SHEDD AQUARIUM

LEARNING PLANNING & EVALUATION

Citizen Science

RESEARCH NARRATIVE

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EXECUTIVE SUMMARY

Citizen science is an effective way to engage people in scientific research projects that address real-world issues. Topics include astronomy, ecology, and climate change, just to name a few. With such a range of topics, people can explore a scientific interest in depth, or even develop new interests.

Citizen science projects have the potential to address scientific, societal, and educational issues on the largest scale (see page 10), but citizen science as a formal community of practice is still in its early stages, yet to fully realize its potential. **Projects can be classified by the role that the citizens play in the project**, which ranges from collecting data for scientists to being the driving force behind projects (see page 5). **Projects can also be classified by their goals**, which include addressing environmental issues that affect public health, conserving a special piece of land, answering scientific questions, or addressing science education goals (see page 8).

There is a great deal of potential for individuals and society to benefit from citizen science projects. **Outcomes from citizen science projects fall into multiple categories that include: scientific, individual learning, and social-ecological systems** (see page 10). Learning outcomes that have been documented include gains in knowledge of science concepts and scientific processes, increases in inquiry and scientific skills, and increases in interest and engagement in science. Changes in attitudes toward science and changes in participants' behaviors have not been well documented due to their complex nature. Researchers are working toward developing a theoretical framework that will help make research more generalizable and guide future research efforts.

Methods for evaluation have included pre- and post-surveys, interviews, and standardized scales, as well as the use of concept maps and online data analysis (see page 18). **A rubric for planning evaluations has been developed and project developers are encouraged to use it in order to facilitate a systematic way to document outcomes across projects** (see pages 19 and 34)**.**

There is still more to be learned about the impact of citizen science projects, and **future research will focus on how to more effectively document changes in scientific literacy, attitudes, and behaviors** (see page 24)**.** Learning about motivations for participation, effectiveness of online social networks, and how to overcome obstacles to participation for underrepresented audiences will lead to a more thorough understanding of citizen science and allow the projects to reach their full potential for influencing science learning, the environment, and society.

1. What is Citizen Science?

Citizen science is also referred to as public participation in scientific research (PPSR) (Bonney et al., 2009), community-based monitoring (Conrad & Hilchey, 2011 and Fernandez-Gimenez, Ballard, & Sturtevant, 2008), or collaborative monitoring (Fernandez-Gimenez, Ballard, & Sturtevant, 2008). Although the field has not come to a consensus on a name for these types of projects, the basic idea is that volunteers are actively engaged in scientific research that focuses on a real-world issue (Wiggins & Crowston, 2011). The level of involvement the volunteers have in the research process and the goals vary depending on the project. There are many different topics that are addressed by citizen science projects. Volunteers can assist with iguana conservation in the Bahamas through a Shedd Aquarium project (Knapp, 2004), monitor rare plants in Chicago (Havens, Vitt, & Masi, 2012), collect baseline data to monitor Maryland's amphibians and reptiles (Cunningham et al., 2012), collect data to inform policies for coral reefs in Jamaica (Crabbe 2012), document the presence of monarch butterfly eggs and larvae in their own backyard (Oberhauser & Prysby 2008), contribute to projects that monitor how plants are affected by climate change through Nature's Notebook,[1] transcribe historical weather information from ships' logs to inform future climate models through Old Weather,[2] or categorize galaxies by sorting through photos through Galaxy Zoo.[3]

Members of the public have collected data about environmental factors long before the term "citizen science" was introduced in 1995 (Bonney et al., 2009). Early projects that involved the public included lighthouse keepers documenting bird strikes starting in 1880, the National Weather Service Cooperative Observer Program that started in 1890, and the first annual Christmas Bird Count sponsored by the National Audubon Society in 1900. If you go even farther back in history, outbreaks of locusts have been documented by citizens in China for over 3,500 years (Miller-Rushing, Primack, & Bonney, 2012). Havens and Henderson (2013) provide a detailed timeline of key points in the history of citizen science.

In the past, it was not that unusual for non-professional scientists to contribute to the scientific body of knowledge because there were very few professional scientists. Over the last 150 years, the field of science has shifted from research being driven by highly-skilled amateurs toward research being conducted by highly-trained professional scientists (Miller-Rushing, Primack, & Bonney, 2012). This does not mean that amateurs do not play a valuable role in research today; in fact, some types of research can only be done with the involvement of non-professional citizen scientists (Miller-Rushing, Primack, & Bonney, 2012 and Catlin-Groves, 2012). Projects that intend to collect large amounts of data on a national level could not be successful with just one small team of researchers, but valuable data sets can be generated on topics such as weather, birds, and plants when trained volunteers from across the country contribute data. Professional scientists are less likely to pursue research that addresses a local environmental issue due to pressures to contribute to advancements in their field of study by studying broader concepts or issues, but local concerned citizens can become champions for community issues. Data they collect can lead to land managers making decisions to improve the environmental situation (Miller-Rushing, Primack, & Bonney, 2012).

Recently, there has been a dramatic increase in the number of citizen science projects. A visit to websites such as Citizen Science Central,[4] SciStarter,[5] and Citizen Science Alliance[6] shows that there are hundreds of projects

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[1] https://www.usanpn.org/natures_notebook
[2] http://www.oldweather.org/
[3] http://www.galaxyzoo.org/
[4] http://www.birds.cornell.edu/citscitoolkit/
[5] http://scistarter.com/

available for people who are interested in participating in citizen science. Silvertown (2009), Toerpe (2013), and Scripa & Moorefield-Lang (2013) are also good sources for lists of citizen science projects. There are several reasons for this increase in citizen science opportunities. Technology, especially the Internet and smartphones, have made it easier for people to learn about projects and to gather data. Professional scientists have realized the benefits that come with engaging the public in their research, which includes drastically increasing the number of people on their research team without the cost of hiring staff, gathering data across vast geographic areas that would not be possible without utilizing volunteers, and the requirements from research funders (e.g., National Science Foundation) for researchers to engage in public outreach as a condition of grants (Silvertown, 2009).

One reason citizen science projects continue to grow is because citizen science has been shown to have an impact on conservation and ecological research. Citizen science projects provide scientists with long-term data sets over huge geographic ranges that assist with determining patterns and testing hypotheses. See Knapp (2004) for a description of how Shedd Aquarium's Rock Iguana Research and Conservation program has incorporated citizen scientists into its conservation efforts in the Bahamas. This narrative focuses on the learning aspects of citizen science projects, but see Cooper, Hochachka, and Dhondt (2012); Zuckerberg and McGarigal (2012); Fink and Hochachka (2012); Hames, Lowe, and Rosenberg (2012); and Greenwood (2012) for information about citizen science and ecological research.

2. Types of Citizen Science Projects

Although citizen science projects are not new, it is a field that is still defining itself. There have been several efforts to review citizen science projects and categorize them based on different aspects of the projects (Conrad & Hilchey, 2011; Fernandez-Gimenez, Ballard, & Sturtevant, 2008; Bonney et al., 2009; Shirk et al., 2012; Lawrence 2006; Wiggins & Crowston 2011). These thorough descriptions of the range of citizen science projects will facilitate future research in the field of citizen science (Wiggins & Crowston 2011). Based on their review of ten years of literature on citizen science projects, Conrad and Hilchey (2011) found that there was not enough information to determine if one category of project is better than the others, and they suggested that the appropriate type of approach would be determined by each individual monitoring situation and the community that is involved.

Projects may have a **top-down or bottom-up structure** (Conrad & Hilchey, 2011). Top-down structures are projects that are led by an organization (e.g., university, non-profit, government agency) and the public is invited to assist with the project but may have little say in the direction of the project. Bottom-up projects are those that are initiated, led, and sometimes funded by the community itself. The community members may collaborate with institutions in order to get the expertise that is necessary to be successful, but the community members are the driving force behind bottom-up projects.

[6] http://www.citizensciencealliance.org/

When citizen science projects involve monitoring of ecosystems, they may be called **community-based monitoring** programs. Activities may include assessing the status of a population, assessing human or natural impacts on an ecosystem, and how to use the information gathered through the monitoring project to effectively manage the ecosystem (Conrad & Hilchey, 2011). Projects may focus on the species that live in an ecosystem, the interactions between species, or the processes that affect an ecosystem. Citizen science is a natural fit for ecological research that requires observations over large geographic areas and over a long timeframe. Scientists may detect new patterns by analyzing data collected through citizen science programs, which may lead to new research into ecological processes. Citizen science data collected over large geographic areas can also be used to test hypotheses that predict patterns. Examples of topics that have benefitted from citizen science data include patterns of distribution and abundance, habitat associations, assessment of the impacts of environmental change, migration patterns, tracking the spread of diseases in wildlife, life history traits, and behavior (Cooper et al., 2012).

Fernandez-Gimenez, Ballard, and Sturtevant (2008) identified **collaborative monitoring** as citizen science projects that involve multiple parties with differing interests and expertise, and they often include people with polar opposite views on an issue (e.g., a conservation group and a consumptive group) on the same monitoring team. The collaboration of people from such disparate groups has led to social learning and community building, which includes building trust between the groups. It has also been found that the groups developed a shared understanding of the ecosystem, which helped the groups better understand the perspectives of different stakeholders. The involvement of the community has also led to the facilitation of disseminating results to the community and to data being used for management decisions.

Lawrence (2006) described **consultative** projects as those in which volunteers contribute information to the researchers. An example of a consultative project is one in which researchers asked farmers and members of the general public to complete a questionnaire that asked them to record past observations of a venomous snake in order to investigate changes in the snake's distribution and abundance. Volunteers did not actively collect data, but rather just recorded their knowledge of previous observations of the snake.

Bonney et al. (2009) described three types of citizen science projects: **contributory, collaborative, and co-created**. These three types differ in the amount of involvement and control they offer to the public participants. In **contributory projects**, also called functional projects by Lawrence (2006) and consultative/functional by Conrad and Hilchey (2011), the scientists design the project and the participants collect data, although they may also engage in other activities in some contributory projects. Long-term data sets are collected by many volunteers over a large geographic area in these projects. Although a large number of volunteers participate, these projects tend to attract a specific group of people depending on the topic (e.g., only people interested in plants), so the stakeholders are not a diverse group of people (Conrad & Hilchey, 2011). An example of a contributory project is Spotting the Weedy Invasives (Bonney et al., 2009). Hikers are trained to identify invasive plants and how to collect the necessary data for the section of the trail that they are assigned. The researchers in this project developed the goals for the project, and the role of the citizen is to be the data collector.

Although the primary role of the participant is data collector, they may also have the opportunity to learn about developing explanations, drawing conclusions, and disseminating conclusions.

Collaborative projects allow the public to get involved in a deeper way through project design, analysis of data, or dissemination of findings (Bonney et al., 2009; Lawrence, 2006; Conrad & Hilchey, 2011; and Shirk et al., 2012). Collaborative projects tend to involve as many stakeholders in a community as possible (e.g., private landowners, general public, and businesses). These types of projects may involve a group of people from different organizations that co-manage an area such as a watershed. This structure allows for the stakeholders to have more decision-making power than the other types of citizen science projects (Conrad & Hilchey, 2011). The Invasive Plant Atlas of New England involves citizens in a project to identify and map invasive plants (Bonney et al., 2009). In this project, participants choose their own study site. They are encouraged to get involved with curriculum and management through the project's website. The project organizers encourage participants to disseminate the data and coordinate ways for participants to become involved in management of the invasive species by connecting them with local management organizations.

Scientists and the public work together to design **co-created projects** (Bonney et al., 2009 and Shirk et al., 2012) and members of the public are much more involved in all of the parts of the research process, such as deciding on the research question, asking new questions, refining the project to improve effectiveness, and disseminating the conclusions. Bonney et al. (2009) described ReClam the Bay as an example of a co-created project that focuses on restoring a shellfish population in New Jersey. Community members help to maintain water quality and restore the shellfish population. Volunteers receive training so that they are qualified to rear shellfish and collect data on water quality and shellfish growth rate. Scientists publish the data and volunteers use the data to guide decisions on bay management. The scientists and the volunteers select their own research questions and both groups develop hypotheses. Volunteers are encouraged to do background research on the issues and share information with scientists. Volunteers have created their own methods for rearing the shellfish and are involved in data analysis, interpretation, and drawing conclusions. Scientists and volunteers disseminate the results and educate the public. The volunteers have been so committed to this project that they have raised almost $100,000 through their foundation and educational programs.

Volunteers are the driving force of the project and utilize the expertise of scientists when necessary in **transformative** projects (Lawrence, 2006 and Conrad & Hilchey, 2011). These types of programs may lead to participants who become empowered and more dedicated to a cause, or even experience a change in values. These types of projects are more citizen-led than the co-created projects that were mentioned by Bonney et al. (2009). The community members are involved in all aspects of the project, but the group may not include a diverse group of stakeholders. Some examples of transformative programs have had issues with credibility and have not always been successful at an organizational level (Conrad & Hilchey, 2011). An example of a transformative project that Lawrence (2006) described comes from Martha's Vineyard. Residents who are involved in the shellfish fisheries in the area took it upon themselves to form pond associations to raise funds to protect the shellfish resources in their local community. These associations do not do the water quality monitoring themselves, but they use the funds they raise through membership and grants to hire experts to conduct the necessary studies. They use this information to lobby for environmental improvements and conduct an educational campaign.

Another approach to categorizing types of citizen science projects is to divide them by the projects' primary goals. Wiggins and Crowston (2011) reviewed 30 citizen science projects and divided them into five types: **Action, Conservation, Investigation, Virtual, and Education**.

Action projects are initiated by community groups who are concerned about a local environmental issue (Wiggins & Crowston, 2011). Scientific research is included in the project because having data about the issue can allow community members to make a more convincing argument for the need for action by the authorities to correct the problem. Scientists are not the driving force behind these projects, but they may work with the group to ensure the research protocols and resulting data can be used.

Conservation projects focus on the stewardship and/or natural resource management of a region (Wiggins & Crowston, 2011). Researchers or land managers are usually the initiators of a project, and they may partner with other local non-profits. Volunteers are invited to assist with data collection as a way to engage communities in the conservation effort and as a way to collect a large amount of data. Since data will be used for land management decisions, it is important that the projects are scientifically valid. Academics or researchers from governmental agencies provide the leadership necessary to ensure the data can be used. These types of projects generally include an explicit education component.

Scientific research is the driving force behind **Investigation projects**, which are usually directed by academics or non-profits (Wiggins & Crowston, 2011). Some scientific questions can only be answered by collecting data from across the nation so citizen science projects allow for data collection that one research team could not accomplish on its own. Scientific validity is of paramount importance for these projects, so multiple methods of validation are employed to ensure that the data are usable. Educational goals may be implicit or explicit, but some form of education is usually included.

Virtual projects have similar goals to Investigation projects, but volunteers do not need to visit a location in order to participate since these projects are completely coordinated through the Internet (Wiggins & Crowston, 2011). One benefit of Virtual projects is they allow people to engage in topics that are of concern in another part of the world (or even outer space in the case of astronomy projects) where they could not easily travel in order to volunteer on a regular basis. Volunteers may not collect data themselves, but they are able to help researchers by sorting through data that has already been collected. Academics are the initiators of these projects, and scientific research is truly the main focus with almost no inclusion of educational materials.

Education projects are focused on education and outreach, to the point that scientific validity is sacrificed for learning goals and the development of scientific inquiry skills in some cases (Wiggins & Crowston, 2011). Data analysis by volunteers has been found to be a component of these types of projects, which isn't the case in the other projects. This demonstrates that coordinators of education projects consider the development of critical thinking skills to be an important aspect of the project. These projects are directed by one or more organizing institutions and provide both informal learning resources and formal curricula.

Classroom-based Citizen Science Projects

Citizen science provides teachers with the opportunity to involve their students in authentic science projects. Scientists, students, and teachers all benefit from the collaboration. Scientists' research benefits from additional data collection. Scientists also receive the benefit of their research being used as an outreach effort. Students have the opportunity to engage in an authentic science experience. Teachers can use citizen science to help them meet their classroom needs, which include meeting national science standards by providing students with inquiry-based learning experiences and motivating and inspiring students through relevant science experiences (Trautmann et al., 2012). Within the last decade, citizen science projects that involve classrooms have evolved from simply using students as data collectors to projects that are designed to allow students to engage in the full range of experiences that comprise scientific inquiry in an effort to better meet the needs of teachers and students (Trautmann et al., 2012). Success of these programs depends on additional support that is given to the teachers and students, including student-friendly data displays and analysis tools, teacher professional development opportunities, connecting teachers with scientists who can support them and their students, and providing students with a way to share their results beyond their classroom (Trautmann et al., 2012).

Zoellick, Nelson, and Schauffler (2012) suggested that classroom-based citizen science projects need to be designed differently than programs that involve volunteers from the general public due to the constraints that are inherent with formal education settings, such as curriculum requirements. In order for classroom-based citizen science projects to have a better chance of being successful, the authors suggested that it is important to approach project design with the understanding that the needs of scientists, teachers, and students are different. A scientist's research question may not directly address the content that students are expected to learn, but working with a scientist can provide students with valuable experience with the scientific process. Zoellick, Nelson, and Schauffler (2012) recommended that classroom-based projects should be designed so that students play an appropriate role in the scientists' work (e.g., collecting data) in order to help the researcher meet his/her goals, but that students also develop their own research questions and projects that are aligned with their needs. By working with a scientist, students see first-hand how science is conducted and they can use that knowledge as they develop their own projects.

Citizen Science in Public Aquariums

There are citizen science projects that are associated with public aquariums around the country. Since 1995, Shedd Aquarium has included a citizen science component in its Rock Iguana Research and Conservation program[7] in the Bahamas (Knapp, 2004). Volunteers are trained to help with field research that includes surveying populations and collecting blood samples. The involvement of volunteers has led to a range of outcomes, which include more data being collected, the opportunity for volunteers to learn more about conservation science and the natural history of iguanas, and even economic benefits to the island through the tourism dollars spent by the volunteers (Knapp, 2004). Shedd Aquarium is also a partner with Project Seahorse on the citizen science project called iSeahorse,[8] which allows the public to help protect seahorses by documenting observations. The Seattle Aquarium[9] works with high school citizen scientists to monitor intertidal areas. The Aquarium of the Pacific[10] in California coordinates a citizen science project to protect the green sea turtles that live in a local river. The ECHO Lake Aquarium and Science Center in Vermont coordinated a Citizen Science Day[11] in 2013 to introduce visitors to citizen science and local projects that they can join.

3. Outcomes of Citizen Science Projects

TYPES OF OUTCOMES

Outcomes from citizen science projects fall into multiple categories that include: **research (scientific findings), individual learning (new skills, knowledge, or behavior), and social-ecological systems (policy decisions and building community capacity)** (Shirk et al., 2012). Jordan, Ballard, and Phillips (2012) suggested that there are three levels at which citizen science programs can have an effect on learning: **individual learning, programmatic-level learning, and community-level learning.** Individual learning outcomes include an increase in a person's awareness, knowledge, engagement, ability to perform science skills, stewardship, identity, and interest. Examples of programs that have resulted in these types of changes will be described in the next section in detail. The other two levels of outcomes will briefly be mentioned, but not elaborated on in this narrative.

Outcomes at the **programmatic level** document whether a program has successfully met its goals (Jordan, Ballard, & Phillips, 2012). Has it led to a better understanding of the ecology of an area? Has it successfully engaged the local community? Has it addressed issues that the community is concerned about? Can the data be used by a scientist in a meaningful way? Answers to all of these questions can be used to help improve the effectiveness of projects.

Community-level outcomes allow for programs to be examined in the broadest sense and look for evidence that programs have had far-reaching impacts at the environmental and social levels. **These broader impacts could include increasing social capital and community capacity or building trust between scientists, managers, and the public** (Fernandez-Gimenez, Ballard, & Sturtevant, 2008). By looking at how citizen science programs impact

[7] http://www.sheddaquarium.org/3227.html
[8] http://www.iseahorse.org/
[9] http://www.seattleaquarium.org/citizen-science
[10] http://www.aquariumofpacific.org/news/story/citizen_science_project_seeks_volunteers
[11] http://www.echovermont.org/events/viewevent.html?event=630

society at the broadest levels, it is possible to see if these programs can play a role in shaping a socioecological system that is resilient and better able to deal with environmental and/or social changes to the community in the future (Jordan, Ballard, & Phillips, 2012). This idea of examining how citizen science programs can lead to a more resilient socioecological system is relatively new, but Jordan, Ballard, and Phillips (2012) recommended that it should be a priority in the future. For more information on social capital, community capacity, and socioecological resilience, please see Adger (2003), Donoghue & Sturtevant (2007), and Folke (2006) respectively.

Although considering community-level outcomes is relatively new, there has been some research on whether collaborative and community-based monitoring can lead to social learning, community building, and the development of trust (Fernandez-Gimenez, Ballard, & Sturtevant, 2008). Collaborative monitoring projects allow groups of people with opposing viewpoints on an issue to work together to monitor a natural resource. The intentional involvement of people with opposing views has been shown to lead to the types of community-level outcomes that Jordan, Ballard, and Phillips (2012) referred to in terms of social capital, community capacity, trust, and the resilience of social-ecological systems and go well beyond simply collecting accurate data to be used by scientists or learning new facts about science (Fernandez-Gimenez, Ballard, & Sturtevant, 2008). This area of research touches on the potential for significant societal impacts that could come from citizen science programs if that is a desired outcome for the project.

INDIVIDUAL LEARNING OUTCOMES

Overview of Learning Outcomes

Although citizen science programs are not new, there is still a lack of documentation of learning outcomes in part due to the lack of a theoretical framework to guide research in citizen science, the cost of conducting evaluations, and the complicating factors that come with the interdisciplinary nature of citizen science (Phillips, Bonney, & Shirk, 2012). Research has been done on citizen science projects, but it has mostly been reported on a project-by-project basis and not in a fashion that allows for general conclusions to be made that apply to the wide range of citizen science projects that are available. The section that follows describes the outcomes that have been documented. In some cases, researchers were unable to detect a significant change in the intended outcomes, but the projects are still described since the research led to insights into the field of learning through citizen science projects.

In *Learning Science in Informal Environments*, the National Research Council (2009) proposed the following six strands of science learning that describe experiences that informal settings can provide to learners and can be used to guide the development of tools and assessments in informal environments. The Council stated that,

> Learners in informal environments:
>
> Strand 1: Experience excitement, interest, and motivation to learn about phenomena in the natural and physical world.

Strand 2: Come to generate, understand, remember, and use concepts, explanations, arguments, models, and facts related to science.

Strand 3: Manipulate, test, explore, predict, question, observe, and make sense of the natural and physical world.

Strand 4: Reflect on science as a way of knowing; on processes, concepts, and institutions of science; and on their own process of learning about phenomena.

Strand 5: Participate in scientific activities and learning practices with others, using scientific language and tools.

Strand 6: Think about themselves as science learners and develop an identity as someone who knows about, uses, and sometimes contributes to science (National Research Council, 2009, p. 4).

Citizen science projects were one type of program that was examined by the National Research Council (2009), and it reported that citizen science programs can provide opportunities for learning related to Strands 2–6. It is interesting to note that Strand 1 (developing an interest in science) was not mentioned. The report did not state why developing an interest in science was not considered an applicable strand for citizen science projects, but this could be because the authors assumed that people who participate in citizen science programs already have an interest in science. The following descriptions of specific research projects relate to these six strands of science learning.

Citizen science projects are an excellent way to engage people in authentic scientific activities (Bonney et al., 2009). The wide variety of projects and levels of engagement can allow people to continue an already established interest or try something new. The number of people who have contributed to citizen science projects across the country is a testament to how engaging the experience can be for people, but can citizen science be used to achieve more complex science education goals? Bonney et al. (2009) conducted a meta-analysis of ten projects, which included contributory, collaborative, and co-created projects. Based on this meta-analysis, Bonney et al. (2009) found that **public participation in scientific research projects can lead to gains in knowledge of science concepts and scientific processes, increases in inquiry and scientific skills, and increases in interest and engagement in science. They also found that changes in attitudes toward science and behavior due to these projects have not been well documented.**

Scientific Knowledge and Skills

Increases in knowledge about the scientific concepts addressed in citizen science projects have been documented in a wide range of projects and are some of the easier outcomes to measure (Bonney et al., 2009). Research has shown that knowledge has been gained about scientific topics that include, but are not limited to, shellfish ecology, water quality, invasive plants, bird biology and behavior, plant ecology, and monarch butterfly biology (Bonney et al., 2009; Jordan et al., 2011; Evans et al., 2005; Brossard, Lewenstein, & Bonney, 2005; and Thompson & Bonney, 2007).

Participants in citizen science projects have shown improvement in scientific skills, such as organism identification, following protocols to collect data, using tools to take measurements, interpretation of graphs, drawing conclusions, and creating new questions (Bonney et al., 2009).

Some skills have been found to be more challenging for participants to learn through citizen science projects because they require more personal instruction, which is not always possible in citizen science projects. Data analysis, the development of scientific questions, and getting volunteers comfortable with disseminating the results have been found to be challenging tasks (Bonney et al., 2009).

Scientific Literacy

Cornell University's Laboratory of Ornithology has capitalized on the dedication of birders from across the nation to conduct a variety of citizen science projects. Researchers have investigated whether people think scientifically when participating in one of their citizen science projects (Trumball et al., 2000). In the Seed Preference Test citizen science project, volunteers were supplied with a research kit to guide them in how to set up an experiment that was designed to determine what kind of birdseed ground-feeding birds preferred and if preferences varied across the United States and Canada. Almost 5,000 volunteers submitted data that could be used by the researchers. The researchers attempted to determine if participation in the project had changed their beliefs about science or if they had learned to think more scientifically through pre- and post-questionnaires. The authors compared questionnaires from people who returned data and those who did not return data and found that there was no significant change in their beliefs or knowledge about science. Although they found no difference by examining the questionnaires, the authors decided to examine 750 unsolicited letters that they had received from participants that described the experiments they had conducted. These letters were not part of a formal evaluation, so there are limitations that accompany the use of the letters, but the authors did find evidence that participants engaged in scientific thinking during their participation in the project. After reviewing the letters, the authors identified several different categories of scientific thinking, which included observation, taking action to modify protocols when they were not successful, creating hypotheses, and suggesting improvements. The authors clearly stated that these letters did not indicate that their project caused this type of scientific thinking, but rather the project provided a situation in which people could think scientifically if they were so inclined.

Cronin and Messemer (2013) described a citizen science project that was redesigned to use adult-oriented programming strategies. The researchers felt that the training and implementation of the program was not explicitly planned to address the needs of adult learners and this could have been one reason for the almost 70% attrition rate the program had seen in previous years. In the revised program, the andragogical principles of Malcolm Knowles were explicitly incorporated into the program as a way to effectively help the adult participants improve their civic science literacy, which is defined as having the knowledge and ability to make personal decisions about issues that are science related (e.g., health issues or climate change). See Knowles (1980 and 1989) for more information about andragogical principles and Shen (1975) for more information about how civic science literacy differs from practical science literacy and cultural science literacy. Through self-report on a survey completed by a small sample of participants (n=15), an increase in scientific vocabulary knowledge and science process understanding was seen. Typically, a much larger sample is required to reach statistical significance, but the authors of this study claimed that this increase was statistically significant. This is clearly a very small sample size, but the use of andragogical principles in citizen programs should be explored in order to see if they lead to adult volunteers achieving learning outcomes.

Jordan et al. (2011) did not find that knowledge of the nature of science changed in their participants in an invasive species project even though the topic was explicitly addressed. The authors suggested that an understanding of the nature of science requires time for participants to practice, reflect, test ideas, make mistakes, and revise ideas and that this may not be possible in projects of short duration. They also suggested that this type of deep learning may not appeal to all citizen science participants. Many people may be participating for other reasons (e.g., spending time with family/friends or contributing to a worthwhile effort), but are not interested in the type of activities that are required for deep learning to occur.

Attitudes toward Science and the Environment

The effect of citizen science projects on attitudes has not been extensively measured or reported (Phillips, Bonney, & Shirk, 2012), but there is evidence that concerned citizens who may not normally engage in scientific activities may do so when a project addresses a community's needs. How involvement in these projects changes their attitudes toward science still needs to be investigated (Bonney et al., 2009).

Although attitudes have not been thoroughly researched, Brossard, Lewenstein, & Bonney (2005) researched the topic in participants in The Birdhouse Network project, but no statistically significant change was found in regard to participants' attitude toward science or the environment. Attitude toward science was assessed through a modified version of the Attitude Toward Organized Science Scale (ATOSS), which was developed by the National Science Foundation (NSF). A portion of the New Environmental Paradigm (NEP) scale, which was developed by Dunlap & Van Liere in 1978, was used to assess attitude toward the environment (see Dunlap & Van Liere (2008) for a description of the scale). The authors suggested that they might need to revise the educational materials in order to affect attitudes toward science. Another possible explanation presented by the authors was that a person's attitude toward science is very complex and further studies should be conducted to develop an instrument that can more accurately assess attitudes toward science.

Behavioral Change

Changes in participants' behavior due to citizen science projects is one of the more complex outcomes and is the least understood, but there is some evidence that people change their behavior after participating in projects. Participants who were part of an invasive species project reported their new knowledge led to changes in which plants they chose to purchase for their yards. People have shown an increased involvement in their community and have become more engaged in political issues that relate to projects (Bonney et al., 2009).

Evans et al. (2005) explored how participation in the Smithsonian Migratory Bird Center's Neighborhood Nestwatch[12] program affected how people viewed their own backyard as a habitat for birds and whether this led to changes in behavior. In order for people to fully understand how humans effect the environment, people need to know about the places they live, in addition to being scientifically literate (Evans et al., 2005). Evans et al. (2005) suggested that there are four components to a person's sense of place: knowledge, skills, awareness, and disposition to care. A person's sense of place is connected to scientific literacy and plays a role in whether people choose to get involved in local conservation efforts. The authors suggested that participating in this citizen science project helped people develop a sense of place and led to behavior changes that can benefit the local environment. Through surveys, interviews, and analysis of e-mails and phone conversations, Evans et al. (2005) found that 83% of participants reported that they had an increased awareness of the how birds interact with the habitat in their backyard and 56% changed their behavior in their backyard in some way due to their new perception of their yard as a habitat for birds. Examples of changes in behavior included planting shrubs for nests, planting plants specifically as a food source for birds, keeping cats inside to protect young birds, and refraining from cutting down trees because of the animals that use the tree as a habitat. These are small behavioral changes on a very localized scale, but Evans et al. (2005) suggested that this outcome was one of the most exciting outcomes from the program. It indicated that participation in a citizen science program played a role in connecting people with their environment in a new way, changing their perception of their backyard as a valuable bird habitat, and motivating them to make changes to their behavior to protect the wildlife in the small corner of the world in which they have direct control.

Evans et al. (2005) noted that it will be necessary through future research to identify the key components of programs that motivate people to make changes to their behaviors. The authors suggested that the opportunity for participants to have in-person conversations with the scientists who visited their home to band the birds that the participants observed may have played a role in its success. The authors also suggested that the fact that participants were asked to record very detailed observations of the banded birds and their behaviors helped people to connect more deeply with the birds. More research needs to be done to identify the critical aspects of programs that can lead to the changes in awareness and the disposition to care that Evans et al. (2005) described in their definition of a person's sense of place.

Cosquer, Raymond, and Prevot-Julliard (2012) also conducted research into how connecting people with nature through a citizen science project that takes place in their own backyard can affect their knowledge and beliefs about biodiversity and whether participation led to changes in behavior. They approached their research through the lenses of conservation psychology and the Theory of Planned Behavior, which is a theory that

[12] http://nationalzoo.si.edu/scbi/migratorybirds/research/neighborhood_nestwatch/

describes the connections between a person's knowledge, perception, and actions. See Saunders (2003) and Schultz (2011) for more information about conservation psychology. See Ajzen (1991) for more information on the Theory of Planned Behavior. The authors interviewed 30 participants in the French Garden Butterflies Watch program, which asks members of the public to identify butterflies that they observe in their own gardens and submit the number of butterflies observed to the French National Museum of Natural History. Due to the simple procedures and the fact that the observations take place in a familiar location, the project attracts people who do not necessarily have experience studying butterflies, citizen science projects, or science in general.

Through interviews, Cosquer, Raymond, and Prevot-Julliard (2012) found that people developed ideas and beliefs through the process of regularly observing butterflies in their gardens, which led to new gardening behaviors (e.g., planting certain plants and changing lawn-care practices). The authors also found that the act of observing nature in an everyday setting led to participants considering the functional and evolutionary aspects of nature and proposed that this can help people make a more personal connection with nature. The scientific knowledge gained through participation can help participants develop their own opinions on the nature that they come across in their everyday lives. The authors suggested that it is important for the general public to achieve these outcomes in order to achieve biodiversity conservation goals.

Unfortunately, seeing a change in participants' behavior is not guaranteed even when encouraging people to change their behavior is explicitly included in a project. Jordan et al. (2011) found that most behavior change after participation in an invasive plant project was passive even though promoting behavior change was explicitly included in the program. The authors found that many participants indicated that they did not change their behavior because they felt that their actions would not make a difference. In addition to explicitly promoting behavior change and motivating people to want to take action, it may be necessary to take the time during the project to help participants understand that their individual actions will make a difference on conservation issues (Jordan et al., 2011).

4. Connections to Shedd Aquarium's Learning Framework

There are a multitude of connections that can be made between Shedd Aquarium's Learning Framework and citizen science projects. Table 1 lists existing Learning Framework outcomes appropriate, and possibly suited, for citizen science projects. The table should not be interpreted in a way that leads to trying to accomplish all Learning Framework outcomes through just one citizen science project. When designing a citizen science project, careful thought and planning should be directed toward deciding which Learning Framework outcomes should be addressed through the project. As seen in Table 1, many outcomes across the Learning Framework could be achieved through citizen science projects, making this a rich area for program exploration. In broader terms for the field of informal science education, it is notable that environmental literacy outcomes (in blue), science literacy outcomes (in orange), and 21st century skills (in green) are all potentially achievable through citizen science projects.

Empathy and Curiosity Outcomes - Learners identify basic links between animals - Learners increase their awareness of the needs of animals - Learners identify basic links between animals and people - Learners feel compassion for animals and the living world - Learners recognize behaviors that align with positive environmental values - Learners' interest is piqued and they are curious to know more - Learners want to extend their learning experience and know how to Citizen science projects may allow people to connect with animals and nature in a new way. See Evans et al. (2005) and Cosquer, Raymond, and Prevot-Julliard (2012) for studies that examined how citizen science projects have led to many of these outcomes.
Question and Investigate Outcomes - Learners understand how to use scientific inquiry - Learners generate investigable questions - Learners use investigative tools/techniques to explore questions about the living world - Learners analyze/interpret data to build explanations - Learners communicate the role of science in responding to issues of the living world - Learners understand the value of generating and investigating questions regardless of the answer - Learners develop positive self-perceptions of their ability to engage in science - Learners understand ecosystems and are aware of environmental issues - Learners use science to understand conservation/ecological challenges By participating in citizen science projects, participants have the opportunity to actively engage in one or many aspects of scientific inquiry. See Jordan et al. (2012) for a description of the benefits of incorporating learning and cognition research into the design of a citizen science project to help participants increase their science knowledge, science process skills, and develop scientific habits of mind.
Developing Solutions Outcomes - Learners apply scientific knowledge in an authentic environment - Learners recognize that there is more than one 'correct' answer - Learners apply systems thinking when studying and solving complex problems - Learners understand various stakeholder perspectives in ecological issues Citizen science allows people to work alongside scientists (in person or virtually) and become part of a team that is working together to solve complex problems. See Fernandez-Gimenez, Ballard, and Sturtevant (2008) for information on how citizen science projects have led to participants gaining an understanding of stakeholder perspectives.
Leading Others Outcomes - Learners are aware of and appreciate sustainable practices - Learners have a diverse range of communication strategies and know how to use them appropriately - Learners make information relevant - Learners coach guests and peers to build skills and knowledge - Learners feel comfortable within a variety of social interactions - Learners feel empowered to make change and take ownership Depending on the type of citizen science project, both participants and Shedd volunteers could have the opportunity to take on a leadership role within citizen science projects. Opportunities may be planned to lead and communicate with others as appropriate.

Table 1. Potential connections between citizen science and Shedd Aquarium's Learning Framework

5. Methods for Evaluating Citizen Science Projects

Planning an Evaluation

Careful planning of an evaluation is important in order to accurately document outcomes from citizen science projects. Jordan, Ballard, and Phillips (2012) suggested a process for developing an evaluation plan that ensures that activities are aligned with established learning goals. The authors suggested that designers should carefully consider how to balance data collection goals with the learning goals for the project. The skills and knowledge necessary to achieve basic data collection goals may not be the same as those necessary for broad learning goals such as scientific literacy. If broader learning goals (e.g., scientific literacy) are important to the project, those goals should be explicit and activities should be included that address those goals, even if those activities go above and beyond what is necessary to successfully achieve the scientific goals. Learning outcomes should be defined based on these learning goals and they "should be specific, measurable, attainable, relevant, and timely" (Jordan, Ballard, & Phillips, 2012, p. 307). Project designers may want to include different levels of outcomes in the evaluation plan for volunteers who are engaged to different degrees. The final step of the evaluation plan is to determine the indicators that will be used to demonstrate that participants have achieved the established outcomes. These indicators should be "targeted, feasible, valid, and reliable" (Jordan, Ballard, & Phillips 2012, p. 308).

Phillips, Bonney, and Shirk (2012) recommended the use of backward planning and the development of a logic model to ensure that citizen science project evaluations are rigorous. Through the use of this planning strategy, the long-term impacts and outcomes are determined first, and then the project team determines which activities and instructional strategies are the most appropriate to achieve those outcomes. More information on developing a logic model can be found in Phillips, Bonney, and Shirk (2012) and W.K. Kellogg Foundation (2004).

An Overview of Evaluation Methods

Bonney et al. (2009) described the different methods that were used to evaluate different aspects of the ten projects that the authors reviewed. A summary of how outcomes in these ten projects were measured is shown in Table 2.

Outcome	Methods Used for Evaluation
Science content knowledge, science inquiry knowledge	Self-reports via pre- and post-project surveys that included close-ended and open-ended questions
Potential behavior change	Anecdotal evidence from e-mails, online discussion groups, interviews, and products produced by participants (e.g., installing bird nest boxes)
Attitude toward science	Attitude Toward Organized Science Scale (ATOSS)
Environmental attitudes	New Environmental Paradigm Instrument (Dunlap & Van Liere, 2008)
Ability to collect and analyze water samples	Before volunteers can start monitoring, volunteers submit a split sample for quality control/quality assurance testing and their analysis is compared with analysis conducted by a lab.
Impacts on child participants	Interviews conducted with adult mentors
Participants' knowledge of local ecology	Semi-structured interviews conducted by researcher
Participants' learning and participants' view of what researcher had learned from working with them	Interviews by external evaluator
Effectiveness of the training used to teach participants how to collect data	Questionnaire with multiple choice and some yes/no questions that gave an opportunity for short answer responses

Table 2. Examples of methods used to evaluate potential citizen science outcomes.

An Assessment Rubric for Evaluating Citizen Science Projects

Bonney et al. (2009) found that few programs had undergone a comprehensive evaluation when they conducted a meta-analysis of citizen science projects. In order to assist with the comparison of outcomes between projects, the authors created an assessment rubric for describing impacts of Public Participation in Scientific Research Projects (PPSR). They suggest this could be used by practitioners in the field of citizen science for evaluation, as well as project planning. This rubric (see Appendix) includes six impact categories that are based on the evaluation framework in *Framework for Evaluating Impacts of Informal Science Education Projects* (Friedman 2008), which is the framework that all Informal Science Education projects funded by NSF are required to use. Phillips, Bonney, and Shirk (2012) recommended that the field of citizen science adopt this rubric for evaluations as a way to systematically learn about the outcomes of citizen science projects. See Phillips, Bonney, and Shirk (2012) for an example of how to apply the rubric to a specific citizen science project.

Using Standardized Scales for Evaluating Citizen Science Projects

The Birdhouse Network citizen science project conducted by the Cornell Laboratory of Ornithology was evaluated by Brossard, Lewenstein, and Bonney (2005). The authors took an approach in their evaluation of outcomes that had not previously been used for a citizen science project. The authors used standardized scales, comparisons to national norms, and theoretically-driven evaluation questions in an effort to compare changes in knowledge and attitudes across projects and demonstrate how working within a theoretical framework can help researchers and practitioners develop hypotheses that can advance the field of informal science learning.

Brossard, Lewenstein, and Bonney (2005) examined the impact of participating in The Birdhouse Network citizen science project on participants' scientific knowledge, knowledge of the scientific process, and attitude toward science and the environment. This project allowed volunteers to contribute data to a study on cavity-nesting birds by putting birdhouses in their neighborhoods and collecting data on the birds who nest in the birdhouses. Using the theory of experiential education, the authors hypothesized that participation in the project would lead to an increase in knowledge in bird biology. See Tuss (1996) for more information about the theory of experiential education. Using a ten-item instrument that was designed specifically for this project to assess knowledge of information that was provided to participants, the authors found that participation led to an increase in knowledge of bird biology.

Brossard, Lewenstein, and Bonney (2005) did not find statistically significant changes in participants' knowledge of the scientific process or their attitude toward science or the environment. Knowledge of the scientific process was assessed using one closed-ended item and one open-ended item taken from the Science and Engineering Indicator (SEI) instrument so that responses could be compared to national data collected by NSF. Both items refer to the scientific process in general terms and were not contextualized to The Birdhouse Network project. Before participating in the project, 93% of the participants reported having a clear understanding of the scientific process in the closed-ended question, but only approximately 67% could provide an acceptable answer to the open-ended question that asked them to explain the term "scientific study" (only 36% of the people in the national study could provide an acceptable answer). When answers from the pre-test and post-test were compared, the results showed that participants in the program did not improve their knowledge of the scientific process based on the two questions that were asked. The authors explained that explicit references to the fact that participants were participating in the scientific process were not included in the project, and they suggested project designers should make that goal explicit during the program if a change in knowledge of the scientific process is desired (Brossard, Lewenstein, & Bonney, 2005).

Since Brossard, Lewenstein, and Bonney's (2005) study was not able to show a statistically significant change in participants' knowledge of the scientific process using one open-ended item from the SEI instrument, Cronje et al. (2011) hypothesized that questions from this standardized scale were too general to detect changes in scientific literacy. Their research was designed specifically to compare the question from the SEI (used in the Brossard, Lewenstein, and Bonney (2005) study) with an instrument contextualized to an invasive plant project that they developed to measure scientific literacy. Cronje et al. (2011) were able to document an increase in the scientific literacy of participants using the four-item contextual instrument while the same participants showed no statistically significant change with the one question from the SEI. The reason Brossard, Lewenstein, and Bonney (2005) did not see a statistically significant change in scientific literacy may have been due to the standardized-scale instrument not being sensitive enough to detect change rather than because the intervention was not effective at changing participants' scientific literacy.

Brossard, Lewenstein, and Bonney (2005) decided to use the less sensitive standardized-scale in an effort to allow for comparisons to national norms and to allow for comparisons between projects. While the contextualized instrument used by Cronje et al. (2011) was able to detect a change in scientific literacy, it was developed for a specific citizen science project and may not be effective in other situations. These two studies are a good example of the complex nature of measuring scientific literacy and the need for further research in order to develop instruments that are reliable and valid and can be used to make comparisons between projects.

Methods for Evaluating an Online Project

Evaluating learning outcomes for projects that are conducted completely online can be challenging. Thompson and Bonney (2007) used a mixed-methods approach to evaluate whether new users of eBird had an increased interest in birds and bird watching, used eBird data to learn more about their local birds and compare local populations to other populations, and had an understanding of how eBird data could be used to inform bird conservation efforts. This three-part survey was administered at the time a new user registered to be an eBird participant and then again after eight weeks of participation. The authors employed standard survey questions, but also used more innovative methods to understand participants' ability to utilize data on the website and to learn about their ideas on conservation.

Evaluating Participants' Ability to Analyze Online Data

eBird is a citizen science project that makes the data that is collected easily available to the public. The data submitted by eBird participants is available for the public to view only after it has been validated by an expert. Users can sort through the data by species or location and have the ability to decide how they would like to visualize the data that they are interested in viewing. They can create maps, histograms, and graphs that display the data of interest. Since there is no person-to-person interaction in eBird, Thompson and Bonney (2007) were interested in learning whether new participants actually used data and if they were able to correctly interpret the visualizations that are available on the website. They wanted to know which data new users wanted to view and their plans for using it, as well as whether users knew which data visualization was the most appropriate for their questions about birds. Standard survey questions were used to learn more about how people planned to use data and how they actually used data. In order to determine if users were successfully able to determine the most appropriate data visualization tool, participants were asked to read three scenarios that related to bird distribution or abundance. They were then presented with live eBird data and asked to select the visualization method (e.g., a map, a graph) that was the most efficient way to answer the question posed in the scenario. They were also asked to rate their confidence in their answer. Through this evaluation tool, Thompson and Bonney (2007) were able to learn that people did use the data and visualization tools (including people who had chosen not to submit data themselves). The use of scenarios and live eBird data was an effective way to show that participants struggled with identifying the appropriate data visualization tool to use because many people gave incorrect answers (or chose to skip the question altogether). These results indicated that additional information on how to use the data visualization tools was needed in order to achieve one of the educational goals of the project.

Using Online Personal Meaning Mapping

In order to capture a rich description of eBird participants' views on conservation that could easily be coded and analyzed, Thompson and Bonney (2007) developed an online version of the Personal Meaning Mapping (PMM) protocol that has successfully been used for in-person interviews (see Falk, Moussouri, and Coulson (1998) and Adelman, Falk, and James (2000) for more information on the use and effectiveness of personal meaning mapping). During the online survey, participants were asked to describe what came to mind when they read the word "conservation." They were then presented with a series of text boxes where they could answer the prompt. During the post-test, after eight weeks of participation, participants were given the opportunity to review their original answers that they had entered into the text boxes and could add new thoughts, modify previous ones, or delete any of the text boxes. Thompson and Bonney (2007) found that the use of the online PMM provided them with rich, descriptive responses regarding participants' concept of conservation and that the tool has the potential to be successfully used as an online evaluation tool. The authors felt that the use of multiple text boxes naturally led participants to provide multiple, detailed responses to the prompt that were separated from each other in a way that facilitated coding of the responses.

The administration of the PMM before and after participation was intended to allow participants to demonstrate whether their ideas of conservation changed due to participation in the project; however, too few people made changes to their maps in the post survey for statistical analysis to be done. Thompson and Bonney (2007) suggested several reasons why changes were not made to the maps after eight weeks of participation. The absence of an interviewer may have made it easier for participants to not take the time to review their first map, or they may have found that the three-part survey was taking longer than expected and skipped the map, which was in the last section. When personal meaning maps are administered in museums, changes to the maps after viewing an exhibit have been found to be phrases that were explicitly presented in the exhibit. This type of phenomenon is not applicable to the eBird situation. Finally, the authors suggested that people who register for eBird may already have well-developed ideas on conservation, so major changes may not occur in the eight week time frame between the pre- and post-survey.

After using PMM in this situation, Thompson and Bonney (2007) suggested that revisions to the online version should be made and tested in order to determine if personal meaning maps can accurately detect changes in knowledge and attitudes. One suggestion they had for modifying the format was to provide participants with the ability to drag-and-drop their text boxes on the page so that they can physically arrange them in a similar fashion to how paper personal meaning maps are created. They are continuing to test the online version of PMM with other projects.

Evaluation of a Citizen Science Project funded by the National Science Foundation

Many organizations do not have the time or resources to conduct a full evaluation of their citizen science projects, but several citizen science projects that have been funded by NSF have had the benefit of being evaluated by external evaluators (Randi Korn & Associates, Inc., 2010 and Sickler & Cherry, 2012). The evaluation methods for only one NSF-funded project will be highlighted in this narrative as an example of what more comprehensive, resourced evaluation might yield.

When the Lost Ladybug Project was evaluated by the Institute of Learning Innovation (Sickler & Cherry, 2012), the evaluators used multiple methods to answer questions about whether the project had met its learning outcomes; whether learning outcomes were different for adults than for children; how prolonged participation over multiple years related to outcomes, attitudes, and motivations; and which strategies might encourage people to continue to participate over multiple years.

This project engaged the general public through its website and all training and interactions with this audience took place via the Internet (Sickler & Cherry, 2012). Without the opportunity to administer surveys in person during trainings or data collection days, the evaluators relied on advertising the opportunity to participate in the evaluation through pop-up messages on the project's website. This strategy resulted in 45 questionnaires completed by adults who participated in the program. An invitation to complete the post-test questionnaire was e-mailed directly to adults who had submitted data to the project. This strategy resulted in 353 completed questionnaires, which is a 36% response rate.

The project also engaged informal and formal educators and the elementary school children in their groups (Sickler & Cherry, 2012). These educators included scout troops leaders as well as formal classroom teachers. These leaders had the opportunity to interact with project staff members through in-person trainings and could also receive additional support from staff. Although this support was made available to educators, many chose to train themselves only using the project's website.

In order to determine if outcomes for children were met, the evaluators collected data from children, educators, and parents after the children had participated in the program (Sickler & Cherry, 2012). Children who participated in the project with an educator completed a concept map. The concept maps were analyzed with a rubric that was based on methods used by Falk (2003) to analyze personal meaning maps. Children who were between the ages of 8 and 12 also completed a paper questionnaire appropriate for their age. To help students answer questions, pictures of kids with varying facial expressions and body language were used to help children represent how much they enjoyed participating in the program. Under each picture was a word that described a possible response to how much fun they had in the program. Options ranged from "boring!" to "yeah!" on the scale. Educators also completed a questionnaire that allowed them to report on their perceptions of the students' learning. Adults who indicated that children were in their group were e-mailed a questionnaire so that they too could report on their perceptions of their children's learning. This use of triangulation helped to gather a more complete understanding of the students' learning than just what the students would have reported on their own.

6. The Future of Citizen Science

Citizen science projects have come a long way from the days of recording bird strikes at lighthouses in the 1800s. They are now complex projects with multiple scientific, educational, and societal goals that engage and connect people from all over the world. A continuing effort to formalize the field of citizen science will lead to more strategic efforts to document outcomes in the future. Evidence that this is happening was demonstrated through the first formal conference on the public participation in scientific research (PPSR) in the summer of 2012. The goals for this conference were to take steps to formalize the public participation in scientific research as a field of study and research; stimulate communication, collaboration, and innovation; and develop an organizational structure for the field, which includes a professional association, a journal, and regular meetings. Recommendations that emerged from discussions included formalizing the field through conferences; online tools to facilitate communication, collaboration, and innovation; professional development opportunities; an open-access journal; a code of ethics and best practices; data management and visualization tools; improving access to PPSR for diverse communities; and a shorter name for the field (Miller-Rushing & Benz, 2013). More information about the conference, including presentation slideshows and poster presentations can be found on the conference's web page.[13]

Public aquariums can continue to play a role in citizen science projects that occur in the field, but citizen science projects that take place inside the walls of an aquarium is an area that is worth exploring. Creative citizen science projects that connect the millions of people who visit an aquarium each year with the thousands of animals who live at a public aquarium could provide visitors and volunteers with a unique experience inside an aquarium while also providing an aquarium with valuable information. Projects might include animal behavior studies, water quality studies, or the review of data that has already been collected. Discussions between an aquarium's educators, animal health specialists, animal care specialists, researchers, volunteers, and local teachers could lead to the development of innovative programs that meet the needs of the aquarium's staff members and the community.

Future Research and Evaluation

The aforementioned studies indicate that there is evidence that learning is occurring through citizen science projects, but there is still much to learn about the effectiveness of citizen science projects (Bonney et al., 2009 and Phillips, Bonney, & Shirk, 2012). There is a need to develop a theoretical framework for citizen science to facilitate future research. Phillips, Bonney, and Shirk (2012) suggested several areas of research that may contribute to the formation of the framework, including activity theory (Roth & Lee, 2002), communities of practice (Lave & Wenger, 1991), and the ecological framework (National Research Council, 2009).

[13] http://www.citizenscience.org/community/conference2012/

Research design should be rigorous (e.g., create a control group through the use of a waiting list for a project and randomly assign people to the waiting list) in order to gain a better understanding of which aspects of a project lead to changes in attitudes, behaviors, scientific literacy, and other outcomes (Wells & Lekies, 2012). For organizations that do not have the capacity to design or implement rigorous evaluations, a partnership with a researcher may make more rigorous evaluation possible (Wells & Lekies, 2012).

Gaining an understanding of how and why a particular citizen science project leads to the desired outcomes is an important area of future research (Wells & Lekies, 2012). Conducting research in this area can lead to information that will be helpful for researchers and practitioners in the field. For example, in order to be able to develop citizen science projects that lead to changes in attitudes and behavior, more information needs to be known about the cognitive and emotional processes that lead people to change their attitudes and behaviors (Wells & Lekies, 2012).

With such a wide range of options when it comes to citizen science projects, additional research needs to be directed toward discovering which types of citizen science projects are most appropriate for different people. More information needs to be learned about the specific aspects and strategies of projects that are most appropriate for people of different ages, genders, and communities so that project planning can be more directed and strategic (Wells & Lekies, 2012).

In particular, more research is needed in the area of engaging children in citizen science projects and the specific aspects of projects that can lead to changes in knowledge, attitudes, behaviors, and, ultimately, to a long-term commitment to the environment (Wells & Lekies, 2012). Research has been done on the effectiveness of different interactions with nature, but more research is needed to determine which aspects of the interactions lead to different types of outcomes (Wells & Lekies, 2012). Researchers are also interested in learning if there is a certain time during childhood when nature interactions are most likely to lead to bonding with nature and lead to pro-nature attitudes and behaviors as an adult. Most research regarding children and nature interactions in connection with attitudes and behaviors has been done with classroom-based studies; research within the informal education field of citizen science would add to the research base and potentially help identify if there is a certain age when an experience with nature is more likely to ensure that children are able to make a connection with nature that has long-term effects on their attitudes and behavior (Wells & Lekies, 2012).

There has been a limited effort to use standardized scales in order to make comparisons between citizen science projects, but these scales were found to be too general to detect changes in attitudes and scientific literacy (Brossard, Lewenstein, & Bonney, 2005 and Phillips, Bonney, & Shirk, 2012). New instruments should be created and tested in the setting of citizen science so that reliable and valid instruments can be established, which can then be adapted for specific projects but still allow for comparison between projects (Phillips, Bonney, & Shirk, 2012). A starting point for the development of generalized instruments for citizen science may be found in already established instruments. Wells and Lekies (2012) suggested testing standardized scales from the field of environmental education to see how well they apply to citizen science projects, such as the Children's Environmental Attitudes and Knowledge Scale developed by Leeming et al. (1995) and instruments to assess environmental attitudes and behaviors of elementary school students through interactive games developed by Evans et al. (2007).

Krasny and Bonney (2005) suggested that future research in how citizen science projects support the goals of the field of environmental education should include whether citizen science projects help people develop critical-thinking and environmental decision-making skills and whether projects lead people to make pro-environmental changes to personal behaviors.

Most of the contributory projects that Bonney et al. (2009) reviewed involve audiences that are already interested in science. They did find that there were collaborative and co-created projects that engaged non-traditional audiences when the topics met specific personal or community needs, but they recommended that research needs to be conducted that addresses how people perceive themselves or the ways that they can develop science identities through citizen science projects.

Some research has been done on the motivations people have for participating in citizen science projects (Raddick et al., 2010), but more needs to be done to explore motivations that include altruism, self-improvement, career-related reasons, empowerment, social activities, a connection with nature, and a self-identification with science and scientists in order to get a comprehensive understanding of citizen science (Phillips, Bonney, & Shirk, 2012). Phillips, Bonney, and Shirk (2012) recommended referring to work done by Clary and Snyder (1999), Clary et al. (1998), Lawrence (2006), Falk and Storksdieck (2009), Fraser et al. (2009), and National Research Council (2009) to help guide the exploration of motivations for participation.

Jordan, Ballard, and Phillips (2012) suggested that evaluating learning at the individual level does not go deep enough to show all of the potential impacts that citizen science projects can have at the community level. The authors recommended that a more comprehensive approach to evaluation should be taken in the future that encompasses individual outcomes, programmatic outcomes, and community-level outcomes. They argued that it is at the programmatic and community levels that the impacts of citizen science projects on the environment and human communities can be seen. They suggested that taking this three-pronged approach in the future will help researchers explore the full potential of citizen science projects in terms of the broader impact they can have on socioecological system resilience. These impacts could include improved social capital, community capacity, economic impact, the building of trust between stakeholders, and ultimately to the development of a socioecological system that is more resilient and is better able to adapt to the environmental and societal changes that will undoubtedly occur in the future.

Online Social Networks and Learning Outcomes

Technology has played a critical role in citizen science projects in the past. New technology will influence the future of citizen science projects in many ways, including data collection, data management, dissemination of results, evaluation, and communication strategies (Newman et al., 2012). The incorporation of online social networking opportunities will change the way that participants interact with each other in virtual citizen science projects, as well as in place-based projects. Social relationships can impact an individual's knowledge, attitudes, and behavior, and research needs to be conducted through the use of social network theory to determine if social learning and communities of practice that develop via online social networking associated with citizen science projects can lead to the same types of outcomes that have been documented from in-person social learning (Triezenberg et al., 2012). Although the use of online social networks is increasing in frequency, there is a need to learn more about the details of how social networks work and a careful examination of the characteristics of the participants who use the networks and their interactions in order to help researchers and practitioners understand how to use online social networks to support learning outcomes (Triezenberg et al., 2012).

Including Diverse Communities in Citizen Science Projects

Making citizen science projects available to more diverse communities is an identified need for the field (Porticella et al., 2013; Pandya, 2012; Miller-Rushing & Benz, 2013; Purcell, Garibay, & Dickinson, 2012; and Fitzpatrick, 2012). Currently, most participants are white, middle-class, and highly-educated people, so there is a need to include people of diverse backgrounds in citizen science projects in the future (Porticella et al., 2013). Porticella et al. (2013) suggested many benefits to making citizen science projects more inclusive. Everyone should have the opportunity to benefit from the outcomes of citizen science projects. Underrepresented environmental regions, such as urban areas, currently suffer from a lack of data, which means that environmental issues in those areas are not as well understood and solutions may not be discovered in a timely manner. If more people are engaged in science and become excited about science, a wider range of people will pursue science-related careers, and the field of science will benefit from having people with diverse perspectives working together. Porticella et al. (2013) recommended including the following six practices in citizen science projects to make them more inclusive: "provide concrete benefits for participants; build on what is familiar; develop collaborative partnerships; be flexible and adaptive; offer genuine, equitable, and sustained personal contact with the community; and uncover and address additional context-specific barriers" (p. 4). See Porticella et al. (2013) for details on all six practices and case studies that illustrate them.

Pandya (2012) suggested a framework in order to include diverse communities in citizen science projects. He suggested that community goals should be incorporated into project design from the earliest stages, and this requires getting input from a variety of community members while still defining the research questions for the project and including the community in every step. The scientists and the community members should co-manage the project, and plans should be in place for ways to deal with any conflicts that may arise. The expertise that community members bring to the project should be respected and incorporated when possible. A culture that encourages the sharing of scientific knowledge with the community and the sharing of cultural knowledge with the scientists should be promoted. The results of the project should be shared in a variety of formats that meet the scientists' needs as well as in ways that are more relevant to the community members.

7. Conclusion

Citizen science projects have become a popular way for the general public to become actively involved in scientific research. Well-designed projects have the potential to lead to scientific, societal, and educational impacts. Scientists, educators, non-profits, and governmental agencies have successfully developed and implemented engaging programs, but there is a lack of documentation of the impacts these programs have on the participants. Researchers and practitioners need to continue down the pathway toward a formalized community of practice. A formal community can lead to more effective projects and collaborations, a set of best practices for the field, and a more strategic approach to documenting impacts, which can help citizen science projects reach their fullest potential.

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Appendix: Rubric for evaluating citizen science projects. (Bonney et al., 2009, p. 21-23)

Table 2. Assessment Rubric for Describing Impacts of Public Participation in Scientific Research Projects

Impact category	Stated goal	Potential indicators	Measured outcomes	Inferred outcomes
Awareness, knowledge, and/or understanding (of) [1]				
Content (Concepts)				
Process				
Nature of science				
Careers				
Community				
Engagement or interest (in) [2]				
Content (Concepts)				
Process				
Community				
Careers				
Skills [3]				
Asking questions				
Study design				
Data collection				
Data analysis				
Data interpretation				
Discuss results				
Disseminate results				
Using technology				
Writing				
Community				

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Appendix, continued (Bonney et al., 2009, p. 21-23)

Attitudes [4]				
Toward science				
Toward content				
Toward people				
About activities				
Toward species				
About careers				
About theories				
About community				
Behaviors [5]				
Time engaged				
Time outdoors				
Lifestyle changes				
Within community				
Community involvement				
Citizen action				
Responsible environmental behavior				
New participation				
Other [6]				
Social capital				
Community capacity				
Economic impact				

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Appendix, continued (Bonney et al., 2009, p. 21-23)

Impact Categories

[1] **Measurable demonstration of assessment of, change in, or exercise of awareness, knowledge, understanding of a particular scientific topic, concept, phenomena, theory, or careers central to the project.**

Evidence for participant awareness can be observed through direct assessments, self-reports, or self-reflection.

[2] **Measurable demonstration of assessment of, change in, or exercise of engagement/interest in a particular scientific topic, concept, phenomena, theory, or careers central to the project.**

Indicators of engagement and interest may include length of commitment to, or depth of involvement with, a project or choices to further pursue content knowledge or related activities beyond a project's scope.

[3] **Measurable demonstration of the development and/or reinforcement of skills, either entirely new ones or the reinforcement, even practice, of developing skills. These tend to be procedural aspects of knowing, as opposed to the more declarative aspects of knowledge impacts. Although they can sometimes manifest as engagement, typically observed skills include a level of depth and skill such as engaging in scientific inquiry skills (observing, classifying, exploring, questioning, predicting, or experimenting), as well as developing/ practicing very specific skills related to the use of scientific instruments and devices (e.g. using microscopes or telescopes successfully).**

Indicators of skill development could include a demonstrated degree of proficiency (such as the ability to identify species) or adoption and employment of a science-related skill (for example, prediction, argumentation, or synthesis).

[4] **Measurable demonstration of assessment of, change in, or exercise of attitude toward a particular scientific topic, concept, phenomena, theory, or careers central to the project or one's capabilities relative to these areas. Although similar to awareness/interest/engagement, attitudes refer to changes in relatively stable, more intractable constructs such as empathy for animals and their habitats, appreciation for the role of scientists in society or attitudes toward stem cell research**

Some standardized metrics for evaluating attitudes are available, but many rely on participant self-reports. In the context of PPSR, outcomes may include changing participants' attitudes about the role of science in their lives or communities, or improving attitudes about particular species, resources, or partnering organizations.

[5] **Measurable demonstration of assessment of, change in, or exercise of behavior related to a STEM topic. These types of impacts are particularly relevant to projects that are environmental in nature or have some kind of a health science focus since action is a desired outcome.**

Evidence of behavior change might include participants' self-reported intentions, and longitudinal tracking to determine whether such behavior change has occurred.

[6] **Other**

The NSF framework allows for measuring outcomes that do not fit well into the other five categories. We chose to look for evidence that projects affected participants' views of their communities, both socially and economically, and/or participants' interactions with other people and scientific institutions.

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