Citizen Science and Youth Education

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In June of 2014 the term "citizen science" entered the Oxford English Dictionary. This event was wonderful news for participants, practitioners, and supporters of this rapidly growing blend of science research and science education. What's more, the OED definition resonated well with those who had unofficially defined the term since it came into widespread usage in the mid 1990s. The OED states that citizen science is a noun referring to "Scientific work undertaken by members of the general public, often in collaboration with or under the direction of professional scientists and scientific institutions." Citizen science practitioners might have preferred the definition to be just a bit more specific, for example, the Program Development and Evaluation group at the Cornell Lab of Ornithology has defined citizen science as "The engagement of volunteers and professionals in collaborative research to generate new scientific knowledge." Even this definition is broad, though, so let's unpack it a bit.

First, citizen science is often used to describe projects for which volunteers—who may or may not have any training as scientists—collect data that can be used in organized scientific research. This usage of the term emerged in 1994 from educators at the Lab of Ornithology who sought a name for the Lab's rapidly growing assemblage of projects involving large numbers of individuals collecting data focused on birds (Bonney 1996). Begun in the 1960s with the Nest Record Card Program, these projects were designed to amass data that would help researchers study bird biology and ecology across North America. The projects were built on a longstanding tradition of amateur involvement in natural history investigations that began as long ago as the 17^{th} century (Miller-Rushing et al. 2012).

At the time that the Lab began using the term, public data-collection efforts were relatively few in number. Most of the projects that did exist focused on monitoring the quality of water in lakes, streams, and rivers. Twenty years later, volunteer data-collection projects number in the thousands and their participants number in the hundreds of thousands. Projects cover topics ranging from migratory birds to native bees, from the spread of invasive plants to the timing of plant blooming, and from air quality to noise pollution (see www.citizenscience.org and www.scistarter.com for project listings). Some projects are hypothesis driven, collecting data to address a specific research question. Others focus on environmental monitoring more broadly.

In the Lost Ladybug Project, for example, participants across the United States photograph ladybugs and upload digital images to the project website. The images allow Cornell University entomologists to track distribution and abundance of ladybug species, including some that are extremely rare and others that are increasing in both abundance and range. In JellyWatch, hosted by the Monterey Bay Aquarium, anyone who sees jellyfish, squid, or related organisms on a beach or in the ocean is invited to submit information and photographs to the project's website. Syntheses of these reports help scientists explore potential causes of jellyfish blooms, examine the effects on ocean ecosystems, and identify consequences of tourism, industry, and fisheries. And for CoCoRahs (the Community Collaborative Rain, Hail, and Snow Network), participants across the country monitor the amount and timing of precipitation occurring in their communities. The information that they collect can help to assess the danger posed by rising levels of rivers and streams.

The scientific value of these types of projects, which yield new knowledge by collecting and analyzing vast quantities of data, is easily measured by the rapidly growing number of peer-reviewed publications based on volunteer-collected information. A summary of the current state of citizen science as a tool for ecological research is provided by Dickinson et al. (2012), and listings of published citizen science papers are available at www.citizenscience.org.

The rapid growth of citizen data-collection projects over the past 20 years has been fueled in large part by development of the Internet, which has substantially increased project visibility, functionality, and accessibility. People who are interested in a subject—such as ladybugs, jellyfish, or rain and snowfall—can quickly locate a relevant citizen science project, follow its instructions, submit data directly to online databases, and in many cases view and use data collected by fellow participants across the continent or even around the world.

Development of the Internet also has allowed a second form of citizen science to emerge based on the concept of crowdsourcing. In 2007, for example, a project called Galazy Zoo began enlisting the public in classifying images of space that were captured by the Hubble Space Telescope. In the project's first year more than 150,000 people classified more than 50 million images, a task that scientists never would have been able to accomplish on their own. Following this lead, citizen science projects that were focused on data transcription, management, and interpretation quickly became popular as new projects were developed to explore the surface of the moon, to model Earth's climate using historic ship logs, and to explore the ocean floor. Participants in these projects, while not collecting data of their own, are contributing to scientific discoveries by helping to analyze what would otherwise be unmanageable amounts of data. Like data-collection citizen science projects, data transcription and classification projects also are yielding a huge number of scientific papers. Data-management projects run by the Citizen Science Alliance, for example, have now yielded more than 50 peer-reviewed articles on topics ranging from galaxies to oceans (Smith et al. 2013).

A third type of citizen science focuses on community-based projects with regional or local emphasis. Often called "Community Science," projects in this category involve data collection but typically have goals for environmental management or ecojustice. Often developed by members of the public who reach out to scientists for assistance, community-based projects can yield powerful outcomes. For example, the West Oakland Environmental Indicators Project empowered individuals living in a very poor neighborhood to collect air-quality and health data documenting the degree to which air pollution affects local residents (West Oakland Environmental Indicators Project 2013).

Yet another concept of citizen science is described by Alan Irwin in his 1995 book *Citizen Science: A Study of People, Expertise, and Sustainable Development*. In contrast to the definition of citizen science as the engagement of volunteers and professionals in collaborative research, the goal of citizen science championed by Irwin seeks to bring the public and science closer together, to consider possibilities for a more active "scientific citizenship," and to involve the public more deeply in issues related to risk and environmental threat. Some data-driven citizen science projects do have objectives for achieving better linkages between science and society and even "democratizing" science, such as the West Oakland Environmental Indicators Project mentioned above. We do not focus on this type of citizen science in this paper.

The potential of citizen science for youth-focused Informal Science Education

By its very nature, citizen science involves participants in one or more steps in the process of science. The practice therefore provides significant opportunities for youth science education, particularly in the realm of inquiry, in both formal and informal learning environments.

Consider two important documents, *A Framework for K-12 Science Education,* which established the framework for The *Next Generation Science Standards (NGSS).* Relevant in informal educational settings as well as the formal environments that they were designed to address, these documents present the vision that to maximize science learning, students should integrate content knowledge with experiences in the practices of scientific inquiry. In addition, both the standards and framework call upon educators to cultivate students' scientific habits of mind, to develop their capability to engage in scientific investigations, and to teach them how to reason in a scientific context. The overall goal is to nurture students' appreciation for the wide range of approaches used to investigate, model, and explain the world. Citizen science projects—because they are real-world scientific investigations intended to address authentic science questions—seem ideal for realizing this goal (Trautmann et al 2013).

For example, citizen science participants can use protocols to collect data that feed into projects of importance in their local communities and beyond. Data collection can be as simple as looking out a window and recording what birds come into view or as complex as capturing and tagging turtles for mark and recovery studies. It can take place in a single event or a series of samplings across several seasons or years. Data can be collected in virtually any setting—urban or rural and with or without access to field or laboratory facilities. And when participants collect and submit data to centralized databases, they can view their information within a broader context of data submitted by others.

But collecting data is only one step in scientific research, and ideally participants' efforts will not end there. By engaging in a full inquiry process they can personally discover the multifaceted nature of scientific research as they analyze and interpret data sets to answer questions that they have posed for investigation. Such work can take place in classrooms under the tutelage of a teacher, in youth groups under the mentorship of a volunteer leader, or in backyards as self-directed explorations.

So how does an educator engage with citizen science? In most settings, whether formal or informal, designing a new citizen science project that has measurable outcomes for both education and science is not feasible because the development process is complex and time consuming. Fortunately, educators do not need to design new projects because opportunities abound to adopt or adapt existing projects appropriate for specific audiences and settings. Listings of citizen science projects are available on the aforementioned scistarter.com and citizenscience.org. In addition, resources for educators who wish to incorporate citizen science into their teaching are becoming increasingly available, such as the NSTA Press book "Citizen Science: 15 Lessons that Bring Biology to Life" (Trautmann et al 2013).

However, the extent to which any given citizen science project can be used to effectively achieve educational outcomes depends heavily upon the degree to which the project was designed with educational outcomes in mind. Many projects are designed primarily to collect or manage data for scientific purposes. Such projects usually provide participants with guidance in project procedures, such as reading materials or instructional videos, to ensure consistency in data collection and accuracy in data analysis. However, most projects do not include specific learning objectives or lesson plans. A skilled and experienced educator can often use such projects as a springboard for teaching, but leaders with less experience may be lost when attempting to employ these projects as teaching tools.

A handful of citizen science projects have developed curricula or lesson plans that can be highly effective in teaching. Most of these involve collecting data that are submitted to a larger, "parent" citizen science project. Examples include BirdSleuth, which supports the Cornell Lab of Ornithology's citizen science projects (www.BirdSleuth.org); Monarchs in the Classroom, which supports the Monarch Larvae Monitoring Project (www.monarchlab.org); and the Nature's Notebook Curriculum, which supports the National Phenology Network's Nature's Notebook (www.usanpn.org/educate/nn_curriculum). Some projects are stand-alone efforts that collect important scientific data but are designed to achieve specific educational goals, such as Vital Signs (www.vitalsignsme.org) (Crowley et al. in press). Often citizen science projects aimed at youth are designed for classroom use but can be employed in informal settings.

That said, successful implementation of any citizen science project to achieve educational outcomes is also dependent on the abilities of the facilitator, particularly if the objective is to achieve true inquiry skills. We know that many classroom educators feel inadequate to facilitate open-ended student investigations (Capps et al. 2012), and this issue is probably exacerbated in informal settings where facilitators, for example 4-H or Scout leaders, may never have had the opportunity to conduct scientific investigations on their own. Currently the Lab of Ornithology is intensively testing its BirdSleuth curriculum in informal settings with support from the Noyce Foundation. Interviews with 4-H educators involved in this project have revealed a general discomfort with facilitating youth participation in citizen science, even for a project with well-developed lesson plans. Specifically, educators desired a stepping stone to inquiry, not just to help youth develop initial capacity for participating in the activities, but also to help adult educators develop that capacity as well (Enck 2014).

Prevalence of Citizen Science in informal settings

At this point we lack a clear understanding of the extent to which educators in informal settings across the country are implementing or attempting to implement citizen science with the youth they mentor and serve. Currently the Lab of Ornithology and the Citizen Science Association are working to develop methods of capturing this information and making it available on www.citizenscience.org. In the meantime, we must rely on published documentation of project outcomes to understand both the impacts and scope of citizen science participation.

Unfortunately such documentation is scarce. A literature search about impacts of citizen science participation for youth--either in formal or informal settings--conducted through Google Scholar, Summons Article Search, and a solicitation posted on the Citizen Science Association listserv, turned up fewer than 10 relevant publications. These papers do document some learning outcomes achieved from citizen science participation and also point to the potential of citizen science for achieving additional learning outcomes. Findings from some of these papers are summarized below. We have focused on project outcomes in informal settings but also have included a few results from projects based in formal settings, partly to provide a more comprehensive review and partly because at least some of the outcomes are likely transferable to informal settings, particularly settings in which youth are being mentored by some type of leader/educator.

Learning Impacts from Citizen Science participation

If learning is defined broadly to include changes in knowledge, attitudes, behaviors, and accumulated life experiences (Dillon 2010), learning is clearly occurring through the informal educational opportunities afforded by participation in citizen science projects. Even if learning is defined more narrowly to focus on science content knowledge and understanding of scientific reasoning skills (Zimmerman 2000), participation in citizen science undoubtedly has the potential for much learning to occur. Still, questions remain about what specific learning outcomes have been documented, what methods have been used to assess outcomes, and whether what is learned is useful in an applied way in the everyday lives of learners.

Data-collection projects

eBird/BirdSleuth. eBird engages the global bird-watching community to collect more than 5 million bird observations every month and to submit them to a central database where they can be analyzed to document the abundance and distribution of bird populations (eBird.org). The data submitted by eBird participants, including students and other youth participants, help researchers to better understand bird distribution, abundance, and habitat requirements—crucial information in determining population trends and conservation needs.

Many leaders who employ eBird in educational settings do so by using BirdSleuth, which is a standards-based curriculum based on eBird and designed by the Lab to involve middle-school students in citizen science projects and inquiry investigations (BirdSleuth.org). Students begin by learning how to identify a few local birds and progress into making observations, asking questions, and conducting observations. They can use the eBird database to find out about their local birds either before or after conducting their own observations, and they can contribute their bird observation data to the growing database generated by bird watchers throughout the world.

At the heart of BirdSleuth is a set of free downloadable lessons, called Investigating Evidence, designed to help teachers guide students through independent investigations focused on birds (Schaus et al. 2007). Whether using their own bird observations or looking for patterns in online data collected by others, BirdSleuth encourages students to develop their own research questions and then to design and conduct an investigation addressing a question of their choice. Students have done everything from playing recordings of animal sounds (such as lions) near feeders to dressing up as trees and bears to see how close they can get to a flock of birds. The Lab publishes the most innovative student research reports in its publication *BirdSleuth Investigator.*

Viewing citizen science data provides opportunities for students to observe patterns and trends, develop inferences, and discuss various interpretations of the data. Students can even conduct investigations exclusively using online data. Also, once students start monitoring local birds or conducting investigations with online citizen science data, many become inspired to undertake habitat improvement or other conservation projects (Trautmann et al. 2013). Says Phil Kahler, a teacher who uses the project with his middle school classes in Orgeon, “It is especially exciting to see how citizen science motivates my students. They know their bird observation data can answer real-world questions, and they are contributing to the global scientific community. The opportunity to publish their results in *BirdSleuth Investigator* strengthens this tie to real science for my students” (Trautmann et al. 2012). Kahler also states “Citizen science makes us all more aware of our environment—both the good and the bad parts of our environment.” He has seen that this awareness can create personal interest and responsibility by “getting youth to ask really good questions about how we’re treating the Earth and whether we are being good stewards” (Fee and Trautmann 2012).

BirdSleuth was developed through funding from the National Science Foundation (DRL-0242666), and an early version of the curriculum received summative evaluation. The final evaluation report showed that students who participated in the project demonstrated increased knowledge of bird biology, communication, and identification. They learned to use a field guide as a tool for obtaining information about bird species. Students’ definition of hypothesis became somewhat more refined, and they showed understanding of key features of scientific investigations and the nature of science research. Overall they enjoyed the curriculum and felt that they would like to count and study birds again in the future (Thompson 2007).

Currently the Lab is intensively testing the BirdSleuth curriculum in a variety of informal learning environments beginning with 4-H. Learning outcomes from this work will be measured with tools validated for citizen science* starting in the spring of 2015, which will begin to provide the field with quantitative data on outcomes for youth participating in bird-related citizen science in informal settings.

***Measuring Impact**

Through a project called DEVISE (Developing, Validating, and Implementing Situated Evaluation Instruments), researchers at the Lab of Ornithology have been working for three years to define potential learning outcomes for adult citizen science participants and to develop and validate instruments and techniques for measuring such outcomes. This work has included extensive communication with citizen science practitioners and has resulted in identification of the following constructs as achievable and measurable citizen science project outcomes:

Interest in science
Self-efficacy for science
Motivation for science
Perceptions of science
(Developed) Skills of science
Data interpretation

Scales to measure achievement of these constructs are just now being released to the informal science education community, therefore, few citizen science projects have used them to assess or evaluate outcomes. In fact, few projects have sought to measure learning outcomes in any methodological way. However, as the scales begin to be more widely used and as we begin to adapt them for use with youth audiences, we hope they will help to collect outcomes data that will be useful in assessing the overall impacts of citizen science participation.

Monarch Larva Monitoring Project. The Monarch Larva Monitoring Project involves citizens in collecting data to help explain the distribution and abundance patterns of monarch butterflies during the breeding season in North America and to inform monarch conservation (www.mlmp.org). The audience comprises all ages and demographics. Participants choose and describe monitoring sites, which include backyard gardens, abandoned fields, pastures, and restored prairies located throughout the monarchs’ breeding range (mainly the eastern half of the

United States and southeastern Canada). Then they conduct weekly surveys of monarchs and milkweeds, which they enter into an online database. Summaries of the data are made available online and through an annual newsletter.

MLMP staff have collected numerous comments that show the importance and significance of the project for its participants. For example, a high school student from Minnesota stated, “It is amazing to me that when people all over the country take a little time every week, and even more in some cases, to count butterfly eggs, the end result is a network of data that can help us decipher where the butterflies go and when and how … This is real life proof that when everybody works together, things can be done.” Another student stated, “MLMP has given me the opportunity to learn how a truly massive research project functions, but has also let me understand how important every piece of data is, no matter how small, when needed to reach a conclusion.” Still another student states, “The MLMP has helped me become a better scientist in so many ways. Most importantly, it gave me a large interest in science. It encouraged me to ask questions such as why and how and to find these answers through experimenting.”

MLMP also has been assessed through an evaluation that focused on understanding the impacts of the project on children who were being mentored by an adult participant (Kountoupes and Oberhauser 2008). The researchers used quantitative surveys and qualitative interviews of 52 adults who involved youth in MLMP activities. Overall, adults reported that children seemed to enjoy most of the field activities (e.g., finding caterpillars or eggs, rearing larvae, being outside, identifying eggs or instars), but that youth did not like (or simply did not participate in) data entry. Interviews revealed that most adults who worked with youth believed that the youth were learning about science and about the nature of science. Interview data also highlighted the importance of the social aspects of the program; the shared experience allowed children to meet new friends with like interests while enjoying time together in the outdoors. One interviewee described the experience for her group of children as “science bonding.” Another emphasized a need for alternatives to sports-centered recreation, describing children’s thirst for learning about nature. Evidence offered by adults in the interviews is open to various interpretations regarding youth outcomes, however, as youth themselves were not interviewed or observed.

Project Butterfly WINGS: Winning Investigation Network for Great Science. WINGS was a 3-year citizen science project focused on butterflies and developed by the Florida Museum of Natural History. Its main goals were to involve youth in generating knowledge about science in general and butterflies more specifically and to utilize butterfly data collected by youth to support research by entomologists. The project was designed as a student-scientist partnership implemented through 4-H in Florida, Oklahoma, and North Carolina. The bulk of the 4-H settings where it was used were after-school programs, with some traditional 4-H clubs and summer camps.

A summative evaluation of the project was prepared by the Institute for Learning Innovation (Koke et al. 2007). The mixed-methods approach included surveys of participating youth (n = 186 returned questionnaires), youth focus groups (11 individuals aged 8-15 in 3 groups), and telephone interviews with 4-H leaders (20 leaders trained in use of program materials). Overall, the authors concluded that “while WINGS appears to be successful in connecting its participants with the natural world, it would appear that it did not fully achieve its “real world science” goal… Youth did not perceive this program strongly as science-based, but rather an opportunity to do cool stuff outdoors with their friends. They could more easily articulate a deeper connection to nature and the natural world, than to “science” – something they stereotypically likened to performing chemistry experiments in a laboratory.” However, most youth (62%) did report that participation increased their interest in science, and many reported that it helped them think more positively about science.

Data-classification projects

Like data-collection projects, many data-classification projects are intended not only to achieve scientific goals but also to help participants learn scientific information and develop positive attitudes toward science while participating in the scientific process. However, few evaluations of such projects exist, and none appear to be focused on youth. Participants in a project called "Citizen Sky" (mean age 41) have demonstrated a positive change in scientific attitudes, apparently related to their engagement in the project's social activities (Price and Lee 2013).

Community-based projects

Barnegat Bay Partnership. This partnership is a hybrid formal/informal education project involving a 9th grade biology class and a local watershed group who partnered to engage in all aspects of a social-science investigation of willingness-to-pay for restoration services in the greater Barnegat Bay area of New Jersey. The research idea originated with the students, who also established hypotheses and chose and implemented research methodologies after they investigated several possibilities. They analyzed their results, drew conclusions, and wrote and published a research paper in the journal *Ecological Economics* (Nicosia et al. 2014).

Based on pre- and post-tests, Nicosia et al. (2014) found increases in participating students' self-reported levels of content knowledge about science, ecology, carbon cycling, human population growth, ecosystem function, conducting a scientific investigation, asking questions, participating in an ecology project, and sharing scientific information with others. Conversely, no changes were found in students' self-reported levels of topic/content knowledge about visiting the outdoors or collecting and analyzing data. Pre- and post-tests found no change in students' interests in any of the topics listed above.

Educators have sometimes balked at implementing collaborative and experimental activities that are characterized as having uncertain outcomes based on a belief that such activities will "… have a negative impact on standardized student assessments" (Nicosia et al. 2014: 150). Therefore, it's important to note that in addition to the gains in self-reported learning from the perspective of students who participated in this project, their teacher reported that they did just as well on standardized science tests as students from previous years.

Among several positive stated conclusions were these two caveats to consider: "… these findings indicate that engagement in real-world scientific investigations may have no, or even negative [but not statistically significant], impacts on student motivation to engage with scientific content and investigation, possibly due to the considerable amount of work, focus, and prolonged engagement required when conducting scientific research" (Nicosia et al. 2014: 150).

Perhaps most informative were comments in a foreword to the journal article crafted by students. "It was a first-hand exposure into what the world of science is like – something very different than what we had originally imagined" (Nicosia et al. 2014:145). Students' initial efforts to draft the journal manuscript were particularly challenging, "… essentially leading to a jumble of sections filled with pretentious scientific jargon that masked a lack of understanding on the part of many students" (Nicosia et al. 2014:145). "Overall, the opportunity provided us with our first exposure to 'real science'. Before this project, all the 'science' we had conducted was predetermined, with a correct outcome. To discover new scientific knowledge was far more challenging but also rewarding because we learned that science is a process, and not just results" (Nicosia et al. 2014:146). "The experience as a whole was eye-opening and intriguing, revealing to us all how science can be used to address problems, make policy decisions and better understand the interactions between the environment and society" Nicosia et al. 2014:146).

MAD Science in Urban After-school Programs. Heggen et al. (2012) assessed outcomes associated with a collaborative project developed as an after-school intervention for at-risk and under-served middle-school students (the project took place at a large school in an urban area, although the city and state are not specified). The goals of the MAD Science project were to increase children's engagement with technology, increase engagement with and knowledge of science, and increase their desire to pursue education and a career in a science or technology field. Adult volunteers who worked with the after-school program were generally professionals from within the local community who acted as mentors to youth who were their apprentices. "Each apprenticeship runs for 1.5 hours, one day a week, for ten weeks" (Heggen et al. 2012:88). As part of this apprenticeship, youth were exposed to a MAD curriculum based on the idea of participatory sensing, which "… can be viewed as an extension of PPSR that incorporates the use of digital sensing technology and software applications to capture, report, and analyze data samples" (Heggen et al. 2012:88).

The evaluation included 21 students (16 male) from 6th-8th grades. Heggen et al. (2012:89) describe the program in this way:

> Throughout the apprenticeship, the students applied the scientific method within the context of a participatory sensing data collection campaign. Students identified issues within the local community and put forth a hypothesis about the cause and a possible solution. Students then identified what data would be needed to evaluate the hypothesis, and created a participatory sensing campaign to collect the needed data. In doing so, students formulated the requirements for a participatory sensing application to support the

> data collection campaign, which was then implemented by our research team and deployed on mobile phones to enable data collection by the students. Once data was collected using the participatory sensing application, students analyzed how the data supported or refuted the hypothesis. At the end of the apprenticeship, the students demonstrated their acquired skills and knowledge to their friends and family.

A majority of the students developed a "participatory sensing campaign" focused on water pollution in a local watershed. The remainder of the students developed a project focused on showing that certain physical activities require a person to exert more energy than other activities. In both cases the MAD Science research team developed and implemented a smart-phone app that allowed students to collect the kinds of data they had determined were necessary to examine the hypotheses they had developed for their project. Students subsequently analyzed and interpreted data they collected. Finally, in the last week of the program, they presented their findings to their friends, families, and other community members.

Participating students completed pre- and post-project questionnaires to assess the impact of the project. Questions in these surveys focused on engagement in science, engagement in technology, and attitudes toward education and careers in both science and computing. The apprenticeship experiences "… had a small but positive effect on the students' engagement with computers … and the students viewed technology more favorably by the end of the apprenticeship" (Heggen et al. 2012:92). Further, use of computers and smart phones for various tasks increased over the course of the program.

The authors found almost no change in engagement with science due to participating in MAD Science, but they also reported high levels of interest and affect about science in the pre-participation survey. They also found that participating students typically had much higher grades in science compared to non-participants, indicating that some self-selection by already interested and motivated students may have occurred. Interviews with after-school staff members provided some anecdotal evidence that participants became more engaged in science during the project. Finally, the evaluation revealed that "… students viewed STEM-based learning more favorably after the apprenticeship … and students understand that computing is an attainable long-term goal" (Heggen et al. 2012:94).

Characteristics of projects successful in impacting school-aged children

One conclusion from our review of the effectiveness of citizen science in achieving documented learning outcomes for youth is that the promise is so far greater than the reality. At least two facts could contribute to this finding.

First, few citizen science projects currently support or provide opportunities for the practices of scientific inquiry to develop. In many projects, providing educational supports for learning are not a priority. Practitioners who design and implement citizen science projects need to understand that learning doesn't just "happen" via project participation. For example, citizen science participants are unlikely to change their attitudes toward science unless their participation includes reflection about their role and how it relates to the processes of science.

Second, individuals who design and implement citizen science projects currently do not have easy methods for assessing the outcomes of their projects. As the field of citizen science grows and matures, more assessment tools such as those being developed by the DEVISE project at the Lab of Ornithology should make it easier for practitioners to both design projects for maximum educational effectiveness and to measure whether educational objectives are being achieved.

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