, students, and scientists’ needs, these projects invest a similar degree of effort in developing supporting resources, and the educators do not work entirely independently on their own implementations. We also observed two further commonalities among the handful of citizen science projects that are well known in FSE and NSE programs, such as Celebrate Urban Birds (celebrateurbanbirds.org). In most cases, educators and students were considered primary stakeholder groups alongside scientists and independent volunteers from the earliest stages of project development, with human and material resources allocated by project managers to meet their needs. In addition, agreements to implement the project were usually at organizational level (e.g., between schools/museum and citizen science projects) rather than the decision of a single classroom teacher or museum educator, and our study results suggest that this organizational commitment to supporting project activities may have an important role in adoption, follow-through, and resource availability to make citizen science participation a feasible option in FSE and NSE contexts.

However, not all citizen science projects can afford the investments currently necessary to ensure educator-friendly project designs, tools, and materials, and organizational-level agreements. For some projects, the primary mission is firmly focused on science, and learning outcomes are considered a desirable bonus, but secondary to the science, and so receive limited attention and resources. The development of supporting resources for educators depends on the human and financial resources available to each citizen science program, which can vary substantially. Many projects do not have the resources to provide supporting materials for educators. In addition, direct interaction opportunities with scientists are not necessarily guaranteed in citizen science due to the ratio of many participants to just a few scientists, plus schedule constraints on both sides. That is to say, there are still limited opportunities for educators to partner directly with scientists and citizen science program staff. Given the limited supporting resources and assistance that most citizen science projects are able to provide, educators interested in incorporating citizen science projects into their teaching and education programs must also independently address practical challenges (Gray et al., 2012) and make effort to develop their own adaptations of the investigation to integrate citizen science into their teaching (Trautmann, Shirk, Fee, & Krasny, 2012; Paige, Hattam, & Daniels, 2015).

Previous research on citizen science in education contexts has not examined educators' strategies for independently implementing citizen science projects across different education contexts with limited support from the project, leaving a gap in our knowledge of how educators would design the implementation to adapt citizen science to effectively meet their needs while also generating data that can address scientists' needs. In this paper, we address this gap by focusing on one citizen science project and studying educators' strategies and practical concerns for implementing it independently in different education contexts.

Study Design

In order to explore strategies for implementing a citizen science project in a variety of environmental education contexts, we first introduced a citizen science project to a group of science educators from different education settings. We participated in and observed a project training workshop. After that, we interviewed with the workshop attendees asking how these educators envisioned incorporating the project into their regular teaching, and identified what factors could influence implementation practices.

3.1. The Biocubes project

Biocubes is an environmental citizen science project for documenting biodiversity that encourages people to examine one cubic foot of space and report all the living things they discover in it (http://qrius.si.edu/biocube). The project was developed by a diverse team including biologists, citizen science researchers, professional photographers, and NSE specialists starting in 2012, and introduced to science educators through a series of training workshops. These workshops focused on scientific processes and pedagogical design: demonstrating procedures, communicating opportunities for customizing the program to fit a variety of learning goals and investigate a range of scientific research questions, and practicing the process with assistance from the project team.

The standard Biocubes protocol includes seven pre-defined data collection steps to guide educators and others in independently implementing the project (Figure 1). Each step involves several tasks and requires different types of resources. The steps are:

a) Preparation: create an account on the data management system, request a biocube ID from a project administrator, define data collection goals, and formulate concrete data collection plans.

b) Build: gather supplies and permissions for data collection, and build the one cubic foot biocube with suggested materials (i.e., aluminum tubes, wire, high visibility quick-drying spray paint).

c) Deploy: select a biocube site, document the area, and place the cube.

d) Explore: observe the biocube, sample things that move through the cube, extract the contents of the cube, and bring them to a work area.

e) Identify: sort organisms from the cube, categorize, count, photograph, and identify them.

f) Clean up: return everything to the site to minimize impact on the landscape.

g) Share: complete the data sheets and upload data into the data management system, iNaturalist, "an online social network site of people sharing biodiversity information and help each other learn about nature" (Loarie, 2016).

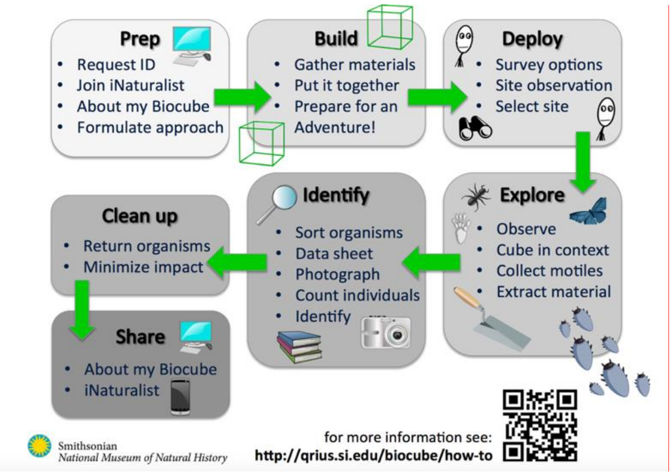

Figure 1. The Biocubes project protocol.

After data are shared on iNaturalist and organism identifications are reviewed, they are automatically incorporated into scientific research data repositories, enabling a variety of uses for scientific research. In an ideal scenario, when educators implemented this project, they would follow all steps exactly as described in the official instructions. In recognition of the need to fit this rather complex process into settings with variable time and resource constraints, however, the project was explicitly designed for flexibility and several alternative process suggestions were discussed with the educators as examples of adaptations. Since a range of options for customization can be made to the general process, our analysis examined how a group of science educators envisioned implementing this project with their students, the practical concerns they expected would influence implementation, and identified the ways in which the expected and actual processes varied for one case study that reached implementation.

3.2. Data collection

We adopted a two-step approach to collect data: we first participated in and observed educator workshop activities, and later conducted longitudinal interviews with workshop participants.

Participant observation

We participated in a two and a half day workshop organized by the Centers for Ocean Sciences Education Excellence (COSEE) Florida and the Biocubes project team in Florida during January of 2015. The workshop aimed to help educators practice the procedures for collecting data while exploring strategies for incorporating this project into their curricula in different education contexts. Throughout the workshop, the researchers made ethnographic field notes, memos, and photos to record the details of the workshop.

A total of 26 people participated in the workshop. The educators were the primary participants—including ten middle and high school teachers from a Title 1 school district in Florida who received continuing education credits for participation—and four non-formal science educators working at aquaria and nature centers. Educator recruitment for the workshop was managed by a partnering organization focused on marine biology. All participating educators received a Biocube kit containing several books, a clip-on smartphone macro lens, the tubes and wires needed to construct a cube, and a USB drive. The USB drive contained copies of worksheets for two activities ("observation in place" and inventorying cube contents) and an accompanying lesson plan, as well as seven files with supplemental activities and a data entry instruction guide; the digital materials were all provided in hard copy as well. Five biologists, two social scientists, three education specialists, and two professional photographers served as project coordinators and workshop facilitators. The workshop included three stages: (1) introductory tutorials; (2) practicing the procedures in the field; and (3) group discussion of plans for implementing the Biocubes project. The analysis here focuses on the observation data from the third session. The 14 primary participants worked in three groups: high school teachers, middle school teachers, and non-formal science educators.

Interviews with workshop participants

After the workshop, we conducted in-depth interviews with five workshop participants who were willing to participate when contacted; they represent the most enthusiastic workshop participants, and therefore those we expected to be most likely to implement the project. Two were non-formal science educators, two were middle school teachers, and one was a school district science coordinator. The interviews were held 3 months after the workshop and included open-ended questions about working environments (e.g., teaching resources, students conditions, previous teaching experiences) and how the educators envisioned implementing the Biocubes project. We conducted follow-up interviews six months after the workshop with two interviewees who implemented Biocubes-related activities over the summer of 2015. Each interview lasted from 50 to 120 minutes. Initial interview questions were customized for the educational context, e.g.:

- Could you give us a general description of the aquarium and the people who visit there?
- How would you describe resources for education outreach at the aquarium?
- How would you envision doing the Biocubes at the aquarium?
- What do you have available for technology or equipment that might be used for Biocubes?
- Could you describe your ideal, perfect world scenario of what that would look like if you could do the project any way you wanted to, without any constraints?
- Do you foresee any issues that would prevent you from doing Biocubes or require major compromises on how you do it?
- What would you expect that you and the students would get out of participating in the project?

Follow-up interview questions were similarly customized, including:

- Could you please describe how you used Biocubes in the summer camp?
- Were there any steps that you had to skip? Why?
- Were there any extra steps you had to take? Why?
- How did you and the students deal with the data?
- How did Biocubes integrate with other activities in the summer camp?
- What was the most unexpected thing about implementing Biocubes?

The interview questions for school teachers were similar but reworded to focus on classes, classrooms, schools, and students, rather than aquariums, visitors, and summer camps.

3.3. Data analysis

We analyzed the field study data and interview transcripts with deductive process analysis (Crowston, 2000) and inductive content analysis (Elo & Kyngäs, 2008). For investigating expected strategies for implementation, we adapted the predefined seven-step process of the Biocubes project as a coding scheme to identify how the educators planned to adapt each step to incorporate the project into teaching. We then conducted an open, bottom-up coding process and refined the coding over time in line with grounded theory (Strauss & Corbin, 1998), identifying emergent themes representing important considerations for citizen science implementation in learning environments.

Findings

We found that the educators easily envisioned creative strategies to incorporate Biocubes into different education contexts, but also had concerns about practical details. We first report the expected implementation strategies based on the workshop discussions and interview data to answer our first research question on the potential implementation strategies. Next, we focus on the degree of convergence between the early visions and actual experience for one implementation case, and highlight the practical concerns from the interviews in response to our second research question on factors that can influence adoption and implementation of citizen science in classrooms.

4.1. Proposed implementation strategies

During the workshop, the educators developed implementation strategies by aligning the Biocubes process with institutionally-mandated requirements to fit their teaching needs. Both science educators from schools and from aquaria focused on practical implementation strategies that conformed to their current teaching model, rather than venturing toward “out of the box” ideas that would require substantial additional effort or changes to expectations. The educators demonstrated established mental models of effective pedagogical practice, especially among the more experienced middle school and high school teachers. For formal teaching in schools, key variables that were seamlessly incorporated into planning included the durations of the class periods, how many sessions of the class are held each week, and which teaching standards and curriculum requirements should be matched to Biocubes activities. The aquarium and nature center educators did not limit their implementation ideas to structured education programs, but also included strategies for independent learner-driven engagement. In these organizations, logistical constraints were less rigid and learning goals were more flexible, but organizational missions and goals clearly guided the educators’ attention and emphasis for the development and implementation of exhibits and programs. For example, as discussed later, the amount of time allotted for Biocubes in a summer camp allowed hands-on discovery and documentation of biodiversity, but not data sharing, which reflected both organizational priorities and complex, negotiated goals for the summer camps.

Biocubes in FSE curricula

During the workshop session on curricular integration, the middle and high school teachers demonstrated that the Biocubes project easily aligned with numerous state teaching standards and local curriculum requirements in the subject area of science. The pre-defined steps were treated as a framework by the teachers, who addressed intended learning outcomes by inserting specific educational material directly into the framework to match the Biocubes process steps, or by modifying the framework based on the available resources and students' needs and abilities.

The high school teachers proposed implementing Biocubes by designing a year-long curriculum linking several thematic units with cumulative, integrated learning activities, many of which were complementary additions to the Biocubes process (as shown in Figure 1). This format took the short-form, intensive Biocubes activity and metered it out over the entire school year. In their sample curriculum, the entire implementation was divided into four quarters. The first quarter incorporated the steps of Preparation, Build, and Deploy, aimed at teaching science practices, helping students pose research questions, and develop an investigation plan. The second quarter focused on the step of Explore, excluding extraction. The students would learn photosynthesis and cellular respiration by observing their biocubes' sites, measuring light, humidity, and temperature, and taking a few samples (e.g., water, plant species). The third quarter integrated the steps of Explore, Identify, and Share, starting with extraction of the biocubes, identifying and classifying the species, exploring the connections among species with the help of books and other reliable sources, and finally uploading data into the data management system, iNaturalist. The teachers expected the students to learn classification, evolution, and energy flow through ecosystems in this quarter. The fourth quarter extended the Identify step; students would continue identifying the species from their photographs and preserved samples and writing lab reports, could participate in evaluating data quality on iNaturalist, compare data across biocubes data from other classes or schools, and reflect on the purpose of biodiversity monitoring and conservation. Students would learn about human impacts, plant structures, and population dynamics in this final quarter.

The middle school teachers proposed a one-time class activity focused on three selected 7th grade science teaching standards to provide a novel way of learning about interdependence among organisms. This activity would only incorporate the steps of Preparation, Explore, and Identify, and eliminating several materials requirements. For Preparation, the teachers planned to help students learn the concept of Biocubes by taking the advantage of a live webcam from an aquarium. The teachers would have students watch the webcam after pasting green tape around the edges of the screen to emphasize the visual frame of the monitor as one side of a green cube (i.e., a biocube) so the students could observe real organisms in a virtual biocube. Some teachers planned to take the students outdoors to first practice how to quietly observe the natural environment. The teachers also mentioned the possibility of dividing a single biocube into different parts, with each group of students given a portion of the cube to inventory it more rapidly. In the steps of Explore and Identify, the students would be encouraged to use smartphones to take photos of the organisms, with a competition to identify the most organisms in a limited time.

Biocubes in NSE programs

The aquarium science educators' discussion during the workshop session and the later interviews with them yielded several ideas for implementing the Biocubes project, closely centered around organizational missions and typically tied to education through a conservation focus. While the examples here focus on marine environments due to the venue and sponsorship of the educator workshop, there should be parallels for organizations of different focus and scope.

These educators envisioned three variations. The first concept was to develop exhibits for one-time aquarium visitors, which can be the majority of patrons in such institutions. A “dry”, static biocube model similar to a diorama could be displayed as a showcase to visitors. A biocube could be installed on the organization’s property with a real-time webcam focused on the biocube *in situ* streamed to monitors indoors. Visitors could use identification keys and data sheets to observe and record what they see in the biocube. Remote participation would also be possible.

The second concept focused on field trips to aquariums. Field trips of different durations were designed to allow school teachers to choose the trips that best fit into their schedules. The longer version could last from a half day to a full day. In this structure, aquariums would provide a selection of sites for teachers and students to do biocubes and arrange the resources to support a more complete process, including steps that might be less feasible for some school teachers, such as extraction.

The third concept was about using the Biocubes project in more structured education programs, such as partnerships with college courses or traditional summer camps, where participant fees could help cover associated costs. However, similar to the middle and high school teachers, some parts of the Biocubes process (particularly sharing data, discussed later) were not fully compatible with the goals of the summer camps.

4.2. Practical concerns

Several recurring themes arose around concerns that were expected to influence Biocubes implementation. Both school teachers and aquarium educators expressed concerns with using specific technologies (e.g., smartphones) and on minimizing human impacts when teaching conservation-related topics. These issues both reflected a desire to send a consistent message to students, and made the tasks of extraction, sorting organisms, and uploading data were most likely to be omitted. Compared to the aquarium educators, the school educators also identified many more practical issues that they expected to encounter when implementing Biocubes.

4.2.1 Concerns shared by FSE and NSE educators

Technologies

The educators were concerned about letting the students use personal cell phones in classrooms and summer camps because it would be inconsistent with the usual policies. In addition, one goal of outdoor activities was focusing on nature, and having students take on these activities was seen as a balance to time spent sitting in front of computers and on cell phones. Using a provided device without cell connectivity was a suggested alternate option, but would require having access to such tools. This issue introduced a substantial logistical challenge for completing data sharing tasks.

Human Impacts

One task in the step of Exploration—extract materials—consistently provoked concern about protecting the plants, animals, and insects in the biocubes. The educators agreed that doing an extraction helps collect useful samples and provides opportunity for close observation of the biotic and abiotic components of the biocubes. However, they still felt conflicted with this task from a conservation perspective. Although the protocol also included the task of returning organisms to their habitat, one interviewee was concerned that students' primary experiences with insects, as pests that are routinely destroyed without consideration, would be problematic.

4.2.2 Concerns of FSE educators

Several additional issues were raised by the middle school and high school teachers, primarily reflecting their institutional environments and student populations, factors that are largely outside of the teachers' control.

Administrator Control & Resources

Organizational administrators' influence was expected to have a direct and powerful impact on whether the school educators could implement Biocubes or not. Although workshop participants and interviewees reported strong interest in implementing Biocubes, the more junior educators were uncertain as to whether they would be "allowed" to use Biocubes in their teaching. Whether and how the educators saw implementing the project was also generally contingent on the administration's support for new teaching strategies and the expected and available financial support, equipment, tools, and facilities. This is consistent with the trend noted earlier of education-focused citizen science projects partnering with schools directly at the organizational level.

Implementing Biocubes requires a few inexpensive and reusable materials, but benefits substantially from access to additional resources, e.g., field guides and lab equipment, such as microscopes and Petri dishes. However, some teachers expected their schools would be unwilling or unable to pay for materials. The public school teachers raised this issue regularly, expecting to purchase materials out of their own pocket. This was undoubtedly a barrier to adoption, despite the kits which were distributed to workshop participants to provide several other key pieces of equipment.

Physical environments

Because Biocubes is a place-based observation project, the location of a school or other facilities matters for project implementation. Due to concerns about safety, the costs of transportation to distant sites, and need for permission from administration and parents to leave school grounds, the most likely location for a biocube would be on school campus. Schools adjacent to parks would be better situated for selecting sites that emphasize biodiversity, but selecting potentially "uninteresting" sites on the school grounds was considered most practical.

Classroom management

Integrating a citizen science project into teaching was a new experience for all educators in the workshop. They mentioned concerns about behavioral problems, especially during outdoors activities. The teachers were inclined to try a pilot implementation with classes that usually demonstrated good behavior to troubleshoot procedures and minimize classroom management issues with a new activity. The teachers were also concerned for students' psychological preparedness for parts of the activities that they recognized as foreign to their students, such as treating insects with respect.

Knowledge gaps

Most educators admitted some concerns about their own abilities to identify an unknown variety of organisms. Although they could use resources like books and the Internet, they knew through the experience of identifying organisms in the training workshop that it would be time consuming and difficult to identify some of the organisms to the species level. It was more efficient to ask for help from the biologists at the workshop, but when implementing Biocubes in their classes, the educators would have to deal with this challenge by themselves. More recent smartphone app developments that generate reasonably accurate automated organism identifications (using computer vision on photos uploaded with observations) would have potential to mitigate this concern.

Students' needs and motivations

The general demographics of the school educators' students were diverse, but composed predominantly of Hispanic and African American children. These students represent a population that often has limited access to the means and opportunities for taking action in science and conservation (Ballard, Dixon, & Harris, 2017). Most faced difficult socioeconomic conditions, as the majority of students in this Title I school district lived in poverty. This was a major challenge for motivating students; according to one teacher at school that was rated as failing, "it's very hard for [students] to relate to anything other than basic needs. They come [to school] and they're hungry...they're at the survival level." She went on to report that her students were also concerned about physical safety due to lifelong exposure to gun violence, which made them uncomfortable being outdoors. The teachers had to prioritize the students' basic needs before they could attempt to cultivate awareness and appreciation of nature.

4.2.3 Concerns of NSE educators

As in the previous section, the educators in NSE settings also identified potential issues that reflected the expectations of their institutional contexts.

Heterogeneous learners

The learners in NSE environments are much more diverse than those in FSE settings, who are more homogeneous in terms of age and amount of contact with the organization. These learners (aquarium visitors) might share similar interests, but may be very different from each other in terms of their ages, knowledge, and cultural backgrounds and expectations. It is challenging to design activities or projects that create valuable experiences for all participants with such diverse audiences.

Educators’ diverse duties

Our interviewees worked in organizations with small staff sizes and were responsible for many other duties. Their major responsibilities involved designing and setting up exhibits, planning and running education programs, and training other staff. However, they also had to take on such tasks as advertising exhibits and activities, managing organizational social media accounts, and making press releases. These tasks consumed most of their working time, so the educators felt that dedicating the time to a new project would be difficult. In addition, unlike the teachers who were usually solo facilitators, aquarium educators expected to work with other staff to implement Biocubes, and also considered their colleagues’ availability to assist.

Competing activities

There were many different projects and activities that the NFS educators wanted to fit into their programs. So the educators needed to decide whether the Biocubes project provided adequate value for the effort and resources compared to other projects and activities. For example, in a one-week summer camp, the educators had also considered incorporating other citizen science projects, outdoor activities (e.g., snorkeling, kayaking), and visits to local biologists and labs. The Biocubes project had to compete with other activities and be adequately compelling to be allocated the necessary time, materials, and resources.

4.3. Implementation case study

The challenges discussed above appeared to prevent prompt uptake of the Biocubes project. However, one NSE educator was able to incorporate the project into a series of marine biology summer camps, and a FSE educator introduced it to peers in a professional development inservice for middle school science teachers. Despite limited adoption, we report on the aquarium summer camp case to show how educator expectations aligned with experience.

4.3.1 Implementation case in aquarium summer camps

One of the aquarium educators, referred to by the pseudonym “Goby”, participated the workshop and both interviews. She implemented Biocubes in three summer camps hosted by an aquarium in Florida. We present this example to illustrate the integration of citizen science into teaching and demonstrate how several practical problems identified at the “envisioning” stage played out in the implementation for this case.

Goby incorporated the Biocubes project into marine biology Camps A, B, and C during different weeks; see Table 1 for basic details about each camp. The students in each camp were divided into two groups, with each responsible for one biocube. Together, the summer camp students completed setting up and collecting biodiversity observation data for a total of six biocubes, with at least one adult facilitator assisting each group of students.

The Biocubes session was organized as follows:

a) Introduction to the topic and project (10 mins)

b) Discussion of site selection, completing a shortened version of the provided “cube in context” observation sheet (15 mins)

c) Extraction: select site and put out the cube (20 mins), move cube to field lab (15 mins)

d) Identify and clean up: taking photos, sorting and identifying organisms, writing records down in notebooks (60 mins)

e) Reflection: Discussion about what they found, what was surprising (flexible)

Table 1. The basic information about three summer camps.

Camp	Age of students (years-old)	Number of students			Number of facilitators	Allotted time for Biocubes session (hour)	Number of species recorded[1]	Number of photos[2]
		Total	Cube I	Cube II				
A	12-14	10	5	5	3	2	13	31
B	12-14	12	6	6	2	2	8	34
C	14-15	7	3	4	2	1.5	2	24

The actual implemented process largely followed the ideal process, as the students could easily access a good site to collect data and had access to aquarium facilities for sorting and documenting organisms. However, the data were not uploaded and shared with scientists until an intermediary provided assistance.

4.3.2 Challenges

Among all the practical problems expected by the interviewees in section 4.2, the challenges around technology policy and access were the most significant and difficult to solve for the summer camps. During summer camp activities, cell phone use was forbidden by policy. Other technology sources available at the aquarium (e.g., computers) were limited enough to make them impractical for sharing observations.

The challenges of heterogeneous learners and competition with other activities also influenced how the Biocubes project was implemented. The educators focused on integrating this project into a summer camp for students ages 12-15, rather than try to engage every visitor in all imaginable demographics. The tasks were adjusted based on what the students were expected to learn, and hands-on engagement in inquiry-driven activities took priority over the technology and data literacy skills required for creating digital observation records. Since the Biocubes were just one activity of many in an action-packed week of summer camp, the protocol was compressed in the interest of time.

Due to these considerations, the data were neither uploaded immediately

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[1] The number of species recorded was counted based on the list of species and photos recorded by the students.

[2] The number of photos reflect the images that could be shared on iNaturalist, images were excluded if they included potentially identifiable images of people.

to iNaturalist by the students in the summer camps, nor by aquarium staff after the summer camps concluded. Goby reported that the students were predictably more excited by discovering cool organisms and enjoying the process of observing than stewarding the data produced by the observation (photos, notes). As a result, Goby became a *de facto* data manager for six teams; she transferred and stored all the data on a local computer. Although Goby clearly understood the Biocubes project goals and the value of contributing data to scientific research, the data manager was a role for which she and other facilitators were not trained, and for which there was less supporting material because of the expectation that the educators would need to improvise anyway. Goby already had many other duties and uploading data was not a work priority, nor did it align with her interests and skills or organizational imperatives.

Later, the Biocubes project coordinators asked Goby to share the data with the project team to be uploaded to iNaturalist on behalf of the students. Goby accepted the offer and shared all the raw data, which included observation sheets, identification lists, and photographs of the observed organisms. Three research assistants reviewed the raw data, aligned the metadata with the photographs, and shared the data on iNaturalist under a group account.

4.3.3 Comparing visions to reality

By comparison to Goby's description in the initial interview, the actual implementation differed in duration. The original plan to spend a half to a full day was not feasible, and the available time was limited to two hours. In addition, Goby initially planned to implement the project with only the older students, but found that the smaller size of summer camp groups was easier to manage than expected. The project was implemented in all age groups to good effect, with the recommendation that the younger students needed a little bit more time.

Two points of uncertainty from the initial interview were resolved through the implementation process. First, Goby was uncertain whether to include extraction step because it is a difficult and time consuming step that raised concerns over consistent conservation messaging. The second issue was also a policy consistency issue in deciding whether to allow students to use their own cell phone to collect, store, and upload data. In the end, she kept the extraction step, but also upheld the rule against cell phones, so students did not upload data.

Discussion

The findings show how educators expected to implement the same citizen science project in different education contexts, and illustrate a variety of practical concerns for implementation. In this section, we propose a two-dimensional model to help educators to be able to adapt and incorporate a citizen science project in their teaching. We then discuss one way citizen science projects can facilitate educator adoption and adaptation of their program. To conclude, we discuss the limitations of this study and opportunities for future work.

5.1. Two dimensions of implementation strategies

In this study, we found that although the Biocubes project could only provide educators with limited supporting resources and opportunities for working with scientists and project coordinators, they had concrete, feasible ideas for implementing the project independently in ways that achieved their teaching goals. We reported five ways that educators envisioned implementing the Biocubes project in different education contexts. For FSE contexts, these included a fully integrated one-year curriculum for high school science classes and a short-term activity for middle school science classes. For NSE contexts, they included new exhibits in an aquarium, field trip activities, and a summer camp activity. None of these strategies exactly matched the standard protocol from the training workshop, and as expected, educators envisioned customizing Biocubes based on their teaching needs and available resources. They prioritized the learning content of the tasks when deciding to follow or omit steps in the process, and inserted new tasks that created meaningful learning opportunities. The educators also adjusted the duration of activities to fit teaching schedules.

We divide the characteristics of these five implementation strategies into two basic dimensions: protocol and time (see Figure 2). The first dimension, protocol, reflects a range of potential adjustments to the complexity of the process. The protocol can be expanded, maintained, or compressed. Expansion describes adding more steps or tasks to the original protocol. Compression indicates omission of original project tasks or reduction in scope through simplification. The second dimension is the length of time spent on Biocubes tasks. Independently of expansion or compression of the protocol, educators can plan for activities to unfold over long or short periods of time. The amount of time planned by the educators in the Biocubes workshop varied considerably from under an hour to periods ranging from one day to weeks or months, and even a multi-year series. Educators also allotted more or less time for specific tasks, depending on the balance of schedule constraints and learning goals.

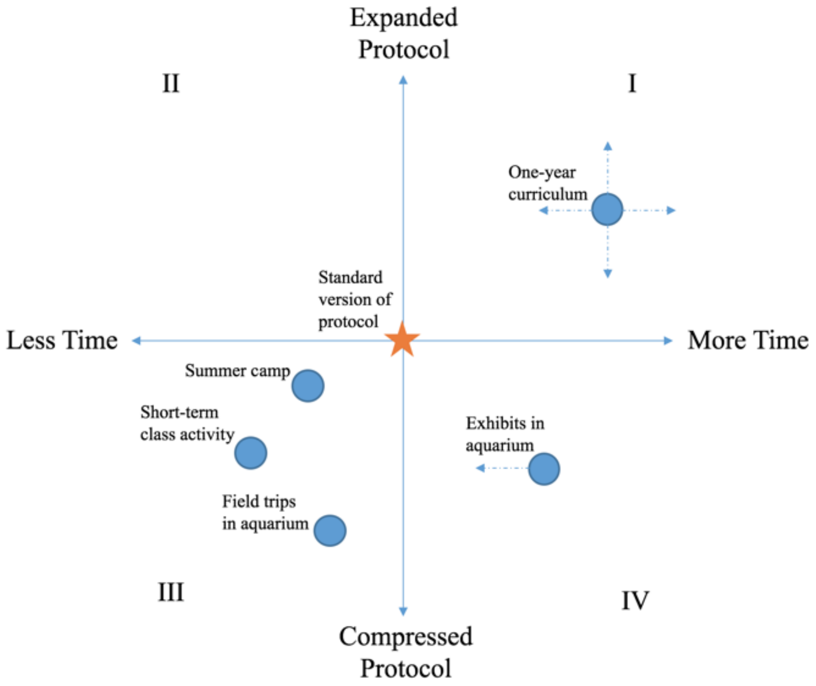

Figure 2. Two-dimensional model of temporal and protocol variations for citizen science project implementation across different education contexts.

Educators interested in independently implementing an existing citizen science project can start from this two-dimensional model to evaluate their implementation options. The first quadrant (I) includes implementation options that allocate *more* time for an *expanded* protocol, such as the year-long curricular integration of Biocubes for high school science students. The second quadrant (II) is empty as there were no proposed strategies that would take *less* time for an *expanded* protocol, and would be both unfeasible and undesirable under most conditions. The third quadrant (III) includes most of the examples from the educators in our study, as it responds to common issues around scheduling constraints and time limitations by taking *less* time for a *compressed* protocol. The fourth quadrant (IV) includes implementation ideas that involve a *compressed* protocol with fewer tasks, but can be allocated *more* time; in the example here, individual encounters with the exhibit might be brief, but the exhibit could be maintained for years. Visually mapping potential options as shown in Figure 2 may be useful for idea generation and comparing the benefits and drawbacks of different configurations.

5.2. Conflicting stakeholder needs

This study reveals several potential strategies for educators to implement citizen science projects independently to meet teaching goals. However, it highlights an important issue, namely that submitting data was not generally considered as important in independent implementations as when project coordinators and scientists are more involved in supporting or supervising the effort. In Biocubes, submitting data was also more likely to be skipped because of the constraints on time, policies around technology use, lack of technology infrastructure, and lack of compelling outputs from data entry (e.g., teachers wanted a report of the contents of the cube with pictures that students could take home to families). By definition, without taking the final step of sharing data, educators and learners are not fully participating in citizen science or STSPs. Instead, the project provides a structure that educators can readily adapt for a hands-on science project or education program that allows authentic engagement, but without contributing to science by sharing data. Once implementation was delegated entirely to the educators, scientists' needs appeared to carry insufficient weight to ensure follow-through on data sharing. Prior work suggests that resolving this tension requires relationship building with educators and learners, as well as direct engagement with project staff and scientists during implementation (Zoellick, Nelson, & Schauffler, 2012). We observed this practice in all of the previously mentioned citizen science projects that are successfully implemented in FSE and NSE contexts. However, this is not the way that relationships are managed in many citizen science projects that develop primarily around independent adult volunteers, so project staff may need to consider new practices for working with educators in order to ensure mutual benefit.

Is involving citizen science project staff and scientists in the implementation the only way to ensure scientists' needs are meet? Citizen science projects would then always be limited in scale by the number of scientists and staff facilitating participation, much like STSPs. Would it be better if educators and learners were motivated by sharing data, rather than feeling compelled to do data entry for someone else's benefit? We suggest that one way to overcome some of these barriers is through persuasive technologies, tools that facilitate the participation process by incentivizing certain activities, such as data sharing (Fogg, 2002). Contributing data must be easy for educators and learners, but almost more importantly, their work needs to be rewarded with desirable outputs, such as species lists and other data displays that can further facilitate teaching and learning. With the right kind of rewards, data entry can be worthwhile (Wiggins, 2013). Providing value-added data outputs can be a scalable way for citizen science projects to support educator facilitation and learner participation. For example, the recently implemented automatic species ID functionality in the iNaturalist smartphone app could to be compelling enough to eliminate the data entry problems and reduce educators' hesitation to use cell phones for this purpose (Yong, 2017). When users upload photos of organisms to iNaturalist, the app immediately suggests possible species names that match the submission, displaying photos of each candidate species to help further refine the identification. Such a tool may be desirable enough to motivate data sharing while also helping learners to get more value out of the observation activities. For the teachers in our study, reducing reliance on external expertise might also reduce educators' concerns about knowledge gaps for identifying species.

5.3. *Limitations and future work*

The findings of this study are limited by its scope, a single citizen science project that focuses on the most typical tasks with a limited pool of participating educators, whose needs and concerns may have limited generalizability, and we were only able to report on a single implementation. Our exploratory methods offer primarily descriptive findings, and also suggest abundant opportunities for future work.

Future research can build on these results with a comprehensive review of a wider variety of citizen science projects across different learning environments, evaluating the distinctive features of projects that could benefit independent implementation, and developing interventions to assess the importance of these features. Developing a clearer understanding of the project design and protocol adaptations required to better support educational implementations should improve outcomes for all stakeholders, and testing the value of persuasive technology designs would help establish guidelines for developing technologies to support citizen science participation across different education contexts.

Conclusion

This study investigated how science educators from different education contexts planned to independently implement an environmental citizen science project, Biocubes, in their teaching and education programs. In order to explore the educators' implementation strategies and their practical concerns that would influence the strategies across different education contexts, we participated in and observed a Biocubes project training workshop, and conducted interviews with the science educators who participated in the workshop. The results revealed different implementation strategies that are shaped by 1) the policies and activities supported by organizational and institutional administration, 2) the constraints on educators' time and material resources, 3) the needs and abilities of learners, and 4) aspects of citizen science project design that are unproblematic for individual self-selecting adult volunteers but constitute a higher barrier to entry for educators managing student contributions. We developed a two-dimensional model to demonstrate the types of adaptations that educators made to citizen science projects and discussed the potential role of persuasive technologies for citizen science projects to facilitate educator and learner participation.

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References

Ballard, H. L., Dixon, C. G., & Harris, E. M. (2017). Youth-focused citizen science: Examining the role of environmental science learning and agency for conservation. *Biological Conservation*, 208, 65-75.

Berkowitz A. R. (1997). A simple framework for considering the benefits of SSPs. *National Conference on Student and Scientist Partnerships: Conference Report*. Cambridge, MA: TERC. pp. 38–41.

Brossard, D., Lewenstein, B., & Bonney, R. (2005). Scientific knowledge and attitude change: The impact of a citizen science project. *International Journal of Science Education*, 27(9), 1099-1121.

Butler, D. M., & MacGregor, I. D. (2003). GLOBE: Science and education. *Journal of Geoscience Education, 51*(1), 9-20.

Cohn, J. P. (2008). Citizen science: Can volunteers do real research?. *AIBS Bulletin, 58*(3), 192-197.

Crowston, K. (2000). Process as theory in information systems research. In *Organizational and social perspectives on information technology* (pp. 149-164). Springer US.

Dickinson, J. L., Zuckerberg, B., & Bonter, D. N. (2010). Citizen science as an ecological research tool: challenges and benefits. *Annual review of ecology, evolution, and systematics*, 41, 149-172.

Elo, S., & Kyngäs, H. (2008). The qualitative content analysis process. *Journal of advanced nursing*, 62(1), 107-115.

Eshach, H. (2007). Bridging in-school and out-of-school learning: Formal, non-formal, and informal education. *Journal of science education and technology,* 16(2), 171-190.

Fogg, B. J. (2002). Persuasive technology: using computers to change what we think and do. *Ubiquity*, 5.

Gray, S. A., Nicosia, K., & Jordan, R. C. (2012). Lessons learned from citizen science in the classroom. a response to" the future of citizen science." *Democracy and Education*, 20(2), 14.

Houseal, A. K., Abd-El-Khalick, F., & Destefano, L. (2014). Impact of a student–teacher–scientist partnership on students' and teachers' content knowledge, attitudes toward science, and pedagogical practices. *Journal of Research in Science Teaching*, 51(1), 84-115.

Jordan, R. C., Gray, S. A., Howe, D. V., Brooks, W. R., & Ehrenfeld, J. G. (2011). Knowledge gain and behavioral change in citizen science programs. *Conservation Biology*, 25(6), 1148-1154.

Kelling, S., Johnston, A., Hochachka, W. M., Iliff, M., Fink, D., Gerbracht, J., ... & Wong, W. K. (2015). Can observation skills of citizen scientists be estimated using species accumulation curves?. *PloS one*, 10(10), e0139600.

Loarie, S. (2016). What is it. Retrieved from http://www.inaturalist.org/pages/what_is_it

Lostal, E., Serrano, F., Carrodeguas, J. A., Martínez, P., Sanz, F. & Val, C. (2013). A case of Citizen Science for Cell Biology Images Analysis. In: *Proceedings of the XXXIII Congresso da Sociedade Brasileira de Computação (CSBC 2013)*. Maceió, Brazil, pp. 1855–1862.

Malmberg, J. S., & Maull, K. E. (2013). Supporting Climate Science Research With 21st Century Technologies and a Virtual Student Conference for Upper Elementary to High School Students. *LEARNing Landscapes*, 6 (2), 249-264.

Masters, K., Oh, E. Y., Cox, J., Simmons, B., Lintott, C., Graham, G., ... & Holmes, K. (2016). Science learning via participation in online citizen science. arXiv preprint arXiv:1601.05973.

Monroe, M. C., Andrews, E., & Biedenweg, K. (2008). A framework for environmental education strategies. *Applied Environmental Education & Communication*, 6(3-4), 205-216.

Paige, K., Hattam, R., & Daniels, C. B. (2015). Two models for implementing Citizen Science projects in middle school. *The Journal of Educational Enquiry*, 14(2).

Penuel, W. R., Bienkowski, M., Gallagher, L., Korbak, C., Sussex, W., Yamaguchi, R., & Fishman, B. J. (2006). GLOBE Year 10 evaluation: Into the next generation. Menlo Park, CA: SRI International.

Rahm, J., Miller, H. C., Hartley, L., & Moore, J. C. (2003). The value of an emergent notion of authenticity: Examples from two student/teacher-scientist partnership programs. *Journal of Research in Science Teaching*, 40(8), 737-756.

Roy, H. E., Pocock, M. J. O., Preston, C. D., Roy, D. B., Savage, J., Tweddle, J. C., & Robinson, L. D. (2012). Understanding citizen science and environmental monitoring: final report on behalf of UK Environmental Observation Framework.

Sadler, T.D., Burgin, S., McKinney, L., & Ponjuan, L. (2010). Learning science through research apprenticeships: a critical review of the literature. *J. Res. Sci. Teach.* 47 (3), 235–256.

Silva, C. G., Monteiro, A., Manahl, C., Lostal, E., Holocher-Ertl, T., Andrade, N., ... & Brito, R. M. (2016). Cell Spotting: educational and motivational outcomes of cell biology citizen science project in the classroom. *JCOM, 15*(01), A02-2.

Schwartz, M. D., Beaubien, E. G., Crimmins, T. M., & Weltzin, J. F. (2013). North America. In *Phenology: an integrative environmental science* (pp. 67-89). Springer Netherlands.

Shah, H. R., & Martinez, L. R. (2016). Current approaches in implementing citizen science in the classroom. *Journal of microbiology & biology education*, 17(1), 17.

Silvertown, J. (2009). A new dawn for citizen science. Trends in ecology & evolution, 24(9), 467-471. Strauss, A. L., & Corbin, J. M. (1990). *Basics of qualitative research* (Vol. 15). Newbury Park, CA: Sage.

Strauss, A., & Corbin, J. (1998). Basics of qualitative research techniques: Techniques and procedures for developing grounded theory. Sage publications.

Sullivan, B. L., Aycrigg, J. L., Barry, J. H., Bonney, R. E., Bruns, N., Cooper, C. B., ... & Fink, D. (2014). The eBird enterprise: an integrated approach to development and application of citizen science. *Biological Conservation, 169*, 31-40.

Tinati, R., Van Kleek, M., Simperl, E., Luczak-Rösch, M., Simpson, R., & Shadbolt, N. (2015, April). Designing for citizen data analysis: A cross-sectional case study of a multi-domain citizen science platform. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (pp. 4069-4078). ACM.

The European Citizen Science Association (ECSA) Working Group "Sharing Best Practice and Building Capacity". (2015). *ECSA 10 Principles of Citizen Science*. Retrieved from http://ecsa.citizen-science.net/engage-us/10-principles-citizen-science

Trautmann, N. M, Shirk J, Fee J, & Krasny M. E. (2012). Who poses the question? Using citizen science to help K–12 teachers meet the mandate for inquiry. In: Dickinson JL and Bonney R (Eds). *Citizen science: public collaboration in environmental research*. Ithaca, NY: Cornell University Press.

Wormstead, S. J., Becker, M. L., & Congalton, R. G. (2002). Tools for successful student–teacher–scientist partnerships. *Journal of Science Education and Technology*, 11(3), 277-287.

Wiggins, A. (2013). Free as in puppies: compensating for ICT constraints in citizen science. In *Proceedings of the 2013 conference on Computer supported cooperative work* (pp. 1469-1480). ACM.

Yong, E. (2017). Finally: An App That Can Identify the Animal You Saw on Your Hike. *The Atlantic*. Retrieved from https://www.theatlantic.com/science/archive/2017/07/an-app-for-identifying-animals-and-plants/535014/.

Zoellick, B., Nelson, S. J., & Schauffler, M. (2012). Participatory science and education: bringing both views into focus. *Frontiers in Ecology and the Environment*, 10(6), 310-313.