ENGAGEMENT AND LEARNING IN ENVIRONMENTALLY-BASED CITIZEN SCIENCE: A MIXED METHODS COMPARATIVE CASE STUDY

A Dissertation

Presented to the Faculty of the Graduate School

of Cornell University

In Partial Fulfillment of the Requirements for the Degree of

Doctor of Philosophy

by

Costanza B. Phillips
December 2017

ENGAGEMENT AND LEARNING IN ENVIRONMENTALLY-BASED CITIZEN SCIENCE: A MIXED METHODS COMPARATIVE CASE STUDY

Costanza B. Phillips, Ph.D.

Cornell University 2017

Citizen science has existed for centuries, but in its modern form is broadly defined as the intentional engagement of the public in scientific research. The potential for achieving learning outcomes in citizen science is great, but there is a need to first understand what those potential learning outcomes are and how they have been studied within the field. Further, engagement in citizen science can take many forms and it is argued that deeper engagement with the science process yields deeper learning outcomes. However, few studies have examined engagement deeply and fewer still across multiple projects. The ways in which people engage in citizen science and how their engagement relates to learning, is largely unknown.

Using a mixed methods comparative case study approach, this research first describes an empirically derived conceptual model for articulating learning outcomes within citizen science that includes the following constructs: interest in science and the environment; efficacy for learning/doing science and environmental action; motivation for learning/doing science and environmental action; understanding of the Nature of Science; skills related to science inquiry; and environmental stewardship. Next, five dimensions of engagement—motivation, behavioral, cognitive, affective and social—are explored qualitatively through interviews with 72 citizen science participants from six different projects. Lastly, using data from an online survey with more than 1,500 respondents from the same six projects, the dimensions of engagement are quantified and analyzed for their association with three learning outcomes: self-efficacy, skills of science inquiry, and environmental stewardship. Triangulation of datasets reveal that participants in co-created projects are more likely to be driven by extrinsic motivations than participants in contributory projects. Aggregated across the dataset, the three most common project activities include: gathering data, submitting data, and sharing information about the project with others. Quantitative data analysis reveals that higher levels of reported behavioral engagement has a positive, statistically significant relationship with self-perceived skills of science inquiry. Other positive statistically significant associations were detected, but the strength of the relationships varied across projects, project types, and project structures. This work lends empirical evidence for theorizing about the nature of learning and engagement in citizen science.

BIOGRAPHICAL SKETCH

Costanza "Tina" Phillips was born in a small town outside of Bari, Italy in 1969. When she was five years old her mother, father, and older brother and sister moved to the United States and took up residence in Baldwin, NY, a small town in the southeast of Long Island. Although Tina does not recall a childhood surrounded by nature, she has vivid memories of tending to rabbits with her parents, digging for clams with her cousins, and watching "Wild Kingdom" with her father. She became deeply interested in great apes and like so many women of the time, saw Jane Goodall as her role model.

Shortly after beginning her undergraduate Biology program at the State University of New York at Stony Brook, she landed a job with Dr. Ivan Chase, helping to study fish dominance hierarchies in his lab. This led to a research assistant position at the Primate Laboratory in the Department of Ecology and Evolution at Stony Brook, led by Dr. Randall Susman. While the goal of the lab was to study the evolution of bipedalism in humans, Tina's role was to maintain the trust of two chimpanzees, Kim and Toya, who were on loan from the National Institutes of Health, so that they did not become too dependent on each other and too fearful of humans. Tina remained at the Primate Lab for two years, learning from and playing with Kim and Toya, as well as the other primates - Tony the Baboon, Gibby the White-handed Gibbon, and numerous Japanese Macaques.

Shortly after graduating, Tina landed a job as a summer camp counselor at the world-famous Bronx Zoo. This opportunity tested her ability to communicate with the public and engage urban youth in science and nature during the height of summer. Following that summer, she landed a job at the Calusa Nature Center in Fort Myers, Florida as an educational naturalist, where she continued to hone her public speaking skills (while handling alligators and snakes!) and add to her natural history knowledge.

During the summer of 1993, Tina headed out west to Steamboat Springs, Colorado to spend time with her best friend Merrie, ski, and enjoy the scenery while she contemplated graduate school. She ended up landing a job as a wildlife technician with the United States Forest Service where she hiked the Routt National Forest daily, documenting evidence of threatened and endangered species. When summer waned, Tina worked in the Education Department helping to create field guides and outreach materials. By all accounts this was a dream job! It was in Colorado that she met her future husband Jamie, and also had the opportunity to spend a summer on safari in Botswana, Africa, a long-held dream since she was a child.

In 1997, she and her husband Jamie got married in Colorado and soon after, moved back east to be closer to family and start one of their own. Tina obtained a job at Cornell's Department of Natural Resources where she entered survey data, and occasionally tagged Atlantic sturgeon in the Hudson River. During this time, Tina made inroads with the Cornell Laboratory of Ornithology, and in 1998, became a staff member in the burgeoning Citizen Science program under the tutelage of Rick Bonney. The following year she gave birth to her daughter Jessie, and in 2003, her son Casey. Working in the citizen science program allowed Tina to keep a foot in both the science and education camps and greatly influenced her decision to apply to graduate school. While working full time at the Cornell Lab, Tina obtained her Master's in Education from Cornell in 2011, and completed her PhD dissertation in 2017.

When not bound to her computer, Tina can be found spending time with her family, cheering on her son at soccer games, hiking with her dogs, skiing, birdwatching, gardening, and enjoying the light of sunsets every chance she gets.

This dissertation is dedicated to my children
Jessica and Casey.
May you grow to understand and appreciate the power of education.

ACKNOWLEDGMENTS

This dissertation represents at least seven years of effort as a doctoral student and full time employee at the Cornell Lab of Ornithology. As such, many people and organizations need to be recognized for helping to make this long held dream a reality. First, I'd like to thank my committee members, Mark A. Constas, Bruce Lewenstein, and Nancy Wells. Your patience throughout this long process and the derailments caused by my personal life, as well as your expertise and critical feedback, have provided the necessary supports to complete a scholarly piece of work to completion.

This work would also not have been possible without Funding from the National Science Foundation for both the DEVISE (NSF DRL-1010744) and EESIP (NSF DRL - 1323221) projects and internal support from the Cornell Lab of Ornithology. The Cornell Lab has given me incredible latitude and autonomy to examine questions of science, learning, and engagement in citizen science, and I consider myself extremely lucky to work in such a flexible and supportive work environment.

Several individuals working with me on these projects need special attribution. Matthew Minarchek and Marion Ferguson made valuable additions to the conceptual model for articulating and evaluating learning outcomes. The DEVISE Advisory Board made important contributions to my early thinking about learning outcomes within the landscape of adult informal science learning. Particular thanks go to Joe Heimlich who was pivotal in providing me with a crash course in psychometrics early on in the DEVISE project, and along with Leslie Goodyear and Kate Haley Goldman, for holding my methodological feet to the fire during the EESIP work. Much of the statistical analyses in the 4th chapter were greatly aided by the consultation of Erika Mudrak of the Cornell Statistical Consulting Unit. Immense thanks go to Holly Faulkner who has been integral to so many aspects of the EESIP project from meeting logistics to survey administration to data visualization. Holly you are a gem! I am incredibly grateful to my friend and colleague Heidi Ballard who has served as an ad hoc committee member and has pushed me to think like an academic, while also having fun. My sincere thanks to each of the project leaders that served as advisors and partners in the study: Robyn Bailey, Karen Oberhauser, Eva Lewandowski, Cora Lund, Nolan Doesken, Noah Newman, Chris Bowser, Julie Vastine, and Jessica Hendricks. I am thankful to the citizen science participants who agreed to be interviewed and to those that responded to the online survey and who continue to contribute their time to science and their communities. I am indebted to Rick Bonney, arguably the father of citizen science, who has been instrumental to this effort from the beginning and has informed much of my thinking about citizen science over the last decade or more.

Lastly, I am forever grateful to my children Jessica and Casey and my husband Jamie for their unequivocal support for me since this work began. Despite the traumatic events that our family has endured over the years, during the times when I wanted to quit, you encouraged me to keep going. You reminded me why I was doing this and how far I had come. You convinced me I could keep going and that I could finish. Thank you for maintaining confidence in me when I wasn't able to provide it myself. Jamie, thank you for always being my rock and serving as both mom and dad when I was unavailable and for helping to quell my eternal, maternal guilt. I love you all dearly and could not have done this without you!

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER I

STUDY OVERVIEW

"Never doubt that a small group of thoughtful, committed citizens can change the world; indeed, it's the only thing that ever has."
— Margaret Mead

INTRODUCTION

For centuries, science has had a broad appeal to individuals interested in the weather, astronomy, fossils, birds, and plants, for example (Miller-Rushing et al. 2012). This phenomenon is underscored by the fact that before the professionalization of science, most scientific endeavors were conducted by private citizens who had a keen interest in understanding and describing the natural world (Ziman 2000). During the last several decades, opportunities to formalize such interests have resulted in the modern form of citizen science, whereby members of the public intentionally engage in scientific research (Cooper 2016). In 2014, the Oxford English Dictionary offered the first formal definition for citizen science: **"***scientific work undertaken by members of the general public, often in collaboration with or under the direction of professional scientists and scientific institutions***."** Spurred on by the growth and availability of the Internet and mobile technologies (Baker 2016, Bonney et al. 2014, Kullenberg and Kasperowski 2016), citizen science leverages the collective crowd to gather data at geographic and temporal scales unattainable through traditional methods that address real-world issues from astronomy to public health to zoology (Dickinson and Bonney 2012, Devictor et al. 2010, Theobald et al. 2015, McKinley et al. 2016).

In addition to the production of new science knowledge, many citizen science projects also seek to influence learning outcomes such as those aimed at improving knowledge, skills, and attitudes toward science and the scientific process, and promoting environmental stewardship practices. While some projects have successfully demonstrated an increase in participants' understanding of science content (see Bonney et al. 2016 for examples) and science process (Trautmann et al. 2012, Trumbull et al. 2000), there is a deficit in our understanding of what learning is intended and observed and how it is supported writ large across the field. This deficit may be due in part to the absence of a unifying theoretical lens within which to study learning in citizen science. Also, citizen science is a highly interdisciplinary endeavor, drawing from diverse fields such as education, psychology, information science, ecology, and sociology (Crain et al. 2014), making it difficult to formulate and test a single theoretical perspective. Additionally, most practitioners develop citizen science projects primarily to increase scientific understanding with less emphasis placed on participant learning (Bonney et al. 2016). As such, learning outcomes from citizen science have not been adequately articulated, addressed, or studied across the field. Further, there are assumptions about citizen science engagement as it relates to learning, but the construct of engagement is also diffuse and in need of clarity and meaning. For example, there is currently little empirical work examining what engagement entails in different types of projects, especially those with an ecological or biodiversity focus, which make up a large proportion of citizen science projects. Integrally related to engagement, there also is little consensus on what motivates and what might prevent people from engaging in citizen science. Thus, the intersection of engagement and learning is also poorly understood and in need of study.

This dissertation is intended to examine these issues through cross-programmatic research of six different citizen science projects employing both qualitative and quantitative methods. The research will articulate common learning outcomes across diverse project types, examine motivations and barriers for citizen science participation, describe and quantify engagement across different projects, and determine how engagement relates to learning outcomes among project participants.

BACKGROUND ON CITIZEN SCIENCE

The term “citizen science” was first coined in 1995 by Alan Irwin to describe the democratization of science via citizen involvement in scientific dialogue and decision making (Irwin 1995). A year later, the term was coined in the U.S. to mean public participation in scientific research through engagement with the scientific process i.e., data collection, asking questions, and analyzing and interpreting data (Bonney 1996). (See Cooper and Lewenstein 2016 for a more nuanced distinction between the two usages of the term.) Since then, many other terms have been coined to describe this phenomenon including: community science, crowd-sourcing, volunteer monitoring, community-based monitoring, participatory action research, and many others (Eitzel et al. 2017, Newman et al. 2011). Projects that occur completely online are most often referred to as crowd-science, networked science, mass collaboration, citizen cyberscience or collaboratories. Other projects that are locally-based and often environmentally-focused, are referred to as community-based, participatory, or volunteer monitoring.

In the early 2000’s interest in citizen science began to grow exponentially, as evidenced by the surge in peer-reviewed publications using citizen science data, which has increased more than 10-fold since the 1990’s (Follett et al. 2015). The volunteer base of citizen science projects continues to grow as well, with nearly 300,000 adults annually participating in citizen science projects maintained by the Cornell Lab of Ornithology alone (Dickinson and Bonney 2012). Globally, there are likely thousands of projects that exist, and participation may well be in the millions. In fact, Theobald et al. (2015) estimate that approximately two million people participate in biodiversity projects annually around the world. Participants may be children or adults, and projects may occur in or out of school with activities ranging from the very simple to the very complex.

Citizen science is diverse in other ways. It covers a breadth of scientific content ranging from astronomy to the abundance and distribution of plants and animals, to air and water quality and public health (Bonney et al. 2014, Baker 2016). Data are being used to study everything from mapping Alzheimer's Disease (www.eyesonalz.com) to mapping marine protected areas (Cigliano et al. 2015). Temporally, projects may last a year or less or go on for decades. The spatial scope of projects can engage a handful of participants in a focused geographic area or reach hundreds of thousands of observers distributed across the globe.

Indeed, worldwide, citizen science can have different meanings dependent on geography and context (Eitzel et al. 2017). For example, citizen science has been referred to as a research tool (Bonney et al. 2009a, Cooper et al. 2007, Dickinson et al. 2010, Wiggins and Crowston 2011), a distinct field of inquiry (Jordan et al. 2015), a social movement (Eitzel et al. 2017) and even a paradigm shift to democratize and make science more accessible (Irwin 1995, Kullenberg 2015). As interest in citizen science grows, typologies to describe the attributes of citizen science have been developed and categorized in various ways including: participants' involvement with the scientific process (Bonney et al. 2009a, Shirk et al. 2012), level of participation (Haklay 2013), project goals and organizational structure (Wiggins and Crowston 2011), or the way in which they are developed, i.e., using a top-down, scientist-driven approach or created from the bottom-up by community members (Wilderman et al. 2005). For the purposes of this work, the term "citizen science" will be used to encompass the Bonney (1996) version of citizen science and with a focus on participation in environmentally-based, scientific research inclusive of outdoor, field experiences.

Alongside the incredible growth of the field, there is also growing interest by funders, project developers, educators, social scientists, and evaluators in studying what learning takes place, the mechanisms that foster or support learning, and how to maximize the potential for learning in citizen science (Bonney et al. 2016, Jordan et al. 2015). A preliminary step in understanding how learning occurs in citizen science requires a basic understanding of current learning theories, especially those that are situated within the socio-cultural landscape because they are well aligned to the practice and operationalization of citizen science. In particular, social learning theories highlight the interplay between social interactions, environmental influences and cognition, as well as the role of direct observations and modeling on behavior (Bandura 1971). Socio-cultural learning theories are ideally suited for examining learning in citizen science because they emphasize the roles that participation in socially organized activities play in influencing learning. Below, I provide a very brief overview of socio-cultural learning theories, and highlight examples of where they have been used to frame research on citizen science.

SITUATING CITIZEN SCIENCE WITHIN THEORIES OF LEARNING

Educational learning theories first emerged in the mid-19th century, mostly in the form of behavioral theories, in which learning was seen as a passive process in response to external stimuli (see the works of Pavlov, Thorndike, and Skinner), and cognitive theories, which focus on knowledge construction and the processes that happen in the mind (see for example, Bruner 1990, Dewey 1938). In the 1920's and 30's, early forms of socio-cultural theories such as Cultural Historical Activity Theory or CHAT – first originated by Vygotsky, and then refined by other psychologists and educational researchers – began to emerge (Yamagata-Lynch 2010). CHAT describes learning as an inherently social process between individuals, mediating tools, and their social contexts and structures.

Activity Theory, an offshoot of CHAT, expanded the unit of analysis from the individual to the collective activity of many toward an object or goal in order to understand how social groups mediate activity and collective action (Engestrom 1999). Activity theory provides a robust framework for examining interactions among the multiple actors in citizen science (i.e., scientists, participants, practitioners, community leaders, and support staff such as educators, evaluators, technologists, and communication specialists) relative to the contexts within which they operate, or what Engestrom (1999) described as an "activity system." An analysis of citizen science through the lens of an activity system would stress not only the learning that is embedded within the object-oriented practice but also the historical change and evolution of the entire system. Roth and Lee (2004) used activity theory to examine how a local water-quality monitoring project with 7th grade students supported science literacy and authentic learning to solve real-world problems.

Researchers have applied other socio-cultural theories of learning in studies of citizen science. For example, experiential learning, first described by John Dewey (1938) describes an individual's experience with an activity or situation that facilitates learning interactions between individuals and their environment. The hands-on nature of citizen science aligns well with experiential learning theory because of the tangible experiences that participants can easily reflect upon. The often-cited study by Brossard et al. (2005)

used experiential learning theory to study citizen science experiences and learning by individuals monitoring bird houses in relation to their knowledge and attitudes toward science and the environment.

Another socio-cultural theory, Situated Learning Theory (SLT), first introduced by Lave and Wenger (1991), provides a lens for examining production and transformation of personal identities, practical skills, and communities of practice through engagement with workplace and everyday activities. Here, learning is embedded within the lived experiences of the individual as part of social practice. These authors suggest that increasing practice of an activity within a community using similar tools and procedures leads to changes in practice and changes in participation, from novice/peripheral to expert or core. Researchers are increasingly using SLT to examine the role of practice in citizen science as it relates to individual learning, engagement, and identity. For example, Raddick et al. (2009) examined changes in involvement in various tasks as leading to increasing knowledge and engagement within the community of an online astronomy project.

Communities of practice is an integral concept to SLT, which also recognizes that all learning is situated and that communities provide the context for learning to occur most effectively (Wenger 1998). Communities of practice can occur in settings such as schools, workplaces, and organizations, and interactions among community members include cooperation, problem solving, trust building, shared understanding, shared use of mutual resources, and maintaining relations. Ballard et al. (2008) describe how a community of practice between ecologists, forest managers, and *Salal* [1] harvesters helped to support environmental learning among community members. Jackson et al. (2015)

[1] Salal (*Gaultheria shallon*) is a berry-producing evergreen shrub native to western North America and harvested for it's fruit, ornamental qualities, and medicinal uses.

also used Community of Practice and conducted semi-structured interviews with Zooniverse Planet Hunters to examine identity shifts among participants. These authors documented movement of participants from legitimate but peripheral members of the community, to sustained participants, to full members of the community with increasingly central roles in the project.

The theories above are just some of the theories useful in understanding *how* learning happens in citizen science and the mechanisms and processes that enable active learning, particularly when developing project activities and experiences. They are discussed here because of their applicability to citizen science and to the proposed work, which uses socio-cultural learning theory to frame the bulk of the research. The theories, along with the few examples of their application in the literature, are also included so that citizen science practitioners interested in understanding how or if learning happens through their projects, might consider the theoretical underlying mechanisms that support learning when developing projects and aligning the activities to intended learning outcomes.

PROBLEM STATEMENT

As described above, citizen science projects are often created to efficiently gather large amounts of data to answer important scientific questions at unprecedented scales. Today, thousands of citizen science projects exist around the world that collectively engage millions of people in the observation, monitoring, and classification of species, habitats, natural and man-made events, and just about everything else in the universe (Mckinley et al. 2016, Theobald et al. 2015). There is increasing desire for citizen science to not only achieve science outcomes, but also produce a host of individual learning outcomes among its participants. These outcomes include but are not limited to: increasing science knowledge and literacy (Fernandez-Gimenez et al. 2008, Jordan et al. 2011, Krasny and Bonney 2005), understanding of the process of science (Trumbull et al. 2000), and influencing participants to take positive action on behalf of the environment (Cooper et al. 2007, Cornwell and Campbell 2012, McKinley et al. 2016).

Many of the above studies however, tend to focus on single projects, making it difficult for the field to examine more collective forms of impact. Although there are a growing number of studies examining learning across multiple *online* citizen science projects (e.g., Jennett et al. 2016), most environmentally-based or volunteer monitoring projects have failed to adequately demonstrate the learning potential of citizen science cross-programmatically (Bela et al. 2016, Bonney et al. 2016, Jordan et al. 2012, Phillips et al. 2012). One reason for this is that projects are often developed with a strong focus on scientific outcomes with less attention being paid to learning outcomes. Consequently, many citizen science practitioners may not be familiar with educational or evaluative approaches for measuring learning or lack expertise on theoretical perspectives about how learning happens. In short, there is little guidance for practitioners to develop learning outcomes that are feasible, measurable, and aligned to project activities. **For all the growth that the field of citizen science has incurred, it has yet to establish common learning outcomes that could be tested more widely to compare learning across projects.**

Additionally, millions of dollars are spent to develop citizen science projects that aim to promote science learning and increase environmental awareness and stewardship, without a complete understanding of whether individual learning goals are even feasible given the project type or how varying levels of engagement affect learning outcomes. In some cases, “engaging” in citizen science refers simply to data collection and submission. In other cases, engagement may include knowledge acquisition, critical thinking, use of technology, community involvement, and interaction with scientists. **Therefore, there is a need to also define and analyze what "engagement" in citizen science looks like across multiple projects, and including the role of motivation.**

Subsequently, there is an assumption that participants who engage more often, for longer periods of time, and with greater intensity demonstrate stronger learning outcomes, but there is yet no clear way to measure or quantify engagement. **Without a clear understanding of what it is or how to measure engagement, we cannot begin to understand its relationship to learning.** These gaps in our knowledge highlight the need to articulate learning outcomes, analyze and define what is meant by engagement, and understand the role of engagement as it relates to learning in citizen science. The persistence of these knowledge gaps will make it exceedingly difficult to determine the collective impacts that are purported to occur within the field of citizen science.

RESEARCH QUESTIONS AND STUDY DESIGN

Using theoretical perspectives from Lave and Wenger's (1991) Situated Learning Theory and Legitimate Peripheral Participation as well as Community of Practice (Wenger 1998), this research will seek to answer the following *overarching* research questions: what does engagement look like across different types of projects and how does it relate to learning? Although this work takes a broad view of learning to include affective dimensions (what people feel), cognitive dimensions (what people know), and behavioral dimensions (what people do) (Phillips et al. 2012), the emphasis will be on observable behavioral dimensions.

To address gaps in our knowledge about what and how to evaluate learning outcomes derived from participating in citizen science, Chapter 2 seeks to answer the following research questions:

2.1) What are the intended learning outcomes of citizen science and to what extent do learning outcomes developed for Informal Science Education (ISE) align with outcomes for citizen science?

2.2) What is the status of evaluation of learning in citizen science?

2.3) What types of learning outcomes have been evaluated and do they differ across different forms of citizen science?

2.4) How can common learning outcomes be operationalized for citizen science?

Chapter 2 methods include a comprehensive literature review, a review of citizen science project web sites to document expected or advertised learning outcomes, and an online survey of citizen science practitioners describing the kinds of outcomes that have been measured and their relative importance to practitioners in the field.

Chapter 3 uses qualitative methods to analyze the construct of engagement and the ways in which it differs across six different citizen science projects, spanning the continuum of contributory (top-down, scientist driven), collaborative (typically scientist driven but with some input from community), and co-created (bottom-up community driven) projects as described by Bonney et al. (2009) (See Table 1). Research questions addressed in Chapter 3 include:

3.1) What are the salient dimensions of engagement in citizen science and how are they described, as expressed in qualitative interviews with participants from different projects?

3.2) What are the motivations for and barriers to engaging in citizen science across different projects?

3.3) How can engagement in scientific practices be quantified and measured within the context of citizen science?

Table 1.1: Summary of projects in the study.

Project	Description	Project Type	Project Structure
NestWatch	Monitoring nest boxes	Contributory	Individual
Monarch Larva Monitoring Project	Counting/classifying monarch larvae	Contributory	Individual
Community Collaborative, Rain, Hail, and Snow Network	Measuring precipitation events	Collaborative	Individual
Hudson River Eels Estuary Project	Counting glass eels	Collaborative	Social
Alliance for Aquatic Resource Monitoring	Water quality monitoring	Co-created	Social
Global Community Monitor	Air quality monitoring	Co-created	Social

The projects in Table 1.1 were purposefully chosen not only because they represent the three model types but also because of their geographic, scientific, temporal, and structural diversity. The projects all have in common however, a focus on some form of field-based, environmental monitoring. The most appropriate research design therefore is a comparative case study, which according to Yin (2013) "is an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident. The case study inquiry copes with the technically distinctive situation in which there will be many more variables of interest than data points, and as one result relies on multiple sources of evidence, with data needing to converge in a triangulating fashion, and as another result benefits from the prior development of theoretical propositions to guide data collection and analysis" (p. 13-14).

Methodology for Chapter 3 includes analysis and thematic coding of 72 qualitative interviews of participants to describe the various dimensions of engagement across the six projects. Responses to questions about what people do on behalf of the project were synthesized and then given to the six project leaders to rank the most important items. Collectively this information was used to develop a 12-item Participant Engagement Metric (PEM), which is used in Chapter 4 to quantify the behavioral aspects of engagement.

Chapter 4 is a quantitative comparison of behavioral engagement and motivation and their relationship to learning outcomes such as science efficacy, science skills, and environmental stewardship. This chapter first describes engagement using an aggregate of the quantitative data, then compares engagement across the six projects, project types (contributory, collaborative, or co-created), and project structures (individual or social). The second half of the chapter focuses on hypothesis testing to determine the relationship between behavioral engagement using the PEM, and science and environmental learning outcomes among participants in the six projects. Research questions addressed in Chapter 4 include:

4.1) How are dimensions of engagement (motivation, affective/emotions, social connections, behavioral, and cognitive/learning) characterized and described across the six projects?

4.2) How do behavioral aspects of engagement (measured via the PEM) relate to commonly sought after outcomes of citizen science such as science efficacy, science skills, and environmental stewardship?

4.3) How do the relationships in RQ 2 differ across the six projects, three project types (contributory, collaborative, co-created), and project structure (individual vs. group-based)?

4.4) What role, if any, does motivation play in the relationship between behavioral engagement and learning?

Methodology for Chapter 4 includes numerous statistical tests including tests to ensure assumptions of normality are met; measures of internal consistency (reliability) regarding the PEM, motivation, and scales measuring dependent variables; Confirmatory Factor Analysis (CFA) of the PEM and the three scales measuring dependent variables; correlation matrices to discern patterns in relationships and Anova to compare means across groups.

SIGNIFICANCE OF THE STUDY

Each year, millions of dollars are granted to develop citizen science projects that aim to promote science learning and increase environmental awareness and stewardship. In a time where accountability is ever more important, the field of citizen science must begin to provide evidence for its collective impact. This research will fill important knowledge gaps about whether individual learning goals are being achieved given a project type as well as provide the field with a measure to quantify engagement that is transferable across the field. This work will be one of the first to study how varying levels of engagement might affect learning outcomes across multiple projects. Results from this study also will inform our understanding of key barriers and motivations to citizen science that can be used to inform modification of existing projects to reach new audiences or retain current participants. Results of this study may have implications for future research on conservation action and the link between spending time outdoors and environmental stewardship practices. Importantly, this research is intended to build on existing theoretical frameworks to create a more clearly defined theoretical model that describes citizen science motivation, engagement, and learning and improves methodologies for systematically studying this dynamic and growing field.

REFERENCES

Baker, B. (2016). Frontiers of citizen science: Explosive growth in low-cost technologies engage the public in research. *BioScience*, 66 (11): 921-927. doi: 10.1093/biosci/biw120.

Ballard, H. L., Fernandez-Gimenez, M. E., and Sturtevant, V. E. (2008). Integration of local ecological knowledge and conventional science: a study of seven community-based forestry organizations in the USA. *Ecology and Society*, *13*(2), 37. https://doi.org/http://hdl.handle.net/10535/2424.

Bandura, A. (1971). *Social learning theory*. Morristown, NJ: General Learning Press.

Bela, G., Peltola, T., Young, J. C., Balázs, B., Arpin, I., Pataki, G., … Bonn, A. (2016). Learning and the transformative potential of citizen science: Lessons from the Study of Nature. *Conservation Biology*, *30*(5), 990–999. https://doi.org/10.1111/cobi.12762.

Bonney, R. (1996). Citizen science: A lab tradition. *Living Bird*, 15(4): 7–15.

Bonney, R., Ballard, H., Jordan, R., McCallie, E., Phillips, T., Shirk, J., and Wilderman, C. C. (2009a). Public participation in scientific research: defining the field and assessing its potential for informal science education. *A CAISE Inquiry Group Report*. Washington, DC: Center for Advancement of Informal Science Education (CAISE). Retrieved from http://eric.ed.gov/?id=ED519688.

Bonney, R., Shirk, J. L., Phillips, T. B., Wiggins, A., Ballard, H. L., Miller-Rushing, A. J., and Parrish, J. K. (2014). Next steps for citizen science. *Science*, *343*(6178), 1436–1437. https://doi.org/10.1126/science.1251554.

Bonney, R., Cooper, C. B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K. V., and Shirk, J. (2009b). Citizen science: A developing tool for expanding science knowledge and scientific literacy. *BioScience*, *59*(11), 977–984. https://doi.org/10.1525/bio.2009.59.11.9.

Bonney, R., Phillips, T. B., Ballard, H. L., and Enck, J. W. (2016). Can citizen science enhance public understanding of science? *Public Understanding of Science*, *25*(1), 2–16. https://doi.org/10.1177/0963662515607406.

Brossard, D., Lewenstein, B., and Bonney, R. (2005). Scientific knowledge and attitude change: The impact of a citizen science project. *International Journal of Science Education*, *27*(9), 1099–1121. https://doi.org/10.1080/09500690500069483.

Bruner, J. S. (1990). *Acts of Meaning*. Harvard University Press.

Cigliano, J., Meyer, R., Ballard, H., Freitag, A., Phillips, T., and Wasser, A. (2015). Making marine and coastal citizen science matter. *Ocean & Coastal Management*, 115 pp: 77-87.

Cooper, C. B., Dickinson, J., Phillips, T., and Bonney, R. (2007). Citizen science as a tool for conservation in residential ecosystems. *Ecology and Society*, *12*(2), 11. https://doi.org/http://hdl.handle.net/10535/2968.

Cooper, C. (2016). *Citizen Science: How Ordinary People are Changing the Face of Discovery*. Overlook Press: New York, NY.

Cornwell, M. L. and Campbell, L. M. (2012). Co-producing conservation and knowledge: Citizen-based sea turtle monitoring in North Carolina, USA. *Social Studies of Science*, 42(1): 101 – 120.

Crain, R., Cooper, C., and Dickinson, J. L. (2014). Citizen Science: A Tool for Integrating Studies of Human and Natural Systems. *Annual Review of Environment and Resources*, *39*(1), 641–665. https://doi.org/10.1146/annurev-environ-030713-154609.

Devictor, V., Whittaker, R. J., and Beltrame, C. (2010). Beyond scarcity: citizen science programmes as useful tools for conservation biogeography: Citizen science and conservation biogeography. *Diversity and Distributions*, *16*(3), 354–362. https://doi.org/10.1111/j.1472-4642.2009.00615.x.

Dewey, J. (1938). *Experience and education*. New York: Macmillan.

Dickinson, J. L., and Bonney, R. (2012). *Citizen Science: Public Participation in Environmental Research*. Cornell University Press.

Eitzel, M. V., Cappadonna, J. L., Santos-Lang, C., Duerr, R. E., Virapongse, A., West, S. E., Kyba, C. M., Bowser, A., Cooper, C .B., Sforzi, A., Metcalfe, A. N., Harris, E. S., Thiel, M., Haklay, M., Ponciano, L., Roche, J., Ceccaroni, L., Shilling, F. M., Dörler, D., Heigl, F., Kiessling, T., Davis, B. Y., Jiang, Q. (2017). Citizen science terminology matters: Exploring key terms. *Citizen Science: Theory and Practice*, 2(1): 1, pp. 1–20, DOI: https://doi.org/10.5334/cstp.96.

Engeström, Y. (1999). Activity theory and individual and social transformation. In R. Miettinen and R.-L. Punamäki (Eds.), *Perspectives on Activity Theory*. Cambridge University Press.

Fernandez-Gimenez, M. E., Ballard, H. L., and Sturtevant, V. E. (2008). Adaptive management and social learning in collaborative and community-based monitoring: a study of five community-based forestry organizations in the western USA. *Ecology and Society*, *13*(2), 4.

Haklay, M. (2013). Citizen science and volunteered geographic information – overview and typology of participation. In: Sui, D.Z., Elwood, S. and Goodchild, M.F., (eds.), *Crowdsourcing Geographic Knowledge: Volunteered Geographic Information (VGI) in Theory and Practice*. Berlin: Springer, 105–122. DOI: https://doi.org/10.1007/978-94-007-4587-2_7.

Irwin, A. (1995). *Citizen Science: A Study of People, Expertise and Sustainable Development* (Vol. 136). London: Routledge.

Jackson, C., Østerlund, C., Crowston, K., Mugar, G., and Hassman, K. D. (2014). Motivations for sustained participation in citizen science: Case studies on the role of talk. In *17th ACM Conference on Computer Supported Cooperative Work & Social Computing*. Citeseer. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.454.9525&rep=rep1&type=pdf.

Jennett, C., Kloetzer, L., Schneider, D., Lacovides, I., Cox, A. L., Gold, M., … Talsi, Y. (2016). Motivations, learning and creativity in online citizen science. *Journal of Science Communication*, *15*(3).

Jordan, R. C., Gray, S. A., Howe, D. V., Brooks, W. R., and Ehrenfeld, J. G. (2011). Knowledge gain and behavioral change in citizen-science programs: Citizen-scientist knowledge gain. *Conservation Biology*, *25*(6), 1148–1154. https://doi.org/10.1111/j.1523-1739.2011.01745.x.

Jordan, R. C., Ballard, H. L., and Phillips, T. B. (2012). Key issues and new approaches for evaluating citizen-science learning outcomes. *Frontiers in Ecology and the Environment*, *10*(6), 307–309. https://doi.org/10.1890/110280.

Jordan, R., Crall, A., Gray, S., Phillips, T., and Mellor, D. (2015). Citizen Science as a Distinct Field of Inquiry. *BioScience*, *65*(2), 208–211. https://doi.org/10.1093/biosci/biu217.

Krasny, M. E., and Bonney, R. (2005). Environmental education through citizen science and participatory action research. In E. Johnson and M. Mappin (Eds.),

Environmental Education and Advocacy: Changing Perspectives of Ecology and Education (pp. 292–319). Cambridge, UK: Cambridge University Press.
Kullenberg, C. (2015). Citizen science as resistance: crossing the boundary between reference and representation. *Journal of Resistance Studies*, 1(1).
Kullenberg C. and Kasperowski D. (2016). What is citizen science? – a scientometric meta-analysis. *PLoS ONE* 11(1): e0147152. doi:10.1371/journal.pone.0147152.
Lave, J., and Wenger, E. (1991). *Situated Learning: Legitimate Peripheral Participation*. Cambridge University Press.
McKinley, D. C., Miller-Rushing, A. J., Ballard, H. L., Bonney, R., Brown, H., Cook-Patton, S. C., … Soukup, M. A. (2016). Citizen science can improve conservation science, natural resource management, and environmental protection. *Biological Conservation*. https://doi.org/10.1016/j.biocon.2016.05.015.
Miller-Rushing, A., Primack, R., and Bonney, R. (2012). The history of public participation in ecological research. *Frontiers in Ecology and the Environment*, *10*(6), 285–290. https://doi.org/10.1890/110278.
Newman, G., Graham, J., Crall, A., and Laituri, M. (2011). The art and science of multi-scale citizen science support, *Ecological Informatics*, 6, 3–4: 217-227, ISSN 1574-9541, https://doi.org/10.1016/j.ecoinf.2011.03.002.
Phillips, T., Bonney, R., and Shirk, J. (2012). What is our impact? Toward a unified framework for evaluating outcomes of citizen science participation. In J. L. Dickinson and R. Bonney (Eds.), *Citizen Science: Public Participation in Environmental Research* (pp. 82–95). Ithaca, NY: Cornell University Press.
Raddick, M. J., Bracey, G., Carney, K., Gyuk, G., Borne, K., Wallin, J., and Jacoby, S. (2009). Citizen science: status and research directions for the coming decade. *AGB Stars and Related Phenomenastro 2010: The Astronomy and Astrophysics Decadal Survey*, *2010*, 46pp.
Roth, W. M., and Lee, S. (2004). Science education as/for participation in the community. *Science Education*, *88*(2), 263–291. https://doi.org/10.1002/sce.10113.
Shirk, J. L., Ballard, H. L., Wilderman, C. C., Phillips, T., Wiggins, A., Jordan, R., … Bonney, R. (2012). Public participation in scientific research: a framework for deliberate design. *Ecology and Society*, *17*(2). https://doi.org/10.5751/ES-04705-170229.
Theobald, E. J., Ettinger, A. K., Burgess, H. K., DeBey, L. B., Schmidt, N. R., Froehlich, H. E., … Parrish, J. K. (2015). Global change and local solutions: Tapping the unrealized potential of citizen science for biodiversity research. *Biological Conservation*, *181*, 236–244. https://doi.org/10.1016/j.biocon.2014.10.021.
Trautmann, N., Shirk, J., Fee, J., and Krasny, M. E. (2012). Who poses the question? using citizen science to help k-12 teachers meet the mandate for inquiry. In J. L. Dickinson and R. Bonney (Eds.), *Citizen Science: Public Participation in Environmental Research* (pp. 179–191). Ithaca, NY: Cornell University Press.
Trumbull, D. J., Bonney, R., Bascom, D., and Cabral, A. (2000). Thinking scientifically during participation in a citizen-science project. *Science Education*, *84*(2), 265–275. doi:10.1002/(SICI)1098-237X(200003)84:2<265::AID-SCE7>3.0.CO;2-5.
Wenger, E. (1998). *Communities of Practice: Learning, Meaning, and Identity*. Cambridge University Press.
Wiggins, A. and Crowston, K., (2011). From conservation to crowdsourcing: A typology of citizen science. In: *System Sciences (HICSS), 2011 44th Hawaii international conference on* (pp. 1–10). IEEE. DOI: http://dx.doi.org/10.1109/ HICSS.2011.207.

Wilderman, C, (2005). Portrait of a watershed: Shermans Creek. Harrisburg, PA: Pennsylvania Department of Environmental Protection.
Yamagata-Lynch, L.C. (2010). *Activity Systems Analysis Methods: Understanding Complex Learning Environments.* Springer, NY. DOI 10.1007/978-1-4419-6321-5_2.
Yin, R. K. (2003). *Case Study Research, Design and Methods* (3rd ed., vol. 5). Thousand Oaks: Sage
Ziman, J. M. (2000). *Real Science: What it is, and What it Means*. Cambridge: Cambridge University Press.

CHAPTER II

ARTICULATING AND EVALUATING INDIVIDUAL LEARNING OUTCOMES FROM CITIZEN SCIENCE: A CONCEPTUAL MODEL

"Self-education is, I firmly believe, the only kind of education there is."
— Isaac Asimov

INTRODUCTION

It is estimated that more than two million people engage in citizen science biodiversity monitoring projects globally (Theobald, et al. 2015). Broadly defined, citizen science is the intentional engagement of the public in authentic scientific research (Bonney et al. 2009b). As a research methodology, citizen science is known for its ability to efficiently gather large amounts of data to answer biologically important questions (Bonney et al. 2014, Dickinson and Bonney 2012, Theobald et al. 2015). Increasingly, citizen science projects may also seek to influence learning outcomes on behalf of their participants through activities aimed at increasing science knowledge and literacy (Fernandez-Gimenez et al. 2008, Jordan et al. 2011, Krasny and Bonney 2005), understanding of the process of science (Trumbull et al. 2005), and influencing participants to take positive action on behalf of the environment (Cooper et al. 2007, Lewandowski and Oberhauser 2017, McKinley et al. 2016).

While the potential for learning through citizen science is purported to be great, most projects have yet to demonstrate how to achieve measurable outcomes such as increased interest in science or the environment, knowledge of science process, skills of science inquiry, and stewardship behaviors, through either research or evaluation approaches (Bela et al. 2016, Bonney et al. 2016, Jordan et al. 2012, Phillips et al. 2012). The dearth of quality project evaluations likely results from limited time and resources for projects to hire external evaluators, a lack of expertise to conduct internal evaluations, and perhaps a lack of priority to conduct evaluations (Phillips et al. 2012).

There is also limited support or guidance for practitioners to carry out evaluations. Of notable exception, a recent paper by Haywood and Besley (2013) presents a framework for describing criteria indicators for science education and learning (using mostly an Informal Science Education perspective) and process indicators for participatory engagement (using mostly a Science Technology Studies perspective). The education indicators relevant to this work include science concepts, theories, and phenomena, science process skills, career connections, transferable skills, lifestyle changes, citizenship and engagement in science. While this framework is helpful in describing potential indicators and associated evaluation questions, much of the framing is at a programmatic, rather than individual level. It also focuses on indicators (or evidence used as measures of success) rather than actual learning outcomes. To date, comprehensive, empirical research is lacking on the kinds of learning outcomes that are both intended and observed from citizen science.

Two other recent documents from the Informal Science Education (ISE) field may also provide a starting point for evaluating and examining learning in citizen science: The *Framework for Evaluating Impacts of Informal Science Education Projects* (Friedman et al. 2008) and *Learning Science in Informal Environments: People, Places, and* Pursuits (National Research Council, 2009). These two documents are useful to this work because most citizen science projects operate in informal environments such as private residences, parks, science and nature centers, museums, community centers, after-school programs, and online. Also, much of informal learning is centered around social and cultural learning theories (Roth and Lee 2007, National Research Council 2009), which emphasize the roles that participation in socially organized activities play in influencing learning (see Chapter 1 of dissertation), and these are increasingly being considered as a lens to study learning in citizen science. Further, many citizen science projects are funded through ISE initiatives because they are believed to provide lifelong learning opportunities (Crain et al. 2014). Thus, the Friedman et al. (2008) Framework and the National Research Council (2009) strands provide strong contextual and theoretical justification for applying them within citizen science.

The current study is aimed at articulating learning outcomes for adults in citizen science by applying learning and evaluation frameworks developed in the field of ISE and attempts to answer the following questions:

2.1) What are the intended learning outcomes of citizen science and to what extent do learning outcomes developed for ISE align with outcomes for citizen science?

2.2) What is the status of evaluation in citizen science?

2.3) What types of learning outcomes have been evaluated and do they differ across different forms of citizen science?

2.4) How can common learning outcomes be operationalized for citizen science?

Much has been said about the learning potential for individuals participating in citizen science. While some strides have been made to highlight such learning outcomes, the evidence base is scattered and disparate, with few ways to compare results across studies. Citizen science practitioners seek guidance on the types of learning outcomes to design for and how best to measure them. The field of citizen science as a whole is eager to demonstrate that collectively, these projects have both an impact on science as well as society. To that end, the objective of this work is to ground-truth a proposed framework for evaluating individual learning outcomes that is both empirically derived and contextually relevant to the citizen science community.

CITIZEN SCIENCE AND INFORMAL SCIENCE LEARNING

Citizen science—particularly when involving adults—draws heavily from ISE or what Falk and Dierking (2002) refer to as "free-choice learning," which is considered lifelong, self-directed learning that occurs outside the K-16 classroom. It is estimated that across the life span, people spend about 60 percent of their waking hours in informal learning environments such as museums, science centers, libraries, and online (National Research Council 2009). In response to the need to measure learning in such settings, the National Science Foundation developed a framework that provides a standard set of outcome categories for ISE programs designed to collect project-level impacts in a systematic way (Friedman et al. 2008). The goal for the framework was to facilitate cross-project and cross-technique comparisons of the impacts of ISE projects on public audiences. A major contribution of the NSF Framework is the formulation and description of outcomes (referred to as impact categories) common among ISE programs, including citizen science. The five impact categories include:

- knowledge, awareness, or understanding of Science, Technology, Engineering and Math (STEM) concepts, processes, or careers
- engagement or interest in STEM concepts or careers
- attitude towards STEM concepts, processes, or careers
- skills based on STEM concepts or processes, and
- behavior related to STEM concepts, processes, or careers.

Another document, *Learning Science in Informal Environments: People, Places, and Pursuits* (National Research Council 2009), focuses on characterizing the cognitive, affective, social, and developmental aspects of science learners, with less of a focus on evaluation or measurement of outcomes. Termed as the LSIE "strands," these aspects of participation in science include: interest and motivation to learn about the natural world; application and understanding of science concepts; acquisition of skills related to the practice of science; reflecting on science as a way of knowing; participating in and communicating about science; and identifying oneself as someone capable of knowing, using, and contributing to science. The authors of the LSIE strands note, that while these concepts originate in research, they have not been applied or analyzed in any systematic venue. There is much overlap between constructs in the LSIE strands and the Friedman et al. (2008) impact categories; however, the current research relied mostly on the NSF framework categories — developed primarily for evaluation purposes — to guide the bulk of the data collection, and the LSIE theoretical constructs for much of the socio-cultural framing. Table 2.1 maps the similarity of outcomes outlined by Friedman et al. (2008) and the National Research Council (2009) strands.

In 2009, Bonney et al. (2009a) developed a rubric based on the NSF Framework (Friedman et al. 2008) as a "first step toward developing an organized methodology for comparing outcomes across a variety of Public Participation in Scientific Research (PPSR) projects" (p.20). The authors looked at 10 NSF-funded projects to determine the extent to which these projects reported outcomes similar to those in the NSF framework. One result of this effort was a realization that the field of citizen science was measuring similar outcomes to ISE, but in disparate ways and there was little opportunity for cross-programmatic research to study the collective impact of the field. Another result from this study was the development of a simple typology based on the participant level of involvement in the scientific process. Rather than using more troublesome terms such as "top-down" and "bottom-up," Bonney et al. (2009a) developed a three-part typology: "Contributory" citizen science is researcher-driven

Table 2.1: NSF Framework and LSIE strands

NSF Framework Category	LSIE Strands
***Knowledge**, Awareness, Understanding: 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.*	*Strand (2), **Understanding**: Come to generate, understand, remember, and use concepts, explanations, arguments, models, and facts related to science.*
***Engagement**, interest or motivation in science: 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.*	*Strand (1), **Interest and motivation**: Experience excitement, interest and motivation to learn about phenomena in the natural and physical world.*
***Skills** related to science inquiry: Measurable demonstration of the development and/or reinforcement of skills, either entirely new ones or the reinforcement, even practice, of developing skills.*	*Strand (3), **Science Exploration**: Manipulate, test, explore, predict, question, and make sense of the natural and physical world; and Strand (5): Participate in scientific activities and learning practices with others, using scientific language and tools*
***Attitudes** toward science: 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. 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.*	*Related to Strand (6), **Identity**: Think about themselves as science learners, and develop an identity as someone who knows about, uses, and sometimes contributes to science. Also, related to Strand (4), **Reflection**: Reflect on science as a way of knowing; on processes, concepts, and institutions of science; and on their own process of learning about phenomena.*
***Behavior**: Measurable demonstration of assessment of, change in, or exercise of behavior related to a STEM topic. Behavioral impacts are particularly relevant to projects that are environmental in nature since action is a desired outcome.*	*Related to Strand (5), **Skills**: Participate in scientific activities and learning practices with others, using scientific language and tools.*

and focused mostly on data collection where scientists develop the questions and protocols and the public collects and shares the relevant data with the scientists. "Collaborative" projects are typically originated by researchers but may include more input from participants in other phases of the scientific process such as designing data collection methods, analyzing data, and disseminating results. "Co-created" projects involve participants in all aspects of the scientific process from defining the question or topic of interest to interpreting data and disseminating findings.

Similar to Haywood and Besley (2013), the rubric developed by Bonney et al. (2009a) needed to be applied to a wider swath of the citizen science field. The current research is a first step at empirically applying the concepts within the LSIE strands, the Friedman et al. (2008) framework, and the Bonney et al. (2009a) rubric to the field of citizen science. Collectively, these documents can serve as starting points for the gathering of common outcomes and developing a conceptual model of learning specific to citizen science.

METHODS

Data to answer the four research questions above have been collected at two separate points in time. To answer the first research question about intended outcomes, we gathered information through a structured Internet search of unique citizen science projects using the following portals: Citizen Science Central (citizenscience.org), InformalScience (informalscience.org), SciStarter (scistarter.com), Citizen Science Alliance (citizensciencealliance.org), and National Directory of Volunteer Monitoring Programs (yosemite.epa.gov/water/volmon.nsf/VPT!OpenViewandExpandView). The last portal included 800 projects, from which we sampled every 5th one. Many citizen science projects were listed on multiple portals, but each was included only once in our analysis. In total, 327 project websites met the inclusion criteria of being in the U.S. or Canada, having an online presence, and being operational at the time of the search (2011). The complete list of databases and search terms used to locate citizen science websites is available in Appendix A.

Information gathered for each project website included: name, goal statement, stated learning outcome or objectives (if any), potential indicators (if any), project URL, and contact information. Looking specifically at learning outcomes within each of the project websites, key terms were searched that stated the expected or intended learning outcomes and/or obvious descriptions of what participants would do and/or learn as a result of participation. Each of the projects' goal statements and learning objectives were carefully read and then coded into the most appropriate learning outcome category. Outcome statements were placed into the major categories (knowledge, attitude, skills, interest, behavior, other) outlined by Friedman et al. (2008) as well as other sub-categories outlined in the LSIE strands and the assessment rubric by Bonney et al. (2009a). If project websites did not describe intended learning outcomes (e.g., some projects advertised their goals to be purely scientific in nature), they were listed as having no specified learning goals.

Many project websites listed multiple intended learning outcomes; in those cases, each distinct outcome was counted separately. For example, the Great Lakes Worm Watch project lists as its goal statement: "Great Lakes Worm Watch is committed to increasing scientific literacy and public understanding of the role of exotic species in ecosystems change." Learning outcomes for participants include: "We provide the tools and resources for citizens to actively contribute to the development of a database documenting the distributions of exotic earthworms and their impacts across the region as well as training and resources for educators to help build understanding of the methods and results of scientific research about exotic earthworms and forest ecosystems ecology." The text in both the goal statement and learning outcomes (left) were then coded into the following categories on the right:

- Increasing scientific literacy and public understanding → content knowledge
- Citizens to actively contribute to the development of a database → data collection and monitoring, data submission
- Help build understanding of the methods and results of scientific research → Nature of Science knowledge

The second source of data collection was an online survey of citizen science practitioners using Survey Monkey™. The survey was conducted to answer research questions 2 and 3 (understand the state of evaluation in citizen science; and what, if any, outcomes have been evaluated and do they differ across project types)? The survey contained 25 questions in all, 20 of which were close-ended questions with pre-determined options including "other"; the remainder of the questions were open-ended text boxes. The first survey question, which required a response, asked respondents to classify their project according to the three-model typology of citizen science developed by Bonney et al. (2009a) described earlier. Other questions focused on the duration of the project, the approximate number of people participating in the project, and the type of training that participants received. To understand the extent to which evaluation was occurring in the citizen science field, respondents were asked if any type of evaluation had ever been conducted for their project; details about said evaluations; what—if any—of the learning outcomes described by Friedman et al. (2008) had been measured; and what other types of outcomes were measured. The complete set of survey questions is available in Appendix B.

The initial email invitation to potential respondents described the goal of the survey (i.e., to obtain feedback regarding practitioners' past experiences with and future aspirations for evaluating learning outcomes of their projects), and that the survey was voluntary and likely to take 15 minutes to complete. Potential survey respondents were contacted via their affiliation with the citizenscience.org listserv (citsci-discussion-l), which anyone can join, and which had approximately 1,100 members at the time the survey was conducted in March, 2011. Not all members of the listserv were project leaders, and likely, multiple list members represent a single project, making it difficult to know the actual number of projects represented by listserv members. After the survey was closed, an extra step was taken to look at the projects represented in the online survey and make sure the project was also counted in the website review described above. This was purposeful so as to have as much overlap between these two datasets as possible.

In all, 199 respondents completed the survey, representing 157 unique projects. Seven projects had more than one entry, in these cases; only the first response recorded was kept. Since the question about project name was optional, 35 respondents skipped this question, but their other responses are included in the analyses. In all, 147 named projects in the survey were also represented in the 327 project websites described above. The remaining ten projects that were in the online survey but not in the website review were either no longer operational, not in the US or Canada, or did not have a web presence.

Results from the website review and the online practitioner survey were examined together and compared to determine gaps and overlaps between intended and measured learning outcomes and to inform an extensive literature review on these outcomes. The literature review involved an analysis of more than 40 peer-reviewed articles describing how these outcomes or "constructs" had been studied in other disciplines and how they could be operationalized for citizen science. This analysis facilitated a re-conceptualization of several of the outcomes, sometimes involving further reduction, specificity, or contextualization to be included in the proposed conceptual model described in the final research question.

RESULTS

Research Question 2.1: What are the intended learning outcomes of citizen science and to what extent do learning outcomes developed for ISE align with outcomes for citizen science?

Research question 1 was answered through the website review data and the survey data (described below). Results from citizen science websites (Table 2.2) reveal that projects ranged from zero to as many as seven learning outcomes. About 40% of projects included at least two learning outcomes. The majority of citizen science projects (55%) are focused on influencing skills related to data collection and monitoring. Such intended outcomes are often stated as "Volunteers gain data collection and reporting skills." The second most frequently stated learning outcome (26% of projects) was understanding of content knowledge (e.g., "volunteers learn about macro invertebrates and stream health"). Increased environmental stewardship, which typically includes some type of behavior change (e.g. "engage watershed residents in protecting water quality"), was specified by about 25% of projects. Eight percent of project websites did not list any intended learning outcomes. Other learning outcomes included shifts in attitude/awareness, increased knowledge of the nature of science, data analysis skills, interest in the environment, civic action, data submission, communication skills, use of technology, science careers, and study design. With the exception of outcomes related to community health or civic action, these results suggest that the majority of intended outcomes described in citizen science websites, also align to the ISE frameworks. A summary of these findings is presented in Table 2.2.

Results from the online practitioner survey describe the extent to which ISE learning outcomes were measured across different project types (below, research question 3). Most of the results are described as the percentage of respondents; in some cases, the count of responses is also included. With the exception of two questions, all questions were optional, therefore, sample sizes vary throughout the survey.

Table 2.2: Count of specified learning outcomes as coded from 327 citizen-science project websites. Percentages represent the proportion of projects that described the stated outcome. Several projects stated more than one outcome.

Stated outcomes on project websites	Count of projects stating outcome (N=327)	Percentage of projects stating outcome
Data Collection and Monitoring	193	59%
Content Knowledge	90	28%
Environmental Stewardship	86	26%
No Education Goal Specified	29	9%
Attitude/Awareness	25	8%
Nature of Science	20	6%
Data Analysis	14	4%
Interest in the Environment	13	4%
Civic Action	12	4%
Submitting Data	12	4%
Interest in Science	10	3%
Community Health	9	3%
Communication Skills	7	2%
Using Technology	6	2%
Science Careers	4	1%
Designing Studies	2	0.5%

Research Question 2.2: What is the status of evaluation in citizen science?

Of the 199 respondents, 114 or 57% indicated that they had undertaken some type of evaluation. Of these, more than half had been administered by internal staff to measure summative outcomes (as opposed to front-end or formative evaluations, which seek to assess needs and implementation processes, respectively), using mostly data collected through surveys. An equal number of respondents (23, or 32%) reported conducting post-only and pre-and posttest evaluation designs. In an open-ended question describing reasons for conducting evaluations, answers included: gauging participant learning, identifying project strengths and weaknesses, obtaining additional funding or support, promoting a project more broadly, and providing recommendations for project improvement.

Another open-ended question asked respondents "Please do your best to provide the name or description of any instrument (e.g., Views on Science and Technology Survey) used to collect evaluation data, (even if you developed the instrument)." Of the 72 people that responded to this question, only three had used a pre-existing, validated instrument. The vast majority of respondents had developed instruments in-house or had an external evaluator develop original instruments. Another subset of respondents replied with "Survey Monkey" or some other data collection platform. Some mentioned tools such as GPS units or calipers as the instruments used, while others stated they did not understand the question. When asked about the overall satisfaction with the evaluation, more than half of all respondents expressed agreement or strong agreement that the evaluation was of high quality, that evaluation findings were informative to the project developers, that recommendations from the evaluation were implemented, that the project has improved as a result of evaluation, that they learned a lot about evaluation, and that they felt confident that they could personally conduct an evaluation in the future.

For all respondents, regardless of whether evaluations had been conducted, they were asked what aspects of the evaluation process they would like assistance with. The highest priority was help with developing goals, objectives, and indicators, followed by creating or finding appropriate survey instruments, help with analyzing or interpreting data, and help with data collection. Participants also were asked what specific resources would be most helpful for conducting evaluations. The most commonly cited resources were a database of potential surveys and data collection instruments, sample evaluation reports from citizen science, examples of evaluation designs, and an entry level guide for conducting evaluations. Finally, respondents were presented with a list of eight different online organizations that support or provide resources for evaluation and were asked how often they access them. Surprisingly, the majority of respondents (between 73%-93%) had never heard of the resource or organization. The only exception was citizenscience.org, where a majority of respondents (46%) stated that they rarely (as opposed to frequently or sometimes), used the resource.

In sum, the results from RQ 2.2 suggest that while most citizen science practitioners have conducted some form of evaluation and have valued the process, there is a need for more support and training to facilitate higher quality evaluations.

Research Question 2.3: What types of learning outcomes have been evaluated and do they differ across different forms of citizen science (i.e., contributory, collaborative, and co-created projects)?

The full set of survey respondents represented mostly contributory projects (146 or 74%), followed by collaborative projects (36, or 18%) and co-created projects (17 or 9%). The majority of projects (72 or 37%) had been operating 1-5 years, and almost half (49%) had fewer than 100 participants. To examine the types of learning outcomes that had been evaluated across different project types, survey respondents that reported having conducted evaluations (114 or 57%) were asked "For the most recent evaluation of your project, which broad categories of learning outcomes, if any, were evaluated?" Responses to this question were based on the Friedman et al. (2008) framework. Aggregated results across the projects revealed that interest or engagement in science was the most commonly measured outcome (46%), followed by knowledge of science content (43%). Behavior change resulting from participation and attitudes toward science process, content, careers, and the environment accounted for 36% and 33%, respectively, of measured learning outcomes. Science inquiry skills (e.g., asking questions, designing studies, data collection, data analysis, and using technology) were the least commonly measured outcomes across all projects (28%). In an open-ended question about other types of learning outcomes, about 10% of respondents also described measuring motivation and self-efficacy or confidence to participate in science and environmental activities. Although these data come from a smaller set than the data from the website review (n=114 vs. n=327), they add to the review of project websites data above, to reaffirm the alignment with outcomes from the ISE framework.

In addition to learning outcomes, the survey also asked what other aspects of the project had been evaluated. Two thirds of participants reported measuring satisfaction or enjoyment with the project, followed by motivation to participate (53%), and evaluation of project outputs such as numbers of participants, web hits, journal articles, amount of data, etc. (44%). Other measured outcomes included scientific/conservation outcomes (39%), effectiveness of workshops and trainings (38%), data quality (37%), community capacity building (23%), and social policy change (3%).

With respect to differences among project types (Figure 1), contributory projects (for which there were 69 respondents that had conducted evaluations), reported measuring interest in science most frequently (43%), followed by knowledge of science content or process (36%), behavior change (30%) and attitudes toward science (29%). The least likely outcome measured by contributory projects was skill, with only 18% of respondents reported having measured skills of science inquiry. Two-thirds of all collaborative projects (N=21), measured content knowledge, followed by interest (57%), behavior change (52%), and attitudes and skills (both 43%). Only nine survey respondents represented co-created projects that had also conducted evaluations, making it difficult to generalize these results more broadly. Interestingly however, six of the nine (66%) co-created projects reported measuring skills the most. The remaining outcomes were all measured by 44% of co-created projects. Responses combined across projects and separated among project types, are summarized in Figure 2.1.

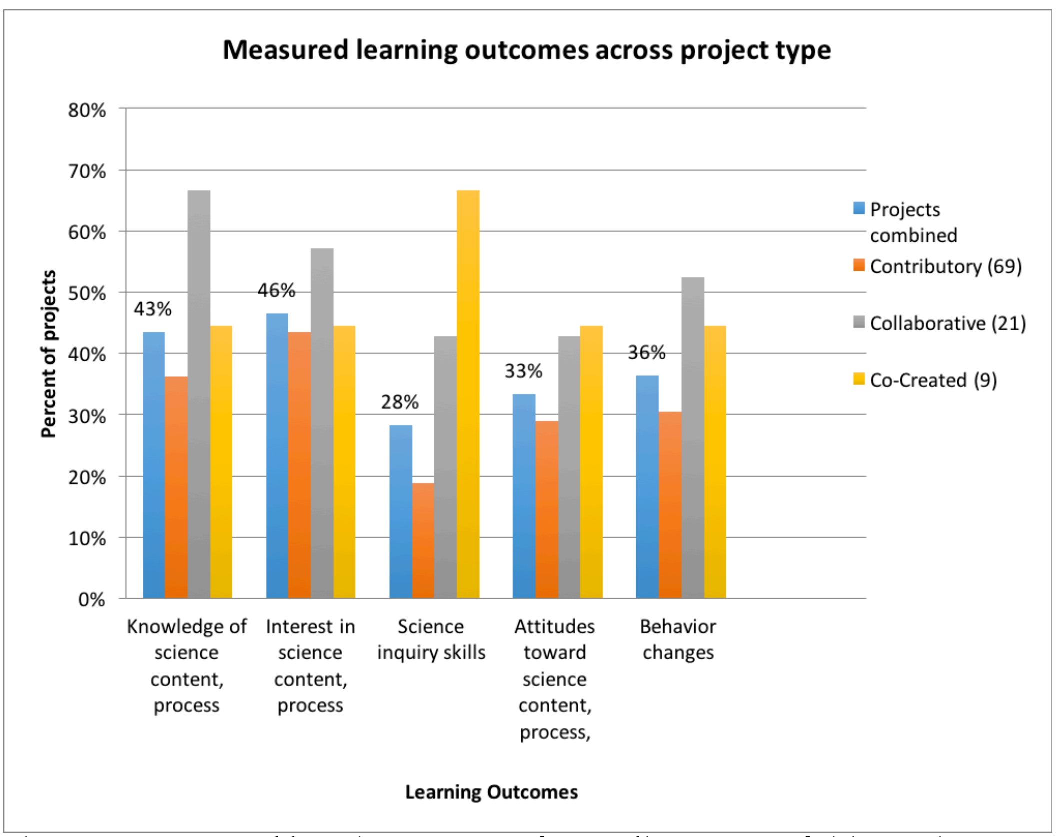


Figure 2.1: Measured learning outcomes from online survey of citizen science practitioners that reported having conducted some type of evaluation (n=99).

It is important to note the limitation of the small sample sizes from both the co-created and collaborative projects making generalizing the nature of learning outcomes within these project types challenging. Also, it is unclear if the distributions across project types reflect actual proportions of these types in the field or is a function of response bias. This presents a further limitation if the audience members in the Citizen Science Discussion Listserv are primarily practitioners of contributory projects. Collectively, however, the survey data does provide strong evidence that the ISE framework categories not only align with citizen science outcomes, but attempts to measure them have occurred, albeit to varying degrees.

Combining the results of RQ1 and RQ3 produces several findings that help to develop a more robust operationalization of common learning outcomes for citizen science (described in Research Question 4, below). First, both data sets helped to "ground truth" the Friedman et al. (2008) framework, which consists of five broad impact categories (knowledge, engagement/interest, skills, attitude, and behavior). Specifically, a majority of citizen science project websites advertised intended learning outcomes very similar to those in the framework, albeit not always using the same language. Additionally, practitioners in the online survey described attempts at measuring these very same outcomes, albeit to varying degrees. Open-ended responses highlighted the need to emphasize efficacy and motivation as important learning outcomes in citizen science. Survey respondents also made it clear that additional resources are needed to help formulate and measure learning outcomes. Collectively, results from these empirically-derived datasets were synthesized and compared together to determine gaps and overlaps between intended and measured learning outcomes and to inform the final research question.

Research Question 2.4: How can common learning outcomes be operationalized for citizen science?

As noted, results from the website review and practitioner survey were synthesized to inform the fourth question: "How can common learning outcomes be operationalized for citizen science?" An extensive literature review was conducted on each of the constructs, resulting in the development of a conceptual model for operationalizing common learning outcomes, particularly in environmentally based citizen science projects (Figure 2.2). Some of the constructs in the conceptual model, such as skills of science inquiry, map quite well to the categories in the ISE framework. Other constructs, such as "attitude" required further specificity, description, or contextualization to citizen science to be included in the model. Thus, the conceptual model combines both empirical data and theoretical contributions and includes the following constructs: Interest in Science and the Environment; Self-efficacy for Science and the Environment; Motivation for Science and the Environment; Knowledge of the Nature of Science; Skills of Science Inquiry; and Behavior and Stewardship.

The conceptual model presented in Figure 2.2 should help practitioners consider some of the more common and achievable learning outcomes when developing their program theory. The individual learning outcomes discussed here are not hierarchical but, beginning with interest in science and the environment, build from and also help to reinforce each other. It is important to emphasize, however, that no single project should try to achieve and/or measure all of these outcomes, as doing so can set up unreasonable expectations for both the project and the evaluation. Although the model's representation implies equal contribution from the six constructs, that is not the intention. Nor is this conceptual model exhaustive. Indeed, as citizen science continues to expand, new research will inevitably reveal other learning constructs that are important to articulate and measure. Below, the constructs within the conceptual model are described, highlighting how they have been studied more broadly and providing examples of their use in published studies of citizen science.

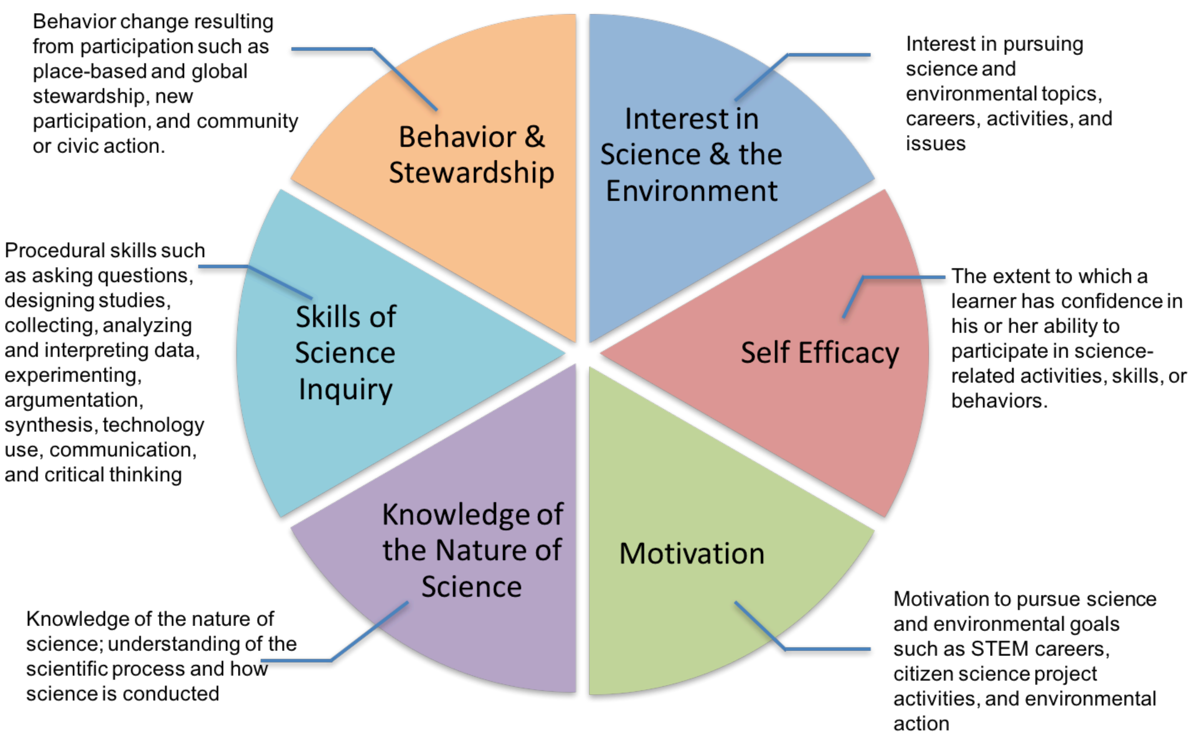


Figure 2.2: Conceptual model for evaluating individual learning outcomes in citizen science.

Interest in Science and the Environment

Interest in science is considered a key driver to pursuing science careers in youth (Maltese and Tai 2010, Tai et al. 2006) and sustained lifelong learning and engagement in adults (Falk et al. 2007, Hidi and Renninger 2006). Further, interest is noted as an important precursor to deeper engagement in democratic decision-making processes regarding science and technology (Mejlgaard and Stares 2010). Although interest is considered to be an attitudinal structure (see Bauer et al. 2000, Fenichel and Schweingruber 2010, Sturgis and Allum 2004), equating interest with attitudes should be avoided because attitude is a very broad construct, encompassing related but distinct sub-constructs such as efficacy, interest, curiosity, appreciation, enjoyment, beliefs, values, perseverance, motivation, engagement, and identity (Osbourne et al. 2003). Interest also has been used synonymously with engagement (Friedman et al. 2008), but as McCallie et al. (2009) point out, engagement has yet to be well defined and has multiple meanings within the literature, particularly ISE. Within ISE, Hidi and Renninger (2006) treat interest as a multi-faceted concept encompassing cognitive (thinking), affective, (feeling) and behavioral (doing) domains across four phases of adoption: *triggered situational interest* typically stimulated by a particular event or activity and requiring support by others; *maintained situational interest* which follows triggered interest and is sustained through personally meaningful activities and experiences; *emerging individual interest* characterized by positive feelings and self-directed pursuit of re-engaging with certain activities; and *well-developed individual interest* leading to enduring participation and application of knowledge.

In the conceptual model proposed here, interest as it relates to science and the environment is defined as "the degree to which an individual assigns personal relevance to a science or environmental topic or endeavor." This definition is compatible with Hidi and Renninger's (2006) later phases of interest development, which are characterized by positive feelings and an increasing investment in learning more about a particular topic. Over time, this type of interest can lead to sustained engagement and motivation and can support identity development as a science learner (Fenichel and Schweingruber 2010, National Research Council 2009).

Citizen science projects, especially those for which repeated visits or experiences are the norm, can lend themselves to deeper and sustained interest in science and the environment, yet few studies have looked at interest as an outcome, and those that have find mixed results. Price and Lee (2013) reported increased interest in science among Citizen Sky observers, and more so among participants who engaged in online social activities. Crall et al. (2012) examined interest in science in general as a reason for participation in citizen science and suggested that interest was not a driving force for joining a project. Interest in specific nature-based topics such as butterflies was seen as a driver for engagement and also as a motivator for adding on increasingly more complex data protocols in the French Garden Butterflies Watch project (Cosquer et al. 2012). Other research has shown that interest in natural resource use can be a very strong determinant for future and sustained involvement in the decision-making process over natural resource management (Danielsen et al. 2009). From these few studies, it would appear that examining interest in science more broadly may be less effective than measuring specific science topics; however, audience motivations may also play a role in using interest as a factor to participation.

Self-efficacy for science and environmental action

Another important construct for studying learning in adult audiences is self-efficacy, or a person's beliefs about his/her capabilities to learn specific content and perform particular behaviors (Bandura 1997). Research has found that self-efficacy affects an individual's choice, effort, and persistence in activities (Bandura 1982, 2000, Schunk 1991). Individuals who feel efficacious put more effort into their activities and persist at them longer than those who doubt their abilities. Self-efficacy is sometimes referred to as "perceived competence" (in Self Determination Theory) and "perceived behavioral control" (Ajzen's Theory of Planned Behavior 1991). Berkowitz et al. (2005) treat self-efficacy as an essential component in environmental citizenship (along with motivation and awareness) that is dependent on an individual's belief that they have sufficient skills, knowledge, and opportunity to bring about positive change in their personal lives or community.

In the context of citizen science, self-efficacy is the extent to which a learner has confidence in his or her ability to participate in a science or environmental activity. In a study involving classrooms, middle school students participating in a horseshoe crab citizen science project showed greater gains in self-efficacy, interest, outcome expectations, and academic achievement than a control group **(**Hiller 2012). In an online astronomy project, however, researchers found a significant decrease in efficacy toward science, possibly owing to a heightened awareness of how much participants did not know about the topic previously (Price and Lee 2013). Crall et al. (2011) determined that self-efficacy is not only important in carrying out the principal activities of the project but also in the potential for individuals to carry out future activities related to environmental stewardship. Working in a participatory action project with *Salal* harvesters, Ballard and Belsky (2010) found that the process of co-developing and implementing different experiments increased workers' efficacy of their skills in scientific research. Although efficacy was not directly called out in the Friedman et al. Framework (2008), it can be considered part of the LSIE Strand 6, "identity as a learner" (National Research Council 2009). Self-efficacy also was mentioned by project leaders in the online survey and appears to be an important potential outcome from participation, therefore it is included in the conceptual model.

Motivation for science and the environment

Motivation is a multi-faceted and complex attitudinal construct with literally dozens of theories, which are beyond the scope of this paper to describe. In general, however, most theories about motivation describe some form of goal setting to achieve a behavior or end result. The LSIE strands (National Research Council 2009) include motivation to sustain science learning over an individual's lifetime as an important aspect of learning in informal environments. The literature on volunteerism frames motivation as an important factor in effective recruitment, accurate placement, and volunteer satisfaction and retention (Clary and Snyder 1999, Esmond et al. 2004). The Volunteer Functions Inventory (VFI), developed by Clary et al. (1998), examines how individuals' behaviors helps them achieve personal and social goals. Clary et al.'s (1998) categories of motivation include values (importance of helping others), understanding (activities that fulfill a desire to learn), social (influence by significant others), career (exploring job opportunities or work advancement), esteem (improving personal self-esteem), and protective (escaping from negative feelings). Schrock et al. (2000) used the VFI with Master Gardeners and found all six categories represented, with learning and values being the most important. Wright et al. (2015) studied the motivations of birders in South Africa using a modified version of the VFI and found five categories of motivation to be most important: recreation/nature, values, personal growth, social interactions, and project organization. The VFI has also been studied in conjunction with instruments that measure altruism, sometimes referred to self-interest motivation (Burns et al. 2006). Altruism was found to be significantly correlated to all six functional motivations, but strongest toward social, protective, understanding, or value motivations to volunteer (Burns et al. 2006). This finding suggest that altruism may indeed play a role in determining who does and does not volunteer, but the strength of altruism is variable depending on the primary motivation. The emphasis on other motivators is due to a lack of evidence depicting altruism as the primary driver (Batson et al. 2003).

Self-determination theory (SDT), with its roots in clinical psychology, treats motivation as an explanatory variable for meeting basic psychological needs (i.e., competency, relatedness, and autonomy) and describes different types of motivations as falling on a continuum from intrinsic to extrinsic. SDT is often used to examine the associations among different motives for volunteering, satisfaction of basic psychological needs, satisfaction and learning while volunteering, and intentions for future volunteer work (Ryan and Deci, 2000a; 2000b). According to SDT, individuals are likely to continue pursuing a goal to the extent that they perceive intrinsic value in the pursuit of that goal (i.e., the extent to which they experience satisfaction in performing associated behaviors themselves versus performing behaviors to comply with extrinsic goals such as conforming to social pressures or receiving rewards). Although SDT can help practitioners better understand the psychological needs behind participation, few known studies have used STD in the context of citizen science. One exception is a recent paper by Nov et al. (2014) that used SDT with social movement participation models in an examination of three digital citizen science projects. Interestingly, they found that intrinsic motivation was one of four drivers that influenced quantity of participation, but that it did not affect quality of participation.

In the context of citizen science, motivation can serve as both an input and outcome, i.e., to understand the basis of motivation for ISE/citizen science experiences (input) and to sustain motivation to continue participating over long time periods (outcome). With the exception of Nov et al. (2014), most published literature on motivations for citizen science tends to focus on *reasons* for participation without presenting an explicit theoretical frame. For example, McCaffrey (2005) described "helping" as a main reason for citizen involvement in the Tucson Bird Count project. Hobbs and White (2012) examined open-ended reasons for participation among volunteers in UK garden and bird watch programs. In both projects, personal interest in wildlife, followed by contributing data to help conservation, were the most commonly cited responses. Bell et al. (2008) cited a connection to nature and socializing with like-minded people as the two most important motives for participation in nine different European citizen science projects. Mostly qualitative data from a large-scale online astronomy project revealed multiple motivations for participation including love for astronomy, desire to contribute, and amazement with the vastness of space (Raddick et al. 2010). Reed et al. (2013) examined motivation in Galaxy Zoo participants using an exploratory factor analysis, which suggested three generic motivations: online social engagement with others, enjoyment and interaction with the Zooniverse website features, and helping or contributing to the project. Another study of motivation in online projects described a complex and changing framework for motivation that was influenced by participant interest, recognition, and attribution (Rotman et al, 2012). Although there are several studies examining motivation, it is not defined nor studied uniformly. The major consensus from these studies appears to be that motivation is dynamic and complex.

Knowledge of the Nature of Science and Science Process

Included within Friedman et al.'s (2008) impact category of "awareness, knowledge, and understanding" are several subcategories such as knowledge and understanding of science content, science processes, and the Nature of Science. Knowledge of science content refers to understanding of subject matter, i.e., facts or concepts. Understanding the process of science refers to the methodologies that scientists use to conduct research (for example, the hypothetico-deductive model or "scientific method"). Understanding the Nature of Science (NOS) refers to the epistemological underpinnings of scientific knowledge and how it is generated, sometimes presented from a post-positivist perspective (Lederman 1992). NOS addresses tenets of science such as tentativeness, empiricism, subjectivity, creativity, social/cultural influence, observations and inferences, and theories and laws (see Lederman 1992, 1999, Lederman et al. 2001, 2002). Generally, understanding of the process of science and NOS are considered more important than understanding basic content or subject matter for improving scientific literacy (American Association for the Advancement of Sciences 1993, National Research Council 1996, Next Generation Science Standards -NGSS 2013). Despite this recognition, most attempts at measuring science literacy fall back on content knowledge, i.e., rote memorization of facts, rather than knowledge of the process of science (Bauer et al. 2000, Shamos 1995).

As in other learning environments, attempts at influencing and measuring science literacy in citizen science have been simplified to assess content knowledge. The majority of studies have focused on the effectiveness of citizen science projects to teach science content related to a specific topic (Ballard and Huntsinger 2006, Bonney 2004, Braschler et al. 2010, Brewer 2002, Brossard et al. 2005, Devictor et al. 2010, Evans et al. 2005, Fernandez-Gimenez et al. 2008, Jordan et al. 2011, Kountoupes and Oberhauser 2008, Krasny and Bonney 2005, Phillips et al. 2006, Sickler et al. 2014, Trumbull et al. 2000, Trumbull et al. 2005). A few exceptions include Overdevest et al. (2004), which did not find a significant increase in knowledge about streams and water quality, probably because new volunteers were already highly knowledgeable about the subject matter. Price and Lee (2013) actually found a decrease in science content knowledge, owing to exaggerated notions of participants' self-perceived content knowledge before starting the project and the realization of how much they did not know after project participation.

Knowledge of the process of science is a regular component of well-established assessments of science knowledge in both formal education and the U.S. workforce as evidenced by its inclusion in the National Science Board's Science and Engineering Indicators surveys (National Science Board 2014), but only a few studies have used these measures in citizen science projects. Jordan et al. (2011) and Brossard et al. (2005) used non-standardized measures and showed no gains in understanding of the process of science as a result of citizen science participation. Using interview data, Ballard et al. (2008) showed evidence that the *Salal* harvesting project "…increased local people's understanding of the scientific process and of the ecosystem on which they were a part (p.14)". Significant increases in understanding of the process of science before and after participation in a stream water quality-monitoring project, was reported by Cronin and Messemer (2013), however, this study had a very small sample size.

Likewise, few citizen science projects have attempted to study understanding of the NOS. Jordan et al. (2011) found no evidence for change in knowledge of the NOS using pre-post scenario-based questions in an invasive species project. Price and Lee (2013) found little evidence for project participation influencing epistemological beliefs about NOS, owing to the fact that "epistemological beliefs are personal beliefs and thus harder to change after participating in only one citizen science project" (p. 793). These findings suggest that while citizen science can effectively demonstrate content knowledge gains, it has a long way to go before it can positively establish increases in science process and understanding of the NOS.

Science inquiry skills and practices

The last several decades have seen no shortage of emphasis on scientific literacy, due in part to the standards movement spearheaded by organizations such as the American Association for the Advancement of Science (*Benchmarks for Science Literacy* 1993) and the National Research Council (*National Science Education Standards* 1996, *Next Generation Science Standards* NGSS 2013). Together these documents specify learning goals for K-12 students that integrate diverse content knowledge with experience in the practices of scientific literacy. Although there is no single definition of scientific literacy, researchers generally agree that it is a complex construct comprising content understanding of scientific concepts and practices, understanding of how knowledge is created, being able to think logically and critically when making personal decisions (i.e., habits of mind), understanding science as a social process, foundational literacy in the use of language as well as mathematics, and possessing certain abilities such as evaluating evidence that can be transferred to daily life (National Academies of Science, Engineering, and Medicine 2016).

For the purpose of this work, the focus is on the subset of scientific literacy dealing with "*abilities*," often referred to as "science inquiry skills." Such skills have many dimensions and interpretations. For example, inquiry can be a method used by scientists to answer questions about the natural world (Windschitl et al. 2008). Or, scientific inquiry can be a set of abilities, both physical and mental, to be acquired by students (Schwartz et al. 2004). Others describe inquiry as an amalgamation of teaching strategies to facilitate specified learning outcomes (Bybee 2000). The skills construct in the conceptual model proposed here aligns best with the NGSS (2013) description of inquiry because of the focus on observable practices such as asking and answering questions; collecting data, developing and using models; planning and carrying out investigations; reasoning about, analyzing, and interpreting data; constructing explanations; communicating information; and using evidence in argumentation.

The hands-on nature of many environmentally based citizen science projects makes them particularly well suited to influence the development and/or reinforcement of certain science-inquiry skills including asking questions; designing studies; collecting, analyzing, and interpreting data; and discussing and disseminating results (Bonney et al. 2009a, Jordan et al. 2012, Phillips et al. 2012, Trautmann et al. 2012). Following protocols and exercising accurate data collection skills are top priorities for practitioners, because together, these practices can directly influence data quality. The field-wide emphasis on data quality likely comes from the over-representation of contributory, scientist-driven projects, where a key goal is to gather data of sufficient quality to add to the existing knowledge base and to be published in peer-reviewed journals. Consequently, the inquiry skills that citizen science projects can most effectively influence are those related to data and sample/specimen collection, identification of organisms, instrument use, and sampling techniques. Many projects also engage participants in the use of various technological tools such as the use of GPS units, digital thermometers, water conductivity instruments, rain gauges, nets, and smartphones, to name just a few.

A small number of researchers have begun to study skill acquisition in citizen science. Becker et al. (2013) showed an increase in estimation of noise levels with increasing participation in WideNoise, a soundscape project operated through mobile devices. Increases in youths' self-reported science inquiry skills, such as their perceived ability to identify pond organisms and develop testable hypotheses before and after participation in Driven to Discover, have also been reported (Meyer et al. 2014). Sullivan et al. (2009) describe the use of communication prompts and strategies to "steer birders toward providing more useful data" and essentially changing the birding habits of eBird participants to provide more high-quality data. Using the theory of legitimate peripheral participation, Mugar et al. (2014) used practice proxies, a form of virtual and trace ethnography, to increase accuracy of data annotation among new members. Additionally, some projects have successfully conducted small-scale studies that compare volunteer-collected data to those collected by experts, thereby creating a baseline metric for their participants' skills (see Crall et al. 2011, Jordan et al. 2011, Schmeller et al. 2009).

Another hallmark of citizen science is the collection of large, publicly available data sets and rich, interactive data visualizations. Many projects that provide data visualizations also may seek to enhance skills related to data interpretation, i.e., the ability to effectively comprehend information and meaning, often presented in graphical form (Devictor et al. 2010). Dozens of extant assessments look at various facets of data interpretation, most of which originate in formal school systems. However, the content matter of these assessments varies widely and is often in a test-like format, which typically does not translate well in informal environments. Numerous studies across multiple decades have shown that assessing the type of reasoning skills needed for data interpretation requires asking a series of reflective questions to determine one's justification underlying the reasoning (e.g., Ayala et al. 2002, Roth and Roychoudhury 1993). In one of the few studies examining data interpretation in citizen science, Thompson and Bonney (2007) showed that even the majority of "active users" of eBird did not use the extensive array of data-analysis tools properly.

Other NGSS inquiry skills such as study design, communication, critical thinking, decision making skills and critically evaluating results are less studied within the citizen science literature. Crall et al. (2012) used open-ended questions to determine whether engaging in an invasive species project improved the abilities of participants to explain a scientific study, write a valid research question, and provide a valid sampling design. The researchers noted positive gains in all but the ability to explain a scientific study. Char et al. (2014) found an increase from pre-post training in COASST volunteers' ability to correctly weigh evidence to determine if there was enough information for accurate species identification. These few studies show potential for using citizen science to study and evaluate more complex science inquiry skills, but better measures are needed for quality assessments of these skills.

Behavior and Stewardship

Behavior change and development of environmental stewardship are among the most sought-after outcomes in science and environmental education programs, both in and out of schools (Bodzin 2008, Heimlich et al. 2008, Kollmuss and Agyeman 2002, Stern 2000, Stern et al. 2008, Vining and Ebreo 2002). Dozens of theories examine various determinants of environmental behavior including: theories espousing the links between knowledge, attitude, and behavior (Hungerford and Volk 1990, Kollmuss and Agyeman 2002, Osbaldiston and Schott 2012, Schultz 2011); attitudes and values (Ajzen 1985, Fishbein and Ajzen 1975); and behavior modification and intervention (De Young 1993).

Here behavior and stewardship is defined as measurable behaviors resulting from engagement in citizen science, but external to the protocol activities and the specific project-based skills of the citizen science project. For example, collecting water quality data may be a new behavior for an individual, but it is part of the project protocol and therefore should be measured as a new skill, rather than a new behavior.

Decreasing water usage as a result of participating in a water quality monitoring project would be an example of behavior change. Through an extensive literature review focused on environmental behavior, five categories of behavior and stewardship were identified that are of interest to the citizen science field: global stewardship behaviors, place-based behaviors, new participation, community or civic action, and transformative lifestyle changes.

Global stewardship refers to deliberate changes in behavior that minimize one's individual ecological footprint and which collectively can have global influence (e.g., installing low-flow shower heads, recycling, purchasing locally grown food, purchasing energy-efficient appliances). Place-based stewardship refers to observable actions to directly maintain, restore, improve, or educate about the health of an ecosystem beyond the activities of a citizen science project (e.g., removing invasive species, cleaning up trash, eliminating pesticide use, engaging in outreach to youth groups). New participation is defined as engagement in science or environmental activities, organizations, or projects spurred on by participation in a citizen science project. Community or civic action refers to participation in civic, governmental, and cultural affairs to solve problems at the local, regional, or national level. This could include donating to environmental organizations, signing petitions, speaking out against harmful environmental practices, or recruiting others to participate in environmental causes. Finally, transformative lifestyle changes are efforts that require a strong up-front cost or long-term commitment to maintain, such as investing in a hybrid vehicle, becoming a vegetarian, or pledging to use mass transit whenever possible.

Citizen science projects, especially those dealing with environmental topics, are typically hands-on, occur in local environments, and require repeated monitoring and data gathering, making them natural conduits for affecting behavior change in participants (Wells and Lekies 2012). However, research has been limited and results have been mixed regarding the influence of citizen science on behavior change. For example, in a study examining two different projects, one on pollinators, the other on coyotes, Toomey and Domroese (2013) show that participants engage in new similar activities and change their gardening practices, but otherwise did not take part in advocacy or change their environmental stewardship practices. Crall et al. (2012) found significant differences between current and planned behavior as a result of participating in an invasive species project using self-reported measures, but the actual behavior change was not adequately described. Using a case-study approach, Oberhauser and Prysby (2008) claim that participants of the Monarch Larva Monitoring Project "work to preserve habitat at many levels, from advocating a more environmentally friendly mowing regimen and insect-friendly pest control, to challenging parking lot, building, and road development projects that threaten monarch habitat" (p. 104). However, the source of these data or accompanying methodology are not well described. Cornwell and Campbell (2011) also used a case study approach and were able to document advocacy and political action by volunteers that directly benefited sea turtle conservation. Evans et al. (2005) documented locally, place-based stewardship in a bird breeding program while other projects showed no change in place-based stewardship practices (Jordan et al. 2011). In a study of human health effects of industrial hog operations, Wing et al. (2008) describe actions being taken by community groups to engage in decision-making that address local environmental injustices. These examples provide some evidence that citizen science may influence behavior and stewardship, but more robust methodologies are needed to suggest causation. There is also plenty of anecdotal data highlighting other examples of behavior change that have not been published or that may exist in the gray literature.

LIMITATIONS

Results from the review of project websites and the practitioner survey confirm the applicability of the ISE frameworks, albeit modified and contextualized to citizen science, and reveal the ways in which constructs within the conceptual model can be operationalized. However, several limitations of the study are apparent. First, distribution across the project types in the online survey is a limitation. It is unclear if this is an actual reflection of the distribution of contributory, collaborative, and co-created projects across the U.S. and Canada, or if a disproportionate number of contributory projects were reached and responded to the survey request. No additional effort was made to include more collaborative and co-created projects in the survey, thus response bias may be an issue. Also, while effort was made to make sure projects from the practitioner survey were also included in the website review, project level data from the two sources were not examined together. Doing so was beyond the scope of work and likely would have violated confidentiality conditions. Lastly, this work reflects a descriptive study, based largely on self-reports in the case of the practitioner survey and advertised outcomes in the case of the website review. This limitation points to the need for more robust inferential studies that can examine field-wide relationships and causal factors.

DISCUSSION

Despite these limitations, the findings provide much needed insight regarding the ways in which learning has been articulated, studied, and measured in citizen science, as well as the role of evaluation in general. For example, an overwhelming majority of respondents expressed positive attitudes toward the evaluation process and the value of evaluation. Yet, there was an obvious need for additional support and resources. Nearly all respondents reported developing their own instruments, despite the fact that most projects measured very similar constructs, but all in different ways. The fact that very few projects had ever heard of the available resources for help with evaluation and finding instruments, suggests that more needs to be done to disseminate tools and resources to the citizen science professional community.

The coarse comparison of intended outcomes described on project websites and outcomes that were measured by projects also highlights interesting tensions that exist within citizen science. For example, less than 5% of project websites stated "increasing interest in science and/or the environment" as an intended outcome, yet across all projects in the online survey, interest in science was the most commonly measured outcome (46%). The frequent measure of interest in science may be due to the relative ease in obtaining instruments to measure this construct or it may be a proxy for interest in the specific topic (e.g., birds, butterflies, astronomy, weather). Still, few studies have published data about changes in interest, likely because the typical demographic of citizen science participants (Caucasian, older, highly educated) already demonstrate a high interest in science when they join a project, making change difficult to detect (Brossard et al. 2005, Thompson and Bonney 2007). Similarly, because many citizen science projects have an environmental focus, attempts to measure attitudes toward nature and the environment have demonstrated a ceiling effect, which is not surprising given that citizen science participants may also be predisposed to positive feelings toward the environment. However, there is ample opportunity to reach those who are not already engaged in citizen science, especially underserved audiences, where access to informal science programming may be limited (Bonney et al. 2016, Flagg 2016). Additionally, projects that reach youth audiences in k-12 settings can minimize self-selection bias and carry out quasi-experimental studies to determine whether interest in science is leveraged through citizen science participation (Bonney et al. 2016).

Self-efficacy was seldom stated as an outcome in the website review; nor was it included in the major categories of outcomes in the online survey. However, approximately 10% of respondents alluded to the idea of "agency," "confidence," or "efficacy" in open comments. As stated earlier, self-perceptions of efficacy affect individuals' choices of activities to pursue, how much effort they will put towards them, and how long they will persist in those pursuits (e.g., Bandura et al. 1977, Weinberg et al. 1979). Enhancing these perceptions may be the single most important outcome for many citizen science projects, and as such it is included in the conceptual model.

As with self-efficacy, few project websites mentioned motivation as a learning outcome. Indeed, in our online survey, it was mostly measured by practitioners to understand reasons for participation. However, there is a strong argument that motivations change over time and to sustain participation it is important to understand motivations for retention and changing roles within a project. More work is needed to understand how motivations connect to Self Determination Theory and serve psychological needs within the context of citizen science. For example, the desire to contribute may be associated with a psychological need for competence; the desire to engage socially with others may serve the psychological need for relatedness. Future examinations of where motivations fall within this intrinsic-extrinsic continuum are needed to understand how motivation might influence sustained participation over time.

Results from the website review and online survey of practitioners reiterate the inclination to expect and measure science *content* gains, typically through context-specific instruments that measure mastery of project activities and program content, rather than increasing knowledge about the process or Nature of Science. Although citizen science provides an authentic context for understanding science process and the Nature of Science, and some projects have begun to demonstrate outcomes related to "thinking scientifically" (Braschler et al. 2010, Kountoupes and Oberhauser 2008, Trumbull et al. 2000), a large gap remains in our understanding of the potential for citizen science to influence deeper understanding of the process and Nature of Science as well as the more complex facets of science inquiry (i.e., critical thinking, reflection, and reasoning). Future work should focus on the development of robust and contextually appropriate tools to better capture deep reflection and rich dialogue about NOS.

In perhaps the most surprising finding of the research, more than half of project websites (55%) in our study listed data collection as an expected outcome, yet across all projects combined, skills related to data collection were the least-measured outcome in the online survey (28%). These findings are not surprising given the difficulty in measuring attributes such as skills acquisition, and the relative ease of measuring other constructs such as knowledge, interest, and attitude. This disconnect also represents a potential tension that exists within the field, particularly among contributory projects: the need for high confidence in data quality, and the dearth of examples assessing data collection skills. While several published studies demonstrate that volunteers are able to collect data similar to experts, these tend to be isolated examples (Crall et al. 2011, Danielsen et al. 2014). Although there are a multitude of ways to validate citizen-science collected data (see Kosmala et al. 2016), there is still a need for tools and techniques that can assess changes in participant data collection skills over time.

Additionally, there is a need to better understand if citizen science can influence other important inquiry skills such as the ability to make decisions regarding appropriate methodologies to best answer scientific questions, use variables and control groups properly, and evaluate evidence. With increased attention on the potential for citizen science to democratize science, further work should examine the extent to which it can support development or reinforcement of critical thinking skills that inform decision making and an informed citizenry. Conversely, in this new world of "Big Data," citizen science is well poised to not only provision the public with large and robust data sets, but also to develop support systems so that users can understand how to effectively use these dynamic resources. Such provisioning also may facilitate new lines of research to better understand how participants engage with these data sets and what meaning they hold for them.

Finally, in the website review, environmental stewardship was mentioned as an outcome by 25% of projects, second only to data collection, suggesting that there is a strong desire on the part of citizen science projects to influence individual behavior change. Although roughly a third of the online survey respondents reported measuring behavior change, in some cases practitioners may see the act of participating in projects as behavior change itself, whereas behavior change here is defined as behavior change that goes beyond the project activities. Other challenges exist with respect to tacit assumptions about behavior change such as the assumption that specific project activities—for example, water-quality monitoring—can lead to more global environmental behaviors such as reducing carbon emissions, recycling, and conserving energy (Kollmuss and Agyeman 2002, Vining and Ebreo 2002). Intended behavioral outcomes should be directly connected to project content and activities, and the knowledge of how to perform these targeted behaviors should be made explicit to participants (Phillips et al. 2012, Toomey and Domroese 2013). Citizen science can likely impact behavior change; however, the development of effective implementation strategies and measurement of those impacts are still in their infancy.

CONCLUSION

Worldwide, thousands of environmentally based citizen science projects exist, reaching potentially millions of people in the observation and monitoring of species and habitats. It is purported that such projects have the potential not only to engage individuals in the process of science, but also to encourage them to take positive action on behalf of the environment (McKinley et al. 2016). If such outcomes are to be achieved, project developers need to better understand how to design projects so that activities and educational learning opportunities support and align with feasible and realistic outcomes (Shirk et al. 2012). The main goal of this research was to provide a conceptual model to support citizen science practitioners in articulating and measuring individual learning outcomes from their projects. In addition, this work is intended to facilitate capacity building for project leaders to conduct evaluations of their programs. In particular, projects should consider program theory to carefully articulate a project's underlying assumptions about how activities affect expected outcomes (Bickman 2000, Chen 2005, Funnel 2000, Funnell and Rogers 2011). In this regard, most evaluators recommend starting with articulation of project outcomes, then working backwards to determine not only what can be achieved and how, but also what can be reasonably measured.

Concurrent work to this research is developing generic, yet customizable, scales that have been tested as valid and reliable in citizen science contexts and that align to the conceptual model described above (see DEVISE: http://www.birds.cornell.edu/citscitoolkit/evaluation/instruments). With adoption of common learning outcomes and measures, the field of citizen science can build evaluation capacity and begin to conduct cross-programmatic analyses of citizen science to provide funders, stakeholders, and the general public with evidence-based findings about the potential for citizen science to impact the lives of its volunteers. Such studies could provide critical information regarding why and how to achieve outcomes and under what conditions outcomes can be maximized.

Future work should support continued development of consistent measures that can be used across studies, particularly those that do not rely on self-reports (Becker-Klein et al. 2016, Phillips et al. 2012, Wells and Lekies 2012). Continued professional development opportunities for citizen science practitioners to spearhead evaluations of projects will build capacity for such endeavors, build a steady source of knowledge about impacts, and lead to improved project design, implementation, and sustainability for the field as a whole. Initiation of more in-depth longitudinal studies that can measure persistence of change over time would add much needed understanding of the impacts of such experiences (Schneider and Cheslock 2003). To the extent possible, more effort should be placed on studies that include experimental designs, random assignment, and control groups. Such efforts will increase the field's ability to provide evidence for causal connections between citizen science participation and learning outcomes. Finally, as citizen science continues to grow, it will be important for the field to take a reflective look at its relative impact and evaluate whether the appropriate questions are being asked by the right people across contributory, collaborative, and co-created projects. Such an analysis will be a first step to gathering much needed evidence to demonstrate the potential of citizen science to truly democratize science.

REFERENCES

Ajzen, I. (1985). From Intentions to Actions: A Theory of Planned Behavior. In J. Kuhl and J. Beckmann (Eds.), *Action Control, From Cognition to Behavior* (pp. 11–39). Berlin, Heidelberg: Springer Berlin Heidelberg. Retrieved from http://www.springerlink.com/index/10.1007/978-3-642-69746-3_2.

Ajzen, I. (1991). The theory of planned behavior. *Organizational Behavior and Human Decision Processes*, *50*(2), 179–211. https://doi.org/http://dx.doi.org/10.1016/0749-5978(91)90020-T.

American Association for the Advancement of Science) (Ed.). (1993). *Benchmarks for science literacy*. New York: Oxford University Press.

Ayala, C. C., Yin, Y., Shavelson, R. J., and Vanides, J. (2002). Investigating the cognitive validity of science performance assessment with think alouds: Technical aspects. Presented at the Annual meeting of the American Educational Researcher Association, New Orleans, LA.

Ballard, H. L., and Belsky, J. M. (2010). Participatory action research and environmental learning: implications for resilient forests and communities. *Environmental Education Research*, *16*(5-6), 611–627. https://doi.org/10.1080/13504622.2010.505440.

Ballard, H. L., Fernandez-Gimenez, M. E., and Sturtevant, V. E. (2008). Integration of local ecological knowledge and conventional science: a study of seven community-based forestry organizations in the USA. *Ecology and Society*, *13*(2), 37. https://doi.org/http://hdl.handle.net/10535/2424.

Ballard, H. L., and Huntsinger, L. (2006). Salal harvester local ecological knowledge, harvest practices and understory management on the Olympic Peninsula, Washington. *Human Ecology*, *34*(4), 529–547. https://doi.org/10.1007/s10745-006-9048-7.

Bandura, A. (1982). Self-efficacy mechanism in human agency. *American Psychologist*, *37*(2), 122–147. https://doi.org/10.1037/0003-066X.37.2.122.

Bandura, A. (1997). *Self-Efficacy: The Exercise of Control* (1st edition). New York: Worth Publishers.

Bandura, A. (2000). Exercise of Human Agency Through Collective Efficacy. *Current Directions in Psychological Science*, *9*(3), 75–78. https://doi.org/10.1111/1467-8721.00064.

Bandura, A., Adams, N. E., and Beyer, J. (1977). Cognitive processes mediating behavioral change. *Journal of Personality and Social Psychology, 35*(3), 125-139.

Batson, C. D., van Lange, P. A. M., Ahmad, N. and Lishner, D. L. (2003). Altruism and Helping Behavior. In Hogg, M.A. and Cooper, J. (eds.) *The Sage Handbook of Social Psychology*. London: Sage, pp. 279-295.

Bauer, M. W., Allum, N., and Miller, S. (2007). What can we learn from 25 years of PUS survey research? Liberating and expanding the agenda. *Public Understanding of Science*, *16*(1), 79–95. https://doi.org/10.1177/0963662506071287.

Bauer, M. W., Petkova, K., and Boyadjieva, P. (2000). Public Knowledge of and Attitudes to Science: Alternative Measures That May End the "Science War." *Science, Technology and Human Values*, *25*(1), 30–51. https://doi.org/10.1177/016224390002500102.

Becker-Klein, R., Peterman, K., and Stylinski, C. (2016). Embedded assessment as an essential method for understanding public engagement in citizen science. *Citizen Science: Theory and Practice*, *1*(1). https://doi.org/10.5334/cstp.15.

Becker, M., Caminiti, S., Fiorella, D., Francis, L., Gravino, P., Haklay, M. (Muki), … Tria, F. (2013). Awareness and learning in participatory noise sensing. *PLOS ONE*, *8*(12), e81638. https://doi.org/10.1371/journal.pone.0081638.

Bela, G., Peltola, T., Young, J. C., Balázs, B., Arpin, I., Pataki, G., … Bonn, A. (2016). Learning and the transformative potential of citizen science: Lessons from the Study of Nature. *Conservation Biology*, *30*(5), 990–999. https://doi.org/10.1111/cobi.12762.

Bell, S., Marzano, M., Cent, J., Kobierska, H., Podjed, D., Vandzinskaite, D., … Muršič, R. (2008). What counts? Volunteers and their organisations in the recording and monitoring of biodiversity. *Biodiversity and Conservation*, *17*(14), 3443–3454. https://doi.org/10.1007/s10531-008-9357-9.

Berkowitz, A. R., Ford, M. E., and Brewer, C. A. (2005). A framework for integrating ecological literacy, civics literacy, and environmental citizenship in environmental education. In E. A. Johnson and M. J. Mappin (Eds.), *Environmental Education and Advocacy: Changing Perspectives of Ecology and Education* (pp. 227–266). Cambridge University Press.

Bickman, L. (2000). Summing up program theory. *New Directions for Evaluation*, *2000*(87), 103–112. https://doi.org/10.1002/ev.1186.

Bodzin, A. M. (2008). Integrating instructional technologies in a local watershed investigation with urban elementary learners. *The Journal of Environmental Education*, *39*(2), 47–58. https://doi.org/10.3200/JOEE.39.2.47-58.

Bonney, R. (2004). Understanding the process of research. In D. Chittenden, G. Farmelo, and B. V. Lewenstein (Eds.), *Creating Connections: Museums and the Public Understanding of Current Research* (pp. 199–210). Walnut Creek, CA: AltaMira Press.

Bonney, R., Ballard, H., Jordan, R., McCallie, E., Phillips, T., Shirk, J., and Wilderman, C. C. (2009a). Public participation in scientific research: Defining the field and assessing its potential for Informal Science Education. *A CAISE Inquiry Group Report*. Washington, D.C.: Center for Advancement of Informal Science Education (CAISE). Retrieved from http://eric.ed.gov/?id=ED519688.

Bonney, R., Cooper, C. B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K. V., and Shirk, J. (2009b). Citizen science: A developing tool for expanding science knowledge and scientific literacy. *BioScience*, *59*(11), 977–984. https://doi.org/10.1525/bio.2009.59.11.9

Bonney, R., Phillips, T. B., Ballard, H. L., and Enck, J. W. (2016). Can citizen science enhance public understanding of science? *Public Understanding of Science*, *25*(1), 2–16. https://doi.org/10.1177/0963662515607406.

Bonney, R., Shirk, J. L., Phillips, T. B., Wiggins, A., Ballard, H. L., Miller-Rushing, A. J., and Parrish, J. K. (2014). Next steps for citizen science. *Science*, *343*(6178), 1436–1437. https://doi.org/10.1126/science.1251554.

Braschler, B., Mahood, K., Karenyi, N., Gaston, K. J., and Chown, S. L. (2010). Realizing a synergy between research and education: how participation in ant monitoring helps raise biodiversity awareness in a resource-poor country. *Journal of Insect Conservation*, *14*(1), 19–30. https://doi.org/10.1007/s10841-009-9221-6.

Brewer, C. (2002). Outreach and partnership programs for conservation education where endangered species conservation and research occur. *Conservation Biology*, *16*(1), 4–6.
Brossard, D., Lewenstein, B., and Bonney, R. (2005). Scientific knowledge and attitude change: The impact of a citizen science project. *International Journal of Science Education*, *27*(9), 1099–1121. https://doi.org/10.1080/09500690500069483
Burns, D. J., Reid, J. S., Toncar, M., Fawcett, J., and Anderson, C. (2006). Motivations to volunteer: The role of altruism. *International Review on Public and Non Profit Marketing*, 3(2):79-91.
Bybee, R. W. (2000). Teaching science as inquiry. In J. Minstrell and E. H. van Zee (Eds.), *Inquiring into inquiry learning and teaching in science* (pp. 20–46). Washington, DC: AAAS.
Char, C., Parrish, J., Friesner, J., and Dolliver, J. (2014). Promoting rigorous citizen science: Coastal Observation and Seabird Survey Team (COASST). *Evaluation Report on Citizen Impact.* Seattle, WA: University of Washington.
Chen, H.-T. (2005). Theory-driven evaluation. In S. Mathison (Ed.), *Encyclopedia of Evaluation*. SAGE Publications, Inc. Retrieved from http://sk.sagepub.com/reference/evaluation/n542.xml.
Clary, E. G., and Snyder, M. (1999). The motivations to volunteer: Theoretical and practical considerations. *Current Directions in Psychological Science*, *8*(5), 156–159. https://doi.org/10.1111/1467-8721.00037.
Clary, E. G., Snyder, M., Ridge, R. D., Copeland, J., Stukas, A. A., Haugen, J., and Miene, P. (1998). Understanding and assessing the motivations of volunteers: A functional approach. *Journal of Personality and Social Psychology*, *74*(6), 1516–1530. https://doi.org/10.1037/0022-3514.74.6.1516.
Cooper, C. B., Dickinson, J., Phillips, T., and Bonney, R. (2007). Citizen science as a tool for conservation in residential ecosystems. *Ecology and Society*, *12*(2), 11. https://doi.org/http://hdl.handle.net/10535/2968.
Cornwell, M. L., and Campbell, L. M. (2011). Co-producing conservation and knowledge: Citizen-based sea turtle monitoring in North Carolina, USA. *Social Studies of Science*, *42*(1), 101–120. https://doi.org/10.1177/0306312711430440.
Cosquer, A., Raymond, R., and Prevot-Julliard, A.-C. (2012). Observations of everyday biodiversity: A new perspective for conservation? *Ecology and Society*, *17*(4). https://doi.org/10.5751/ES-04955-170402.
Crain, R., Cooper, C., and Dickinson, J. L. (2014). Citizen science: A tool for integrating studies of human and natural systems. *Annual Review of Environment and Resources*, *39*(1), 641–665. https://doi.org/10.1146/annurev-environ-030713-154609.
Crall, A. W., Jordan, R., Holfelder, K., Newman, G. J., Graham, J., and Waller, D. M. (2012). The impacts of an invasive species citizen science training program on participant attitudes, behavior, and science literacy. *Public Understanding of Science*, *22*(6), 745–764. https://doi.org/10.1177/0963662511434894.
Crall, A. W., Newman, G. J., Stohlgren, T. J., Holfelder, K. A., Graham, J., and Waller, D. M. (2011). Assessing citizen science data quality: an invasive species case study: Assessing citizen science data quality. *Conservation Letters*, *4*(6), 433–442. https://doi.org/10.1111/j.1755-263X.2011.00196.x.
Cronin, D. P., and Messemer, J. E. (2013). Elevating adult civic science literacy through a renewed citizen science paradigm. *Adult Learning*, *24*(4), 143–150. https://doi.org/10.1177/1045159513499550.

Danielsen F., Jensen P. M., Burgess N. D., . . . Young, *R.* (2014). A multicountry assessment of tropical resource monitoring by local communities. *BioScience*, 64*:* 236–51. https://doi.org/10.1093/biosci/biu001.
Danielsen, F., Burgess, N. D., Balmford, A., Donald, P. F., Funder, M., Jones, J. P. G., … Yonten, D. (2009). Local participation in natural resource monitoring: A characterization of approaches. *Conservation Biology*, *23*(1), 31–42. https://doi.org/10.1111/j.1523-1739.2008.01063.x.
Devictor, V., Whittaker, R. J., and Beltrame, C. (2010). Beyond scarcity: citizen science programmes as useful tools for conservation biogeography: Citizen science and conservation biogeography. *Diversity and Distributions*, *16*(3), 354–362. https://doi.org/10.1111/j.1472-4642.2009.00615.x.
De Young, R. (1993). Changing behavior and making it stick: The conceptualization and management of conservation behavior. *Environment and Behavior*, *25*(3), 485–505. https://doi.org/10.1177/0013916593253003.
Dickinson, J. L., and Bonney, R., eds. (2012). *Citizen Science: Public Participation in Environmental Research*. Cornell University Press.
Esmond, J., Dunlop, P., and Clan, W. (2004). Developing the volunteer motivation inventory to assess the underlying motivational drives of volunteers in Western Australia. CLAN WA Perth. Retrieved from http://biggestdifference.com/morevolunteers/resources/MotivationFinalReport.pdf.
Evans, C., Abrams, E., Reitsma, R., Roux, K., Salmonsen, L., and Marra, P. P. (2005). The Neighborhood Nestwatch Program: Participant outcomes of a citizen-science ecological research project. *Conservation Biology*, *19*(3), 589–594. https://doi.org/10.1111/j.1523-1739.2005.00s01.x.
Falk, J. H., and Dierking, L. D. (2002). *Lessons Without Limit: How Free-choice Learning is Transforming Education*. Rowman Altamira.
Falk, J. H., Storksdieck, M., and Dierking, L. D. (2007). Investigating public science interest and understanding: evidence for the importance of free-choice learning. *Public Understanding of Science*, *16*(4), 455–469. https://doi.org/10.1177/0963662506064240
Fenichel, M., and Schweingruber, H. A. (2010). *Surrounded by Science: Learning Science in Informal Environments*. National Academies Press.
Fenwick, T. J. 2000. Expanding Conceptions of Experiential Learning: A review of the five contemporary perspectives on cognition. *Adult Education Quarterly*. 50 (4): 243-272. doi:10.1177/07417130022087035
Fernandez-Gimenez, M. E., Ballard, H. L., and Sturtevant, V. E. (2008). Adaptive management and social learning in collaborative and community-based monitoring: a study of five community-based forestry organizations in the western USA. *Ecology and Society*, *13*(2), 4.
Fishbein, M., and Ajzen, I. (1975). *Belief, Attitude, Intention, and Behavior: An introduction to Theory and Research*. Reading, Mass: Addison-Wesley Pub. Co.
Flagg, B. (2016). Contribution of multimedia to girls' experience of citizen science. *Citizen Science: Theory and Practice*, *1*(2). https://doi.org/10.5334/cstp.51
Friedman, A. J., Allen, S., Campbell, P. B., Dierking, L. D., Flagg, B. N., Garibay, C., … Ucko, D. A. (2008). *Framework for Evaluating Impacts of Informal Science Education Projects, InformalScience.org*. National Science Foundation Workshop. Retrieved from http://www.informalscience.org/framework-evaluating-impacts-informal-science-education-projects.

Funnell, S. C. (2000). Developing and using a program theory matrix for program evaluation and performance monitoring. *New Directions for Evaluation*, (87), 91–101. https://doi.org/10.1002/ev.1185.
Funnell, S. C., and Rogers, P. J. (2011). *Purposeful Program Theory: Effective Use of Theories of Change and Logic Models* (Vol. 31). John Wiley and Sons.
Haywood, B. K., and Besley, J. C. (2014). Education, outreach, and inclusive engagement: Towards integrated indicators of successful program outcomes in participatory science. *Public Understanding of Science*, *23*(1), 92–106. https://doi.org/10.1177/0963662513494560.
Heimlich, J., and Ardoin, N. (2008). Understanding behavior to understand behavior change: a literature review. *Environmental Education Research*, *14*(3), 215–237. https://doi.org/10.1080/13504620802148881.
Hidi, S., and Renninger, K. A. (2006). The four-phase model of interest development. *Educational Psychologist*, *41*(2), 111–127. https://doi.org/10.1207/s15326985ep4102_4
Hiller, S. E. (2012). *The Impact of a Citizen Science Program on Student Achievement and Motivation: A Social Cognitive Career Perspective*. Retrieved from http://mars.gmu.edu/handle/1920/8050.
Hobbs, S. J., and White, P. C. L. (2012). Motivations and barriers in relation to community participation in biodiversity recording. *Journal for Nature Conservation*, *20*(6), 364–373. https://doi.org/10.1016/j.jnc.2012.08.002.
Hungerford, H. R., and Volk, T. L. (1990). Changing learner behavior through environmental education. *The Journal of Environmental Education*, *21*(3), 8–21. https://doi.org/10.1080/00958964.1990.10753743.
Jordan, R. C., Ballard, H. L., and Phillips, T. B. (2012). Key issues and new approaches for evaluating citizen-science learning outcomes. *Frontiers in Ecology and the Environment*, *10*(6), 307–309. https://doi.org/10.1890/110280.
Jordan, R. C., Gray, S. A., Howe, D. V., Brooks, W. R., and Ehrenfeld, J. G. (2011). Knowledge gain and behavioral change in citizen-science programs: Citizen-scientist knowledge gain. *Conservation Biology*, *25*(6), 1148–1154. https://doi.org/10.1111/j.1523-1739.2011.01745.x.
Kollmuss, A., and Agyeman, J. (2002). Mind the gap: Why do people act environmentally and what are the barriers to pro-environmental behavior? *Environmental Education Research*, *8*(3), 239–260. https://doi.org/10.1080/13504620220145401.
Kosmala, M., Wiggins, A., Swanson, A., and Simmons, B. (2016). Assessing data quality in citizen science. *Frontiers in Ecology and the Environment*, 14 (10), 551-560. http://dx.doi.org/10.1002/fee.1436.
Kountoupes, D. L. and Oberhauser, K. S. (2008). Citizen science and youth audiences: Educational outcomes of the Monarch Larva Monitoring Project. *Journal of Community Engagement and Scholarship*, *1*(1), 10–20.
Krasny, M. E., and Bonney, R. (2005). Environmental education through citizen science and participatory action research. In E. Johnson and M. Mappin (Eds.), *Environmental Education and Advocacy: Changing Perspectives of Ecology and Education* (pp. 292–319). Cambridge, UK: Cambridge University Press.
Lederman, N. G. (1992). Students' and teachers' conceptions of the Nature of Science: A review of the research. *Journal of Research in Science Teaching*, *29*(4), 331–359. https://doi.org/10.1002/tea.3660290404.

Lederman, N. G. (1999). EJSE Editorial: The state of science education: Subject matter without context. *Electronic Journal of Science Education*, *3*(2). Retrieved from http://ejse.southwestern.edu/article/view/7602.
Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., and Schwartz, R. S. (2002). Views of Nature of Science questionnaire: Toward valid and meaningful assessment of learners' conceptions of Nature of Science. *Journal of Research in Science Teaching*, *39*(6), 497–521. https://doi.org/10.1002/tea.10034.
Lederman, N. G., Schwartz, R. S., Abd-El-Khalick, F., and Bell, R. L. (2001). Pre-service teachers' understanding and teaching of Nature of Science: An intervention study. *Canadian Journal of Science, Mathematics and Technology Education*, *1*(2), 135–160. https://doi.org/10.1080/14926150109556458.
Lewandowski E., and Oberhauser K. (2017). Butterfly citizen scientists in the United States increase their engagement in conservation. *Biological Conservation*, (208): 106-112. https://doi.org/10.1016/j.biocon.2015.07.029
Maltese, A. V., and Tai, R. H. (2010). Eyeballs in the fridge: Sources of early interest in science. *International Journal of Science Education*, *32*(5), 669–685. https://doi.org/10.1080/09500690902792385.
McCaffrey, R. E. (2005). Using citizen science in urban bird studies. *Urban Habitats*, *3*(1), 70–86.
McCallie, E., Bell, L., Lohwater, T., Falk, J. H., Lehr, J. L., Lewenstein, B. V., and Wiehe, B. (2009). *Many Experts, Many Audiences: Public Engagement with Science and Informal Science Education.* (A CAISE Inquiry Group Report). Washington, D.C.: Center for Advancement of Informal Science Education (CAISE). Retrieved from http://digitalcommons.calpoly.edu/cgi/viewcontent.cgi?article=1011andamp;context=eth_fac.
McKinley, D. C., Miller-Rushing, A. J., Ballard, H. L., Bonney, R., Brown, H., Cook-Patton, S. C., … Soukup, M. A. (2016). Citizen science can improve conservation science, natural resource management, and environmental protection. *Biological Conservation*. https://doi.org/10.1016/j.biocon.2016.05.015.
Mejlgaard, N. and Stares, S. (2010). Participation and competence as joint components in a cross-national analysis of scientific citizenship. *Public Understanding of Science*, *19*(5), 545–561. https://doi.org/10.1177/0963662509335456.
Meyer, N. J., Scott, S., Strauss, A. L., Nippolt, P. L., Oberhauser, K. S., and Blair, R. B. (2014). Citizen science as a REAL environment for authentic scientific inquiry. *Journal of Extension*, *52*(4).
Mugar, G., Østerlund, C., Hassman, K. D., Crowston, K., and Jackson, C. B. (2014). Planet hunters and seafloor explorers: legitimate peripheral participation through practice proxies in online citizen science (pp. 109–119). ACM Press. https://doi.org/10.1145/2531602.2531721.
National Academies of Science, Engineering, and Medicine. (2016). *Science Literacy: Concepts, Contexts, and Consequences.* Washington DC: The National Academies Press. doi:10.17226/23595.
National Research Council. (2009). *Learning Science in Informal Environments: People, Places, and Pursuits*. Washington DC: The National Academies Press.
National Science Board. (2014). *Science and Engineering Indicators 2014* (Vol. (NSB 14–01)). Arlington, VA: National Science Foundation. Retrieved from http://eric.ed.gov/?id=ED565774.

NGSS Lead States. (2013). *Next Generation Science Standards: For States, By States*. Washington, DC: National Academies Press. Retrieved from https://www.nap.edu/catalog/18290/next-generation-science-standards-for-states-by-states.
Nov, O., Arazy, O., and Anderson, D. (2014). Scientists@Home: What drives the quantity and quality of online citizen science participation? *PLoS ONE*, *9*(4), e90375. https://doi.org/10.1371/journal.pone.0090375.
Oberhauser, K., and Prysby, M. D. (2008). Citizen science: creating a research army for conservation. *American Entomologist*, *54*(2), 103–104. https://doi.org/http://dx.doi.org/10.1093/ae/54.2.103
Osbaldiston, R., and Schott, J. P. (2012). Environmental sustainability and behavioral science meta-analysis of proenvironmental behavior experiments. *Environment and Behavior*, *44*(2), 257–299. https://doi.org/10.1177/0013916511402673.
Overdevest, C., Orr, C. H., and Stepenuck, K. (2004). Volunteer stream monitoring and local participation in natural resource issues. *Human Ecology Review*, *11*(2), 177–185.
Phillips, T., Bonney, R., and Shirk, J. (2012). What is our impact? Toward a unified framework for evaluating outcomes of citizen science participation. In J. L. Dickinson and R. Bonney (Eds.), *Citizen Science: Public Participation in Environmental Research* (pp. 82–95). Ithaca, NY: Cornell University Press.
Phillips, T., Lewenstein, B. V., and Bonney, R. (2006). A case study of citizen science. In D. Cheng, J. Metcalf, and B. Schiele (Eds.), *At the Human Scale, International Practices in Science Communication* (pp. 317–334). Beijing: Science Press.
Price, C. A., and Lee, H. S. (2013). Changes in participants' scientific attitudes and epistemological beliefs during an astronomical citizen science project. *Journal of Research in Science Teaching*, *50*(7), 773–801. https://doi.org/10.1002/tea.21090.
Raddick, M. J., Bracey, G., Gay, P. L., Lintott, C. J., Murray, P., Schawinski, K., … Vandenberg, J. (2010). Galaxy Zoo: Exploring the motivations of citizen science volunteers. *Astronomy Education Review*, *9*(1). https://doi.org/10.3847/AER2009036.
Reed, J., Raddick, M. J., Lardner, A., and Carney, K. (2013). An exploratory factor analysis of motivations for participating in Zooniverse, a collection of virtual citizen science projects. In *2013 46th Hawaii International Conference on System Sciences (HICSS)* (pp. 610–619). https://doi.org/10.1109/HICSS.2013.85.
Roth, W. M., and Roychoudhury, A. (1993). The concept map as a tool for the collaborative construction of knowledge: A microanalysis of high school physics students. *Journal of Research in Science Teaching*, *30*(5), 503–534. https://doi.org/10.1002/tea.3660300508.
Rotman, D., Preece, J., Hammock, J., Procita, K., Hansen, D., Parr, C., … Jacobs, D. (2012). Dynamic changes in motivation in collaborative citizen-science projects (pp. 217–226). Presented at the *Computer Supported Cooperative Work 2012*, Seattle, Washington: ACM Press. https://doi.org/10.1145/2145204.2145238.
Ryan, R. M., and Deci, E. L. (2000a). Intrinsic and extrinsic motivations: Classic definitions and new Directions. *Contemporary Educational Psychology*, *25*(1), 54–67. https://doi.org/10.1006/ceps.1999.1020.
Ryan, R. M., and Deci, E. L. (2000b). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American Psychologist*, *55*(1), 68–78. https://doi.org/10.1037/0003-066X.55.1.68.

Schmeller, D. S., Henry, P.-Y., Julliard, R., Gruber, B., Clobert, J., Dziock, F., … Henle, K. (2009). Advantages of volunteer-based biodiversity monitoring in Europe. *Conservation Biology*, *23*(2), 307–316. https://doi.org/10.1111/j.1523-1739.2008.01125.x.
Schneider, B., and Cheslock, N. (2003). *Measuring results*. Coevolution Institute.
Schrock, D. S., Meyer, M., Ascher, P., and Snyder, M. (2000). Reasons for becoming involved as a master gardener. *HortTechnology*, *10*(3), 626–630.
Schultz, P. W. (2011). Conservation means behavior. *Conservation Biology*, *25*(6), 1080–1083. https://doi.org/10.1111/j.1523-1739.2011.01766.x
Schunk, D. H. (1991). Self-efficacy and academic motivation. *Educational Psychologist*, *26*(3-4), 207–231. https://doi.org/10.1080/00461520.1991.9653133.
Schwartz, R. S., Lederman, N. G., and Crawford, B. A. (2004). Developing views of Nature of Science in an authentic context: An explicit approach to bridging the gap between Nature of Science and scientific inquiry. *Science Education*, *88*(4), 610–645. https://doi.org/10.1002/sce.10128.
Shamos, M. H. (1995). *The Myth of Scientific Literacy*. Rutgers University Press.
Shirk, J. L., Ballard, H. L., Wilderman, C. C., Phillips, T., Wiggins, A., Jordan, R., and Bonney, R. (2012). Public participation in scientific research: A framework for deliberate design. *Ecology and Society*, *17*(2). https://doi.org/10.5751/ES-04705-170229.
Sickler, J., Cherry, T. M., Allee, L., Smyth, R. R., and Losey, J. (2014). Scientific value and educational goals: Balancing priorities and increasing adult engagement in a citizen science project. *Applied Environmental Education and Communication*, *13*(2), 109–119. https://doi.org/10.1080/1533015X.2014.947051.
Stern, P. C. (2000). New environmental theories: Toward a coherent theory of environmentally significant behavior. *Journal of Social Issues*, *56*(3), 407–424. https://doi.org/10.1111/0022-4537.00175.
Stern, M. J., Powell, R. B., and Ardoin, N. M. (2008). What difference does it make? Assessing outcomes from participation in a residential environmental education program. *The Journal of Environmental Education*, *39*(4), 31–43. https://doi.org/10.3200/JOEE.39.4.31-43
Sturgis, P., and Allum, N. (2004). Science in society: re-evaluating the deficit model of public attitudes. *Public Understanding of Science*, *13*(1), 55–74. https://doi.org/10.1177/0963662504042690
Sullivan, B. L., Wood, C. L., Iliff, M. J., Bonney, R. E., Fink, D., and Kelling, S. (2009). eBird: A citizen-based bird observation network in the biological sciences. *Biological Conservation*, *142*(10), 2282–2292. https://doi.org/10.1016/j.biocon.2009.05.006
Tai, R. H., Qi Liu, C. Q., Maltese, A. V., and Fan, X. (2006). Planning early for careers in science. *Science*, *312*(5777), 1143–1144. https://doi.org/10.1126/science.1128690.
Theobald, E. J., Ettinger, A. K., Burgess, H. K., DeBey, L. B., Schmidt, N. R., Froehlich, H. E., … Parrish, J. K. (2015). Global change and local solutions: Tapping the unrealized potential of citizen science for biodiversity research. *Biological Conservation*, *181*, 236–244. https://doi.org/10.1016/j.biocon.2014.10.021.
Thompson, S., and Bonney, R. (2007). Evaluating the impacts of participation in an online citizen science project: A mixed-methods approach. In J. Trant and D. Bearman (Eds.), *Museums and the web 2007: Selected papers from an international conference* (pp. 187–199). Toronto: Archives and Museum Informatics.

Toomey, A. H., and Domroese, M. C. (2013). Can citizen science lead to positive conservation attitudes and behaviors? *Human Ecology Review*, *20*(1), 50–62,67.
Trautmann, N., Shirk, J., Fee, J., and Krasny, M. E. (2012). Who poses the question? Using citizen science to help k-12 teachers meet the mandate for inquiry. In J. L. Dickinson and R. Bonney (Eds.), *Citizen Science: Public Participation in Environmental Research* (pp. 179–191). Ithaca, NY: Cornell University Press.
Trumbull, D. J., Bonney, R., Bascom, D., and Cabral, A. (2000). Thinking scientifically during participation in a citizen-science project. *Science Education*, *84*(2), 265–275.
Trumbull, D. J., Bonney, R., and Grudens-Schuck, N. (2005). Developing materials to promote inquiry: Lessons learned. *Science Education*, *89*(6), 879–900. https://doi.org/10.1002/sce.20081
Vining, J., Ebreo, A., Bechtel, R. B., and Churchman, A. (2002). Emerging theoretical and methodological perspectives on conservation behaviour. Retrieved from https://www.researchgate.net/profile/Joanne_Vining/publication/253703309_Emerging_theoretical_and_methodological_perspectives_on_conservation_behavior/links/53f494e00cf2fceacc6e8f2d.pdf.
Weinberg, R. S., Gould, D., and Jackson, A. (1979). Expectations and performance: An empirical test of Bandura's self-efficacy theory. *Journal of Sport Psychology*, *1*(4), 320—331.
Weiss, C. H. (2000). Which links in which theories shall we evaluate? *New Directions for Evaluation*, *2000*(87), 35–45. https://doi.org/10.1002/ev.1180.
Wells, N. M., and Lekies, K. S. (2012). Children and nature: Following the trail to environmental attitudes and behavior. In J. L. Dickinson and R. Bonney (Eds.), *Citizen Science: Public Participation in Environmental Research* (pp. 201–213). Ithaca, NY: Cornell University Press.
Windschitl, M., Thompson, J., and Braaten, M. (2008). Beyond the scientific method: Model-based inquiry as a new paradigm of preference for school science investigations. *Science Education*, *92*(5), 941–967. https://doi.org/10.1002/sce.20259
Wright, D. R., Underhill, L. G., Keene, M., and Knight, A. T. (2015). Understanding the motivations and satisfactions of volunteers to improve the effectiveness of citizen science programs. *Society and Natural Resources*, *28*(9), 1013–1029. https://doi.org/10.1080/08941920.2015.1054976.

CHAPTER III

A QUALITATIVE ANALYSIS ON THE DIMENSIONS OF ENGAGEMENT IN CITIZEN SCIENCE

The purpose of life after all, is to live it,
To taste experience to the utmost,
To reach out eagerly and without fear for newer and richer experience.
--Eleanor Roosevelt

INTRODUCTION

The ways and extent to which participants engage in scientific activities is at the core of many free-choice or informal science learning initiatives (Falk 2001, Falk and Dierking 2002). Informal learning can occur in a multitude of places outside formal K-12 structures including museums, science centers, community centers, television and radio, online media, and citizen science. Such encounters tend to fall under the large umbrella term of "engagement." Friedman et al. (2008) refer to engagement in informal learning contexts as basic interest and excitement. This description however, fails to acknowledge the complexities of the learning process or experiences of learners. McCallie et al. (2009) note that within Informal Science Education (ISE), engagement is poorly defined; sometimes it is referred to as interest-oriented behaviors or interactions, sometimes it is considered a psychological precursor to learning. Lewenstein (2015) notes that the term "engagement" is particularly problematic because it holds different meanings across different disciplines. Azevedo (2015) goes so far as to say, "Engagement is one of the most widely misused and overgeneralized constructs found in the educational, learning, instructional, and psychological sciences" (p. 84). From dictionary definitions, engagement can mean anything from being present, to being emotionally committed, to even military intervention. Thus, the context in which the word is used clearly matters.

Citizen science – the intentional involvement of members of the public in scientific research – is often categorized as a form of informal science learning because of its dual emphasis on research and education (Bonney et al. 2014), and is also grappling with how to articulate and measure engagement. Typically, citizen science has defined engagement through output measures such as the numbers of participants, web pages accessed, data collection and submission rates, and other baseline measures of recruitment, retention, and outreach (Phillips et al. 2012). The simplistic nature of measuring engagement through outputs alone however, leaves critical gaps in our understanding of what engagement means and entails for project participants. For example, we know little about how duration and frequency of participation influences engagement. There are also untested assumptions about what participants do as a function of their engagement. Participants in citizen science projects may be engaged in any number of scientific activities including collecting and submitting data, formulating hypotheses, asking and answering questions, interpreting and analyzing data, and using data as evidence (Bonney et al. 2009b). Or they may be engaged in other ways such as knowledge acquisition, using social media, community involvement, and/or interacting with scientists. Also, very little is known about the linkages between what participants do and what learning outcomes are likely. The purpose of this research therefore, is to deeply explore through case study analysis what engagement entails in citizen science and develop a conceptual framework for measuring engagement in such contexts.

At a more fundamental level, few citizen science studies have tried to actually define "engagement," or describe participant experiences, particularly in field-based projects and rarely across multiple projects. For instance, in a recent paper by Lewandowski and Oberhauser (2017), the word "engagement" is included in the title and mentioned more than 30 times in the text, but the authors fail to clearly define what they mean by the term, ascribing both conservation-oriented actions resulting from participation, as well as activities related to project protocols to engagement. In trying to solve a methodological issue of measuring engagement in short term citizen science events, Zoellick et al. (2015) attempted to operationalize engagement using an observation framework that categorized behaviors as "doing," "initiation," and "breakthrough." While they found the method to be reasonably successful, it would require in-person observations to utilize, and is likely limited to events lasting just a few hours. These examples are highlighted here not to call out the authors, but to emphasize the dearth of studies deeply examining engagement compared to the term's frequent usage.

Studying engagement is important because it is integrally tied to learning. Although there is no clear-cut agreement on a theory of learning for citizen science, there have been suggestions that learning happens through the experience of engaging in project activities, and several typologies have been developed to characterize different project types according to what participants do in the project. For example, Bonney et al. (2009a) differentiates project types by the aspects of the scientific process that participants engage in in environmentally-based projects: "*Contributory*" projects are said to involve participants mostly in collecting and submitting observational data; "*Collaborative*" projects tend to engage participants in more aspects of the scientific process such as data analysis and/or interpretation; "*Co-Created*" projects generally involve participants in many or all aspects of the scientific process and are purported to result in the deepest learning outcomes. A similar typology was created by Haklay (2013) to describe different participation levels within Volunteered Geographic Information (VGI), beginning with "*Crowdsourcing*" to describe passive participation with no cognitive demands on the participant, to increasing levels of participation in the form of "*Distributed Intelligence*," "*Participatory Science*," and finally, "*Extreme Science*," where scientists and participants are working collaboratively and equally in all facets of knowledge production.

While the above typologies are helpful at examining and framing engagement broadly, few studies have applied and tested them at the individual level. Thus, individual engagement and experiences in informal settings, including citizen science, are poorly understood. In short, there are many assumptions about how citizen scientists engage, with little empirical support for those assumptions (Curtis 2015). Consequently, other researchers have devoted special issues to presenting the definitional, conceptual, theoretical, and methodological challenges of this ubiquitous, misused term (Azevedo 2015).

Distinct from, but often closely related to engagement, is the concept of motivation, i.e., what drives and what might prevent people from engaging in citizen science. Multiple motivation theories exist, but broadly defined, "motivation refers to factors that activate, direct, and sustain goal-directed behavior. Motives are the 'whys' of behavior—the needs or wants that drive behavior and explain what we do" (Nevid 2013 p. 288). Within the volunteer literature, there is general consensus that motivation to volunteer in any capacity or for any organization is complex, and often influenced by situations and context (Clary et al. 1998, Yeung 2004). Motivation is also dynamic, able to change over time (Rotman et al. 2014) and multifaceted, meaning there may be several motives at work for any particular behavior (Raddick et al. 2010).

Although some work on motivation has been undertaken within citizen science, many of the studies describe atheoretical reasons for participation as opposed to understanding the psychological basis of behavior. For example, many studies suggest that the desire to contribute to science is important, but without an understanding of *why* such contribution is important. The lack of such studies suggests a need to understand the motivation of citizen scientists through a richer theoretical lens, such as through Self-Determination Theory (SDT), which examines motivation based on an intrinsic to extrinsic continuum and goes a step further to ask the question "why is contributing to science a key factor of motivation in citizen science?"

There is ample evidence that the term engagement is broad, contextually dependent, lacking clarity, and also related to motivation. With the increased focus on measuring learning outcomes from citizen science, it is important to understand the context in which citizen science engagement, and therefore learning, happens. In other words, we cannot study learning without first understanding the drivers of learning, how learning happens, in what context, and under what conditions. To fully understand what it means to engage in citizen science, the current research addresses the following questions:

3.1) What are the salient dimensions of engagement in citizen science and how are they described, as expressed in qualitative interviews with participants from different projects?

3.2) What are the motivations for and barriers to engaging in citizen science across different projects?

3.3) How can engagement in scientific practices be quantified and measured within the context of citizen science?

The current study is intended to provide an empirically grounded understanding of what engagement looks like across different types of citizen science projects, and what meaning it holds for participants. Here, the process of engagement is examined through a case study analysis where information about participant experiences are gathered through qualitative interviews. Much of the framing for the data collection and analysis was informed by various theoretical perspectives, many outside of citizen sceince. To begin, a review of the theoretical perspectives surrounding the construct of engagement in the literature is presented, followed by the empirical work applying such perspectives.

LITERATURE REVIEW

Despite the challenges of defining and measuring engagement in informal science contexts, there is ample research in other disciplines such as education, psychology, science communication, organizational labor, and information science, that can benefit and inform our understanding of the term and how it could be applied to the citizen science context. For instance, engagement has been studied within organizational labor settings to understand the root causes of workplace burnout (Schaufeli et al. 2002, Schaufeli et al. 2006, Sonnentag 2003). Macey and Schneider (2008) conceive of employee engagement as a psychological state that has an organizational purpose, and connotes involvement, commitment, passion, enthusiasm, focused effort, and energy, so it has both attitudinal and behavioral components. In science communication, the term "engagement" refers to the power and governance structures within science and the public's role in those structures (Rowe and Frewer 2005). Typologies for public engagement in science are considered at a programmatic level to describe communication structures, but not necessarily at the participant level to describe individual engagement (Rowe and Frewer 2005). A brief overview of some of these different perspectives is provided below to provide foundation for defining engagement within the proposed study.

Student Engagement

Engagement has been studied most intensively in K-12 settings to describe student dropout rates, school achievement, and high school reform efforts (Furrer and Skinner 2003, Appleton et al. 2006, Martin 2007). In these K-12 contexts, engagement may also simply refer to whether a student completes a task in class or is paying attention. The focus on student engagement in K-12 is considered critical because the lack of it is believed to be intricately tied to low academic performance, behavioral issues caused by boredom and feelings of isolation, and high dropout rates (Fredricks 2011). Within this body of work, there appears to be some consensus about engagement. First, engagement is malleable and can change over time (Fredricks et al. 2004). Second, engagement is integrally tied to learning, and likely a necessary precursor or mediator of learning (Skinner and Pitzer 2012), as was also suggested by McCallie et al. (2009). Third, while it is a distinct theoretical construct from motivation (Martin 2012), engagement and motivation appear to be operating within a broader socio-cultural system. In other words, it is challenging to study engagement without also studying motivation (Crick 2012). Also, there is general agreement that contextual factors such as cultural and ecological influences (experiences, friends, family, and community structures) are important and require a wider sociocultural lens with which to conceptualize engagement (Lawson and Lawson 2013).

Aside from these basic commonalities, much of the work on engagement in the K-12 realm is extremely broad, diverse, and sometimes lacks definitional clarity. In the epilogue of a comprehensive handbook on student engagement, the editors offer this definition "Student engagement refers to the student's active participation in academic and co-curricular or school-related activities, and commitment to educational goals and learning. Engaged students find learning meaningful, and are invested in their learning and future. It is a multidimensional construct that consists of behavioral (including academic), cognitive, and affective subtypes. Student engagement drives learning; requires energy and effort; is affected by multiple contextual influences; and can be achieved for all learners" (Christenson et al. 2012 p. 816). It is worth diving a bit deeper into the language of this broad definition and describing some of the dominant perspectives that helped to shape it.

Appleton et al. (2008) and Fredricks et al. (2004) both argue for a three-pronged "meta-construct" conception of engagement, which includes the affective/emotional, behavioral, and cognitive dimensions. Affective engagement is typically used to describe students' psychological, emotional and social connections at school. The affective/emotional dimension is sometimes split into two further categories; one to describe enjoyment, boredom, interest, and anxiety toward academic endeavors (Appleton et al. 2008, Skinner et al. 2008), and the other to describe students' broader sense of belonging or connection with school in general, teachers, mentors, and peers (Finn and Zimmer 2012, Voelkl 2012). The majority of these studies conclude that emotional attachments and connections at school are positively related to motivation to pursue academic activities and the lack of affective/emotional connections may leave students less engaged, leading to behavioral and disciplinary issues.

Research on the cognitive dimension of engagement also tends to split into two camps, one that focuses on students' effort toward school work (Fredricks et al. 2004), and the other regarding students' thinking about their learning and how they make meaning (Cleary and Zimmerman 2012, Lam et al. 2012). Students with high cognitive engagement are said to be much more invested and disciplined with respect to their learning (Newman and Wehlage 1993). Cognition also can be considered with respect to what is learned, as is more common in citizen science.

Research on behavioral engagement within K-12 is quite broad; for example, many studies examine the behavioral dimension through the lens of school drop-out, behavioral disengagement, absenteeism, and suspensions (Finn and Zimmer 2012). Other work focuses on positive indicators such as time spent on homework or compliance with school rules (Finn and Voelkl 1993) and involvement in extracurricular or social activities (Mahoney et al. 2003). These and other behavioral studies demonstrate the strong relationships between positive behavior and academic outcomes (Finn and Zimmer 2012, Fredricks et al. 2004**)** or the reverse, high risk behavior and drop-out rates (Griffiths et al. 2012, Rumberger and Rotermund 2012). However, an all-encompassing approach to engagement that includes affective, behavioral, and cognitive dimensions, aligns most readily with citizen science experiences that often involve multiple dimensions of doing, thinking, and feeling.

Researchers have also looked at youth engagement in extra-curricular activities by looking at variables such as duration (years), intensity (hours), and breadth of participation alongside the behavioral, affective, and cognitive domains (Bohnert et al. 2010). The authors describe a "best practices" approach that is theoretically and empirically grounded in studies of organized, out of school-time activities. Other researchers contrast static, traditional forms of student engagement with more 'agentic' approaches that put youth at the center of their learning, engaging collectively and authentically in action-oriented behaviors, involving active contribution, dialogue, and use of culturally relevant tools and technologies (Reeve 2012). The latter studies could be used as a model for citizen science, which is action-oriented, involves contribution, dialogue, and the use of socially-mediated tools.

Collectively, the studies on student engagement provide strong evidence for examining engagement as a meta-construct, but, as pointed out by the handbook editors

(Christenson et al. 2012), the sub constructs of engagement may be interrelated, and definitional boundaries between cognitive, behavioral, and affective engagement may become diffuse when operationalized, particularly when using different quantitative measures among different researchers.

Technology-mediated social participation

Another source of literature that has addressed engagement is found in the field of Human Computer Interaction (HCI), which studies the ways in which humans interact with computers. Studies examining "mass collaboration" or "crowdsourcing," — where the crowd contributes services or ideas via the Internet with little required qualifications (Howe 2006), — are especially useful for studying engagement in citizen science. HCI offers multiple frameworks on technology-mediated social participation, most of which categorize different forms of engagement. For example, Preece and Schniederman's (2009) "Reader to Leader" framework categorizes engagement by the broad sets of activities that individuals take part in while online with platforms such as Wikipedia. A "reader" is someone who is passively involved with online platforms, usually ingesting written or visual information from user-generated content, discussions boards, or blogs. A smaller group of individuals will over time, become "contributors" by uploading photos, sharing opinions, and writing reviews of products or information. Some contributors may become deeply engaged in discussion boards, or edit or create original content to become a "collaborator" in a defined user group. Finally, a smaller number of users may become leaders, serving as mentors to others, curators of material, or upholding governance policies. Such a framework could have valuable utility to citizen science as a way to categorize behavioral forms of engagement. It is unclear if this framework also considers affective and cognitive dimensions of engagement.

Haythornthwaite (2009) examines peer production in online communities through categorization of activities as either light or heavyweight relative to three overarching dimensions: Contribution Type, Granularity and Authentication; Individual to Group Focus; and Recognition, Reputation, and Reward. Lightweight contributions can be one time, simple and straight forward, and often directed by rules authored by others. SETI@ home and ClickWorkers, both online citizen science projects, are used as examples of lightweight activities. Heavyweight contributions are more complex, requiring greater time commitment, interactions with other contributors, and peer to peer negotiations. Academic activities that seek production of knowledge are examples of heavyweight contributions. Attributes of lightweight individual to group focus include simple, repetitive, discrete tasks with low barriers to entry and anonymous personas. Lightweight systems tend to support two types of users: contributors or leaders. Heavyweight individual to group focus attributes include attribution to someone, usually with a history of contribution, multi-tiered levels of experience, greater barriers to entry, and expectations of continuing contribution. Finally, lightweight recognition, reputation, reward attributes tend to be quantitative in the form of contribution rates or numbers of products. In contrast, heavyweight attributes tend to be qualitatively recognized, focusing on value and peer review. Although Haythornthwaite (2009) tends to put different peer production activities into either lightweight or heavyweight categories, it is likely that citizen science projects have attributes that span both light and heavyweight dimensions.

Curtis, (2015) used Preece and Schniederman's (2009) reader-to-leader framework to characterize participation in three online citizen science projects (Foldit,

Foldit@Home, and Planet Hunters) as either all registered participants; transient or dabblers; active; or core participants. In this operationalization, the registered participants are analogues to Preece and Schniederman's (2009) "readers;" transient or dabblers are contributors; active participants are collaborators; and core members are leaders. Unlike Preece and Schniederman's framework, Curtis suggests that participants don't necessarily move linearly from one level to the next. Participants can move within these different levels in a manner that suits their time commitments and inclination. Curtis (2015) also emphasizes that it should not necessarily be the goal for projects to encourage movement from one level to the next, as many participants are happy to simply contribute at a basic level. A similar conclusion was made by Haklay (2013), who also stated that within a given type of project, varying levels of individual participation are likely.

Other work examining engagement in online citizen science projects have revealed an uneven pattern of contribution, where a very small number of individuals (sometimes as little as 1%), contribute up to 90% of data. This is often referred to as the 90-9-1 rule where 90% of visitors to a site are consumers of the information, often reading or lurking; 9% contribute occasionally; and 1% contribute regularly and account for the vast proportion of the information (Nielson 2006). For example, Jennett et al. (2014) describe high and low contributors, with low contributors dabbling in small doses with little additional involvement, and high contributors with more regular and robust participation, including taking part in social features such as discussion forums. Similar patterns were found by other researchers studying a suite of Zooniverse projects (Ponciano et al. 2014). However, most characterizations of engagement here are based on quantitative summaries of contribution, rather than the nature of the task or qualities of engagement.

Volunteer Engagement and Motivation

According to the Corporation for National and Community Service (https://www.nationalservice.gov/vcla/national, accessed September 8th, 2017), 62.6 million volunteers in the United States contributed nearly eight billion hours of service in 2015, estimated at $184 billion dollars of service collectively. Volunteer services permeate numerous sectors of society including education, social services, religious groups, health, and leisure activities such as sports and the arts. However, rather than a specific focus on operationalizing engagement, these studies typically examine factors related to recruitment, retention, satisfaction, and motivation, all of which also pertain to volunteering in citizen science. For example, studies have reported that volunteer motivations are positively correlated with volunteer satisfaction and actual experiences (Farrell et al. 1998). Subsequently, if volunteers are adequately motivated, these individuals will experience satisfaction with the activity, which will likely lead them to volunteer more in the future.

There are dozens of theories on motivation; in general, however, most describe it as the psychological basis for goal setting to achieve some behavior or end result (Deci and Ryan 2000). Many of the psychological theories also center around the notion of 'needs,' largely originating from the work of Maslow (1943), who laid out a hierarchy that included basic physiological and safety needs, psychological needs like love, belonging, and self-esteem, and lastly, self-fulfillment or self-actualization needs. The hierarchy was later modified to include cognitive, aesthetic, and transcendence needs. Examining the vast literature base on motivations is beyond the scope of this work; however, covered here are some of the most relevant to studying volunteer motivation.

Self-determination theory (SDT) is a motivation theory that emphasizes types of motivation that differ in their effectiveness for promoting persistence at activities such as volunteering. Whereas many motivational theories treat motivation as a unitary concept that differs in amount (with the underlying assumption being that more motivation will yield more subsequent behavior), SDT maintains that examining different types of motivation will allow one to predict different qualities of experience, behavior, and persistence, issues that are not well addressed by simply knowing the amount of motivation a person has (Ryan and Deci 2000a, 2000b). SDT is often used to examine the associations among different motives for volunteering, satisfaction of basic psychological needs, satisfaction and learning while volunteering, and intentions for future volunteer work (Ryan and Deci 2000a, 2000b).

With its roots in clinical psychology, SDT treats motivation as an explanatory variable for meeting basic psychological needs (i.e., competency, relatedness, and autonomy) and describes different types of motivations as falling on a continuum from intrinsic to extrinsic. Accordingly, individuals are likely to continue pursuing a goal to the extent that they perceive intrinsic value in the pursuit of that goal, i.e., the extent to which they experience satisfaction in performing associated behaviors themselves versus performing behaviors to comply with extrinsic goals such as conforming to social pressures or receiving rewards. Although SDT can help practitioners better understand the psychological needs behind participation, few known studies have used SDT in the context of citizen science. One exception is a paper by Nov et al. (2014) that used SDT with social movement participation models in an examination of three digital citizen science projects. Interestingly, Nov and colleagues found that intrinsic motivation was one of four drivers that influenced quantity of participation, but that it did not affect quality of participation, as defined by the accuracy and sensitivity of their observations to an online astronomy project.

Clary and Snyder (1999) use a functional motivation approach to study the personal and social factors that influence origination and maintenance of actions. This approach can also be used to examine how individuals' behaviors helps them achieve personal and social goals (Clary et al. 1998). The Volunteer Functions Inventory operationalizes six categories of motivation including: values (importance of helping others), understanding (activities that fulfill a desire to learn), social (influence by significant others), career (exploring job opportunities or work advancement), esteem (improving personal self-esteem), and protective (escaping from negative feelings). Schrock et al. (2000) used the VFI with Master Gardeners and found all six categories represented, with learning and values being the most important. Wright et al. (2015) studied the motivations of birders in South Africa using a modified version of the VFI and found five categories of motivation to be most important: recreation/nature, values, personal growth, social interactions, and project organization. On face value, the functional approach could be well aligned to understanding motivation in citizen science, however, it is worth noting that many studies that purport to study motivation end up studying "reasons for participation" rather than the psychological underpinnings of motivation. Interestingly, Clary and Snyder (1999) state that the six functions represented in the inventory "are consistent with the results of previous studies of people's reasons for volunteering" (p. 156).

Other studies examining effects of environmental monitoring have linked theories of ecological identity and place attachment as drivers for engagement. Lawrence (2006) compared various models of "top-down" vs. "bottom-up" citizen science projects and found that motives for participation in top-down projects centered around "affirmations of one's usefulness" (p. 290), while motivation for bottom-up approaches tended to focus on concern for local environments associated with place attachment. Using a framework to describe participation in social movements, Nov et al. (2011) looked at participant motivations in two online citizen science projects and found that enjoyment or intrinsic motivations as well as the collective value of the work were the most relevant motives for participation. Rotman et al. (2014) conducted cross-cultural interviews of volunteers and professional scientists in the U.S., India, and Costa Rica and found a temporal pattern to motivation with initial motivation being driven by interests, self-promotion, self-efficacy, and feelings of social responsibility. Long-term motivation was largely based on within project relationships that facilitated trust, recognition, and mentorship and external relationships that supported education, empowerment, policy, and advocacy. Rotman et al. (2014) also found that motivations were culturally influenced and that they can change over time, requiring different support systems to sustain over the long term.

Many other studies examining citizen science motivation tend to be descriptive, with less emphasis on theoretical perspectives. For example, McCaffrey (2005) described "helping" as a main reason for citizen involvement in the Tucson Bird Count project. Hobbs and White (2012) examined open-ended reasons for participation among volunteers in UK garden and bird watch programs. In both projects, personal interest in wildlife, followed by contributing data to help conservation, were the most commonly cited reasons. Bell et al. (2008) cited a connection to nature and socializing with like-minded people as the two most important motives for participation in nine different European citizen science projects. Raddick et al. (2010) examined mostly qualitative data from a large-scale online astronomy project to reveal multiple motivations for participation including love for astronomy, desire to contribute, and amazement with the vastness of space. Reed et al. (2013) examined motivation in Galaxy Zoo participants using an exploratory factor analysis. Their results suggested three generic motivations: Social engagement with others online, enjoyment and interaction with the Zooniverse online features, and helping or contributing to the project.

Whether descriptive or theoretically driven, these studies reaffirm the notion that motivation to volunteer is complex and multifaceted and make a strong case for including motivation in studies of engagement. SDT, in particular, provides a lens with which to study the underlying psychological aspects of engaging in citizen science because it predicts that intrinsic motivation tends to result in sustained behavior, while extrinsic motivations tend to wane over time. Applied to this study, "sustained behavior" refers to continual and repeated engagement, an often-cited goal of citizen science projects, particularly those focused on environmental monitoring at a given location (Bonney et al. 2009b). Also, similar to Lawrence's findings (2006), Haklay (2013) demonstrates that the various forms of citizen science projects (e.g., top-down, scientist driven vs. bottom-up community driven), may have very different motivations requiring different supports to sustain. An examination of motivation using SDT therefore, can provide insight on the extent to which intrinsic and extrinsic motivations exist across a variety of projects. Understanding how to leverage different motivations is important to better recruit, accurately place, and successfully retain citizen science volunteers.

Whereas other disciplines have examined engagement through a multitude of theoretical perspectives, including affective, cognitive, behavioral, and socio-cultural lenses, the same is not true for studies on citizen science, where engagement has mainly been characterized through various measures of quantity (Phillips et al. 2012). The field of citizen science is at a turning point however, and there is rich discussion regarding the need for citizen scientists to be considered as more than just sources of data (Eitzel et al. 2017). Citizen scientists are diverse, committed, concerned, and often empowered individuals and to ignore other dimensions such as emotions, motivations, and social connections does their contributions and experiences a great disservice. To that end, the present study attempts to reveal what's inside the black box and provide a qualitatively rich and empirically derived understanding of what engagement looks like across various forms of citizen science.

METHODOLOGY

Research Design

This study is part of a larger study in collaboration with UC Davis, examining how informal science learning experiences such as citizen science, support lifelong science learning. Answering the research questions presented above involved both the Cornell and UC Davis team interviewing 72 citizen science participants from six different projects that represent the range of project models described in (Bonney et al. 2009a). This typology differentiates project models by the aspects of the scientific process that participants are engaged. To recap:

- *Contributory* projects are said to involve participants mostly in collecting and submitting observational data; here they are represented by **NestWatch (NW)**, a nesting bird monitoring project and the **Monarch Larvae Monitoring Project (MLMP),** a butterfly larva monitoring project.
- *Collaborative* projects tend to engage participants in more aspects of the scientific process such as data analysis and/or interpretation and are represented here by the **Community Collaborative Rain, Hail, and Snow Project (CoCoRaHS)**, a national precipitation monitoring program, and the **Hudson River Eel Project (EELS),** a seasonal project along the Hudson River that monitors American Eel populations.

- *Co-Created* projects generally involve participants in many or all aspects of the scientific process and here include the **Alliance for Aquatic Resource Monitoring (ALLARM),** a community-based volunteer stream monitoring network and **Global Community Monitor (GCM)**, a grassroots organization involving community members in local air quality monitoring.

The six projects all have in common a focus on some form of field-based, environmental monitoring and were purposefully chosen because they represent the three model types, but also because of their geographic, scientific, temporal, and structural diversity. This work uses a comparative case study design to study the phenomenon of citizen science within its real-world context Yin (2013) and includes several units of analysis. The six individual projects (NestWatch, MLMP, CoCoRaHS, EELS, ALLARM, and GCM) serve as one unit of analysis; the three project types (contributory, collaborative, and co-created) serve as a second unit of analysis; and the two project structures (individual vs. group projects) form a third unit of analysis. Projects where most of the participation occurred on an individual basis included NestWatch, MLMP, and CoCoRaHS. Group-like projects typically involved one or more participants interacting in person with one another and included EELS, ALLARM, and GCM. Case study analyses typically gather multiple sources of data (Creswell 2003). Here, the bulk of the data were gathered through interviews with participants, documentation and conversations with project leaders, and artifacts collected online or provided by the participants. This type of analysis across and within units is what Gerring (2004) refers to as a "hierarchical model" research design.

Interview Guide

A semi-structured interview guide for conducting the interviews was chosen to identify topics in advance and support a systematic flow to data collection (Patton 2002). Major sections within the interview guide were informed by the *a priori* themes from the above-mentioned literature on engagement and motivation including: effort (duration and frequency of participation), motivations and barriers, affective dimensions such as interest and emotions, behavioral aspects of engagement, i.e., what participants do on behalf of the project, what engagement means to them (cognitive and affective), and social/project connections. The interview guide ensures that individuals are responding to the same set of questions, while still allowing interviews to feel conversational and flexible enough to probe deeper when necessary (Patton 2002). A draft version of the interview guide was shared with the six project leaders and an expert review panel to elicit their feedback. This resulted in small wording changes to the interview and the addition of a few questions particularly relevant to the project leaders. See Appendix C for a copy of the full interview guide.

Sample

The sample for this study was drawn using a maximum variation sampling method to identify a diverse variety of individuals and experiences from which to identify patterns from participants of the six projects named above (Patton 2002). In an attempt to obtain interviewees who represented various levels of engagement, each of the project leaders were asked to provide characteristics of what would constitute a "low," "medium," and "high" level of engagement for their particular project. After synthesizing each of these characteristics from the six projects, several themes were revealed that were common across most of the projects, including: frequency of data submission, quantity of sites monitored, diversity of activities, communication with project staff or through social media, and leadership activities. These characteristics are summarized in Appendix D and were offered as a reference tool to help project leaders identify, with some level of consistency, participants that engaged at various levels in their respective projects. It was made clear to project leaders that no one project mentioned all of these characteristics and that some characteristics might not apply to their projects at all. It was also noted that within any one level of engagement, an individual might not necessarily represent all of the stated characteristics. (For example, a participant at a low level might only meet one of the bullets within the "frequency" characteristic). Project leaders were asked to use the list of characteristics as a reference tool to provide an equal or close to equal balance of participants demonstrating low, medium, and high characteristics. Additionally, project leaders were asked to consider diversity in demographic variables such as geography, gender, and ethnicity when choosing participants as potential interviewees.

Each project leader provided a list of 10-20 potential contacts, which included the participant's name, email, presumed engagement level, and when available, demographic information. Collectively, the initial sampling frame across the six projects was 101 adults over the age of 18. In March 2014, each of the 101 individuals were sent an email, inviting them to participate in the study; seven responded and declined to participate, three were returned as bad emails, eight individuals never responded to the request, and the remaining 83 individuals agreed to participate in the study. IRB approval through Cornell University was obtained prior to the start of the study. Before participating, interviewees had to read and agree to the consent form, which described the purpose of the study, any associated costs, benefits, and risks to their voluntary participation, and how to contact the research team or the ethics board.

Data Collection

To ensure consistency among the interviewers, four members of the project team from UC Davis and Cornell pilot tested the interview protocol and conducted two "mock interviews," in which one team member acted as the interviewer and the other was the interviewee, while the other two researchers listened in and took notes on what was and was not working well. These mock interviews helped the research team understand the purpose of each question, bound the scope of the follow up questions, and provide guidance to minimize interviewer bias.

Each of the 83 participants was interviewed by one of the four researchers over the telephone between April and June 2014 and each granted permission for the interview to be recorded. Table 3.1 provides a summary of the number of interviews conducted by each researcher across the different projects. Table 3.2 presents the distribution of low, medium, and high interviewees across the three project types for all interviews.

Table 3.1: Distribution of interviews by interviewees and projects (N=83).

	CLO-led Interviews		**UC Davis-led interviews**		
	Author	**Interviewer 2**	**Interviewer 3**	**Interviewer 4**	Total
MLMP	5	4	5	1	15
NW	4	5	6	0	15
CoCoRaHS	5	4	5	1	15
EELS	6	4	2	1	13
ALLARM	3	3	3	1	10
GCM	6	3	3	3	15
Total	29	23	24	7	83

Table 3.2: Distribution of engagement levels from all interviewees (N=83) across the three project types.

	Low	Medium	High
Contributory	9	9	12
Collaborative	6	11	11
Co-created	6	9	11

Interviews lasted between 60 and 120 minutes. Some interviewees were fairly brief with their responses, this was especially true for CoCoRaHS participants; other interviewees, especially those in GCM and EELS, were especially descriptive and verbose in their responses. Many steps were taken to ensure the various forms of validity in qualitative research. For example, descriptive validity, or the accurate observation of what a researcher claims to have heard, seen, touched, or observed (Maxwell 1992) was addressed by recording each of the interviews. If something was unclear, participants were asked to repeat or clarify their statements. Additionally, during the interview, the interviewers took hand-written notes within the blank spaces of the interview guide, attempting to summarize key phrases or ideas. Immediately following each interview, the interviewer also wrote a short memo summarizing the conversation, and documenting anything that was interesting, surprising, or noteworthy. Audio files of the recorded interviews were sent to a commercial transcription service, VerbaLink, for digital transcription. To ensure confidentially, all names of interviewees were changed. At the end of each interview, participants were sent a $25 Amazon gift card as a token of appreciation.

Due to poor audio quality, 11 interviews could not be transcribed and resulted in a loss of three interviews each from NestWatch, MLMP, and CoCoRaHS and one less interview from EELS and GCM. This resulted in an overall loss of 13% of the data. The remaining 72 transcribed interviews were saved to a shared Dropbox folder that both

Cornell and UC Davis teams were able to access. The relative distribution of the 72 participants used in this study and categorized initially as low, medium, and high are presented in Figure 3.1. Only NestWatch had equal representation among low, medium, and high level characteristics.

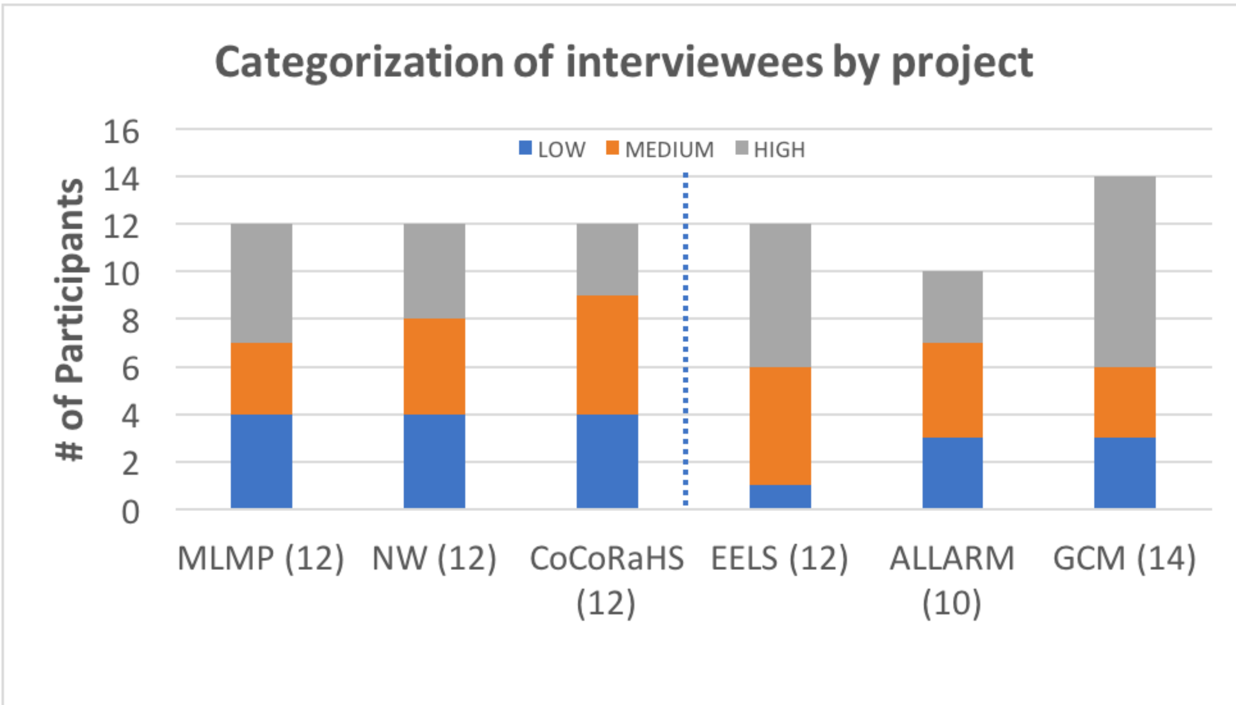


Figure 3.1. Final categorization of low, medium, and high participants across projects

Recall that the case study analysis allows for multiple units of analysis. From the sampling frame, four different units of analysis are possible:

1) across the 72 individuals as an aggregate;
2) between the six projects;
3) between the three project types (contributory, collaborative and co-created);
4) between two project structures (projects where participants mostly worked as <u>individuals</u> and projects that mostly operated in <u>groups</u>).

The overall sampling frame for the final data set used in the analyses is shown in Table 3.3.

Table 3.3: Sampling frame separated out by six projects, three project types, and two project structures.

	Group Structure				Individual Structure	
	Co-created		**Collaborative**		**Contributory**	
	GCM	**ALLARM**	**EELS**	**CoCoRaHS**	**MLMP**	**NW**
Total Sample	14	10	12	12	12	12

Data Analysis

Codebook Development

The first step in the data analysis procedure was to create a codebook, which provides the blueprint for identifying salient themes in the interviews (Patton 2002). As previously mentioned, the literature review provided a starting point for the generation of mostly *a priori* set of major nodes within the codebook including but not limited to: motivations and barriers, feelings and emotions (affective), project activities (behavioral), learning (cognitive) and social and project connections (social). Developing the codebook using existing literature helps to enhance another of Maxwell's (1992) criteria for validity in qualitative research, namely theoretical validity, or the ability of a claim to accurately explain the phenomenon in question. Theoretical validity takes into account not only interpretation of participants' perspectives; it is also influenced by the researcher's theoretical lens. Using terminology that has consensus in the research community can bolster justification of claims and address threats to theoretical validity.

Codebook development was an iterative process, going back and forth between coding and refinement of code definitions, particularly for sub codes within the major nodes. This constant comparative method assured that the codebook was not stagnant and reflected the diversity of interviewee respondents (Strauss and Corbin 1990, Creswell 2003). Some codes were emergent during the analysis phase. For example, sub-codes describing barriers to participation continued to be added throughout the data analysis process as new interviewees described barriers that had yet to be mentioned. Also, interviewees often described other aspects of their lives separate from citizen science, requiring the need for a code for "non-project activities." When completed, the final codebook. See Appendix E for the codebook in its entirety.

The codebook was also used as one of the tools to achieve interpretive validity, which refers to the ways in which researchers make meaning of the words and actions of participants (Maxwell 1992). Lack of interpretative validity can increase researcher bias, where data are selectively chosen or interpretations of meaning subjectively formulated that are consistent with researcher expectations. The codebook was generated to be extremely specific containing ten major nodes or themes and over 120 sub codes. This level of specificity during the coding phase helped minimize researcher bias and increase interpretative validity during the interpretation phase.

Data Analysis Procedure

The quote below by Hatch (2002) and quoted in Leech and Onwuegbuzie (2007), quite accurately summarizes the goals for this phase of the research:

> *"Data analysis is a systematic search for meaning. It is a way to process qualitative data so that what has been learned can be communicated to others. Analysis means organizing and interrogating data in ways that allow researchers to see patterns, identify themes, discover relationships, develop explanations, make interpretations, mount critiques, or generate theories. It often involves synthesis, evaluation, interpretation, categorization, hypothesizing, comparison, and pattern finding" (p. 564).*

The work of analyzing interview transcripts relied heavily on "classical content analysis," which takes into account the frequency of code utilization, is able to inform important concepts, and also can be analyzed quantitatively (Leech and Onwuegbuzie

2007). Content analysis involves "identifying, coding, categorizing, classifying, and labeling the primary patterns in the data (Patton 2002, p. 463). Having measureable counts of events rather than descriptive terms such as "few" or "some" decreases threats to descriptive validity (Maxwell 1992). Additionally, a review of the notes and memos for each interview was conducted to obtain a more holistic understanding of the interview and interviewee, and preceded reading of the full transcript.

Transcribed data were imported into NVivo, a qualitative data analysis software program that uses major "Nodes" to categorize different themes or topics and sub nodes within major nodes. The nodes and sub nodes were identical to the codebook described above. Each interviewee served as a "case" along with corresponding attributes related to gender, level of engagement, and type of project (contributory, collaborative, co-created). Methodology for coding interviews included a careful read of each line of transcription for all 72 interviews and categorization into one or more major nodes or sub nodes as defined by the codebook. A single line of text was frequently coded into more than one node. NVivo automatically quantifies the number of individuals that are coded for a node or sub-node (labeled "sources") and the number of times a particular node is mentioned (labeled "references") across the entire dataset, making it ideal for use in content analysis and categorization of the frequency of referenced topics. Providing quantitative results of qualitative data also allows for aggregation, comparison, and the detection of patterns among the different units of analyses described in Table 3.3 above.

Establishing Interrater Reliability

As described earlier, one of the biggest threats to validity in qualitative research is interpretive validity, or how researchers make meaning of participants' words and experiences. Lincoln and Guba (1985) suggest several techniques to increase interpretative validity including: the use of analyst triangulation, peer debriefing, and member checking. The current research used inter-rater reliability, a measure of the agreement between different raters, as a form of analyst triangulation to increase interpretative validity.

To begin the inter-rater reliability analysis, the author and another Cornell researcher coded six interviews in common (one from each project), and then ran an interrater reliability test using the NVivo software. The initial reliability for these six interviews was Cohen's Kappa = 0.71, for all nodes, equally weighted. This Kappa is considered to have "fair to good agreement" on the NVivo/QSR website (www.qsrinternational.com) and "substantial agreement" by others (Viera and Garrett 2005). To improve the inter-rater reliability, the researchers looked at the two interviews with the largest discrepancies and discussed the coding rationales. Most of the disagreements occurred when several different codes were tagged onto a single statement, forcing the team to increase the specificity of certain nodes and the addition of additional sub nodes. After considerable dialogue to reach consensus, the codebook was updated to reflect changes in our thinking and how we redefined certain major nodes and sub nodes. To test the Kappa score again, another six interviews were coded in common between the two researchers. The analysis for the second set of six interviews yielded an inter-rater reliability of .84, which is considered extremely high agreement by some (Viera and Garrett 2005). Each of the two Cornell researchers then separately coded the remaining 60 interviews. In total, 51 of 72 interviews were coded by the author, and 42 of 72 by the research assistant.

Content Analysis

Much of the data analysis relied on frequency counts of how many interviewees (sources) mentioned a particular topic, and how many times that topic was mentioned (references). In some cases, the number of sources that mentioned a particular node or sub node is highlighted in the results, in other cases the number of times a topic was referenced is highlighted. Using the sources, or number of individuals, as the unit of analysis allows for detection of the *breadth* of a particular node across the sample. Using the references as the unit of analysis provides understanding of the *depth* of a particular node. For example, if a node is mentioned by nearly all participants, but referenced relatively infrequently, interviewees as a whole did not spend much time discussing it. If the number of references is large compared to the number of sources, this likely means that for a small number of individuals this node was extremely important to them, and worth spending considerable time detailing. Nodes that have high numbers of both sources as well as references indicate nodes that were discussed at length by a majority of interviewees, and indicative of high importance.

Additional Analysis for Research Question 3.3

After the 72 interviews had been coded, additional analyses were conducted to answer research questions 3: "How can engagement in scientific practices be quantified and measured within the context of citizen science?" The goal of this question was to create a metric to quantify behavioral engagement with respect to the project specific activities so that it could be administered on a wider scale in the next phase of this study (i.e., quantitative survey, Chapter 4). The focus on the behavioral engagement dimension (as opposed to social, cognitive, or emotional engagement dimensions) was purposeful because the need to understand scientific practices across many types of ISE activities, and such a metric could be transferrable in other contexts outside of citizen science. Thus, the initial coded list of 30 project activities describing what participants did on behalf of the project was analyzed for evidence of convergence or what Patton describes as "recurring regularities in the data" (2002 p. 465). Convergence helps to remove redundancies and bring meaningful cohesion to the coding scheme. In some cases, certain project activities diverged or didn't fit well into any established categories, and required the addition of a "miscellaneous" code. For example, some individuals described driving their vehicle to the site or photographing their surroundings. While in both cases these are behavioral activities, they are not considered scientific practices such as those described in the literature (see Chapter 2), and therefore fell outside of the main set of project activities. The convergence and divergence of data resulted in a reduction of the list to 20 different activities.

Next, the six project leaders and two expert reviewers were asked to look over the project specific lists of activities to judge for overall clarity, completeness, and relevance. Leaders and reviewers were then asked to rate the importance of the 20 activities using a five-point scale where "1 = not at all important" and "5 = extremely important". Leaders and reviewers were also asked to provide additional language for each activity to better define the term. The ratings were averaged and the written notes were further synthesized and analyzed alongside the participant data on frequency of the activities. Collectively, these data were used to develop the Participant Engagement Metric (PEM) to quantify behavioral engagement in citizen science. The PEM is discussed further in the results section.

RESULTS

Overarching results

A summary of the frequency of the major nodes as determined by the number of individuals (sources) that mentioned a particular node or sub node, as well as the number of times the node or sub-node was mentioned (references) is presented in Table 3.4. These data provide an overall snapshot of the content analysis of the data set. With the exception of Barriers and Memorable Quotes, all major nodes were discussed by all 72 participants. Each of the major nodes and associated sub-nodes is discussed further, with quotes used to exemplify sub-nodes, that help to answer the research question.

Table 3.4: Frequency of major nodes coded

Major Node	Sources	References
Barriers	65	511
Degree of participation - effort	72	1088
Feelings, affective, attitude	72	2066
Learning	72	1533
Memorable quotes	66	445
Motivations	72	2761
Non-project activities	72	1179
Project activities and practices	72	4797
Social/Project Connections	72	1684

Research Question 3.1: What are the salient dimensions of engagement in citizen science and how are they described, as expressed in qualitative interviews with participants from different projects?

Recall, the apriori dimensions of engagement included social, affective, cognitive, behavioral, and motivational factors. Each of these is described in turn.

Cognitive (Learning)

The cognitive dimension is made up of both learning through the process of engagement and thinking about the engagement itself. The UC Davis team is conducting an extensive analysis on how participants think about their engagement, mostly in the form of their science identity. Results presented here however, focus just on the learning, with emphasis on how learning happened and what type of learning happened. Participants were asked how they went about learning the protocol, what tools they used, and what resources they were drawing from. Aggregated across all projects, those responses are presented in Table 3.5. Across all projects, there was little variation with respect to the proportion of sources mentioning aspects of learning (data not shown).

Table 3.5: Frequency of sub-nodes coded for the major node "Learning."

Learning	Sources	References
Total	72	1539
Experiential learning	60	361
New knowledge from materials	59	254
Pre-existing knowledge	52	256
Learning from others	47	306
Increased awareness	46	131
Science process or citizen science	43	123
New skills	24	53
New behaviors	6	11

With respect to how learning happened, 60 of 72 (83%) interviewees described learning that was experiential, i.e., through their experiences and interactions with the project, as highlighted in the quote below by a NestWatcher.

> *"I kind of liked watching the life cycle type things with the birds, a little bit more of the activities and trying to – I've added another nest box here, for example, we'll see what – who's going in and out of there and what they're doing and I'll be able to observe those guys and learn a little bit more about what's going on around me in terms of the birds that I can see more of these kinds of things, it increases my observations on it and so*

forth, and I'm trained as being an observer anyway, so that's important. I've gotten a lot out of it, it's been a fun type of thing and it's not been my usual scientific deal, it's been other science deals." (Jay, NW)

An almost equal number of participants (59) described learning new knowledge in the more traditional approach, that is, through materials and resources provided by the project:

"I was seeing my world behind, I don't know, colored sunglasses or whatever. And everything was beautiful and all this and then having those sunglasses removed and having a different set of spectacles, you start to say I've got a different reality that I've got to deal with. And so they helped me by giving me a perspective. They helped me by putting a name to some of the chemicals in the area." (Serge, GCM)

"It's just I can't stress that enough because each time I learn something whether it's, again, by reading the reports or else the flowers that are blooming. Sometimes I know the names of a flower, sometimes I don't. Our leaders always – so I'm learning about other things besides the monarchs themselves but having learned about all the stages and all the different things about the monarchs is really exciting for me." (Laney, MLMP)

Approximately 72% (52) of participants described drawing on pre-existing knowledge that they brought to the project, suggesting the role of interest as an important driver of the learning process:

"I would say I was predisposed to science from when I was little, and an interest in landscape issues and water issues and forestry issues and the like. So, I don't know if it's changed anything, but it's allowed me to get in deeper and closer and to be able to do this stuff that I didn't go into as a career. So, it's given me that avenue and I've appreciated that, that I can keep my hand in science on a weekly basis. It's interesting to go looking through these umpteen years of data collection and realize what a real gold mine there is there." (Shalin, MLMP)

In addition to learning new knowledge or content illustrated above, a majority of participants described an increased awareness of the connectivity of living things; this was especially salient in the EELS project:

"One of the things is that I have an understanding of, I should say a better understanding of how all the little parts make the whole picture. Who would've thunk, you know, that collecting and counting glass eels coming out of the Hudson, you know, into their little, you know, streams would have any kind of impact at all?" (Rochelle, EELS)

According to Situated Learning Theory, tools are an important mediator in the learning process, and all six projects provided experiential opportunities for participants to gain new skills in using a variety of tools, as exemplified by this quote:

> *We divided up into small groups and we were given maps and shown which showed where drilling was taking place. So that was an important part and then of course we were given time to have hands on practice with meters and were shown how to measure, take a water sample. They gave – how to, what do you call it? The term is, to get your meter ready, I forget what that term is right now. But it's getting it ready before you go out. Oh, here I've got it. Doing the calibration. Calibrating our meter and then using the sample that they had brought with them, to take the readings and each of us did that." (Madeline, ALLARM)*

More than half of all interviewees (43) also described how the projects had increased their understanding of science, the science process, or citizen science:

> *"NestWatch is successful because there's an awful lot of data points and an awful lot of people. I mean, there are 800 or 900 people watching Carolina chickadee nests in the United States. Where are you going to find 800 or 900 people in a research department you're going to send out and say, "Go find this and go look at this and collect this in the next three or four months," I mean, it's impossible. So citizen science provides a very powerful tool for data collection over a wide area, and that's very important." (Jay, NW)*

Examination of the number of references to learning by project showed some variation with respect to the experiential learning node, with a disproportionate number of references (about 30%) coming from NestWatch participants. As highlighted in the quote above, this is likely due to the great emphasis on observation of birds and nature that the project endures. GCM participants also had higher mentions of "new learning" that was likely a result of many participants not having much experience with the technical aspects of air quality, which is heavily reliant on chemistry concepts. In some cases, the form of learning being described was difficult to categorize and considered "other learning." For example, one NestWatch participant described the end result of the learning "*as a nice way to kind of keep that part of my brain sharp, or sharper, or less dull*." The GCM project had nearly a third of the references in the other category. For instance, Layla from GCM notes having to learn the politics of this kind of effort and the need for community involvement:

> *"Sadly, I have learned that the regulators that are supposed to be doing all of this are, seem like often they're protecting industry. They're not doing the job that they should. So, it's up to communities if they think there's a problem to find out and educate themselves and get the word out."*

Adele, also from GCM describes learning about the kinds of careers that will have the most impact in her community:

> *"So many people would kind of think well why would you switch from environmental studies ... to public relations and communications, and my biggest reason for doing that was my work with Global Community Monitor in the sense that we don't need any more scientists necessarily to interpret the data and to be able to sift through it. We have so many and I technically don't need an environmental studies manager or PhD to be able to do that. That can come out of self-education because it's very – it's mathematically driven."*

In these interviews, we purposely did not ask questions about specific content that participants learned because other studies have shown the immense potential for learning content-specific topics through citizen science (see Brossard et al. 2005, Crall et al. 2012, Evans et al. 2005, Jordan et al. 2011, Trumbull et al. 2000). Had participants been asked what they learned, it is likely that most of these interviews would have gone well over two hours. However, many participants, whether driven by interest or concern, described learning science concepts and facts, increased awareness of ecological principles, learning about the process of science and/or citizen science, and perhaps most important, engaging in science that had personal meaning for them.

Feelings/emotions/meaning (Affective)

Throughout the interview, participants described their feelings and emotions, often times without any prompting, other times with intentional prompting. In all, feelings were referenced nearly 2,100 times by the 72 interviewees (Table 3.6). At the very end of the interview, participants were also asked to briefly summarize what the project meant to them; this also elicited strong feelings, most of which were extremely positive. Some of the affective states that were coded in the interview were related to feelings of commitment, efficacy or confidence, excitement, interest, recognition, credibility, uncertainty, and surprise in terms of new ideas or unique experiences.

Table 3.6: Sub-nodes coded under the major node of "Affective feelings/emotions"

	Sources	References
Feelings, affective, attitude	72	2066
Positive	64	614
Negative	62	425
QA-QC concerns	57	255
Commitment	54	205
Surprise/new ideas or experiences	53	136
Interest	47	154
Excitement	46	242
Uncertainty	35	132
Efficacy or confidence	30	67
Recognition or credibility	29	72

Figure 3.2 depicts how feelings were referred to across the projects. Most of the variation was seen among individual projects as opposed to project types or structures. Commitment to projects seemed to be universally mentioned across all six projects. Efficacy or confidence as a result of participation was mentioned the least overall, but the most often by GCM (recall, GCM had more interviewees than all the other projects). Excitement was most prominent in the EELS and MLMP projects, which was evident by the way in which they spoke about their participation, as illustrated in these two quotes:

> *"But I would say for sure last year, so the 2013 season, we had some major catches of eels that had not been experienced before in any of the net sites and has not been experienced since. So our biggest catch day was over 8,000 eels, and I wasn't there for the 8,000, but*

I was there for a day we caught 6,000 glass eels! And it was just tremendously exciting for us to see those numbers!" (Lea, EELS)

"I guess the other one of course is when I saw that large – first of all it was very exciting because it was a large instar and second of all because it was unusual and I was very excited to send it and then to find out that it was something that was sort of – Kip agreed that it was unusual and that it was a queen or something. That was very, very exciting." (Laney MLMP)

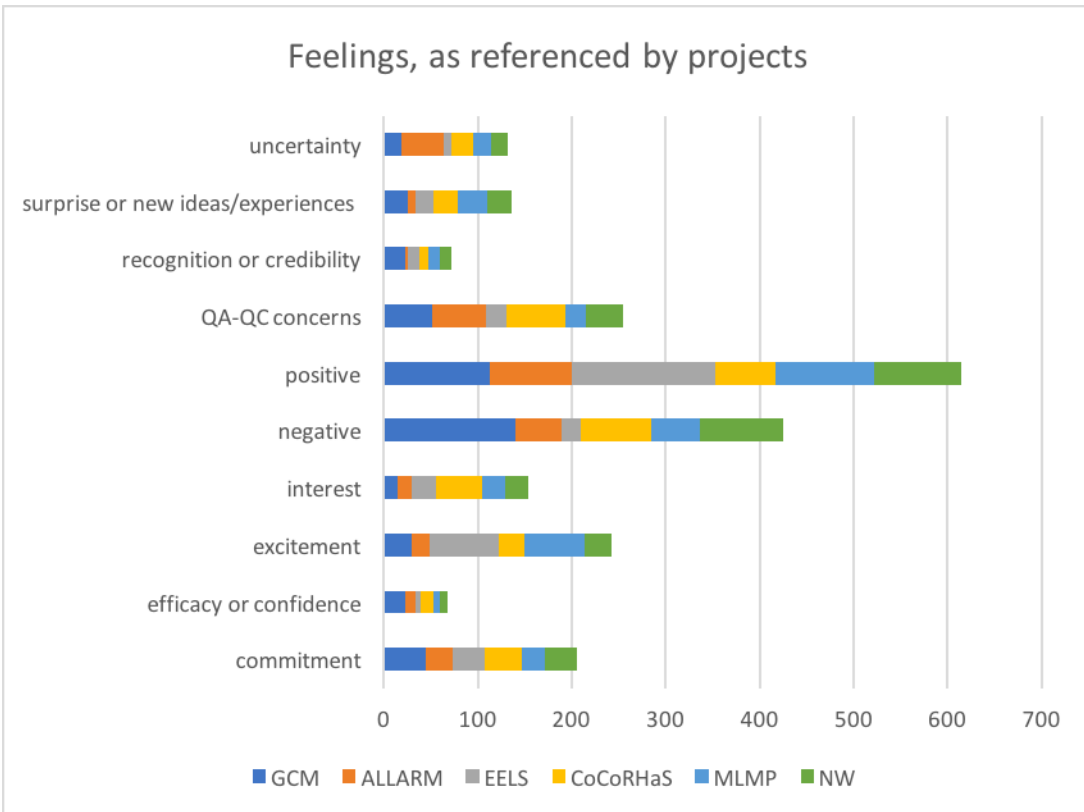


Figure 3.2: Feelings referenced across projects.

Interest was most often described by CoCoRaHS participants, most of whom entered with a strong interest in weather or meteorology. Concerns about Quality Assurance and Quality Control (QA/QC) were most often heard from CoCoRaHS participants who often expressed frustration with other participants who were not following the regimented protocol of submitting data every day. GCM and ALLARM participants also expressed QA/QC concerns about the integrity of their own data. Recognition or credibility by way of data collection was heard most often from GCM participants, followed by those in EELS. Surprise or new experiences was consistent across five of the six projects, with ALLARM participants not mentioning it very much. Lastly, uncertainty seemed to emerge in the co-created projects, ALLARM and GCM, with ALLARM participants emphasizing their uncertainty about where the data go and how they are used, and GCM participants mostly unsure of the fate of their communities.

While all projects did share negative statements, GCM had a disproportionate amount of dialogue that was negative, owing to the deep level of concern and worry expressed for local communities. NestWatch also had a fair share of negative discussion, likely due to the fact that participants see both life and death as a function of observing breeding cycles of birds. Positive emotions were the most referenced feeling and also fairly consistent across all projects, but EELS participants were especially verbose in attributing positive attitudes to the project. Participants also were asked to describe their most memorable day, whether good or bad. Examples of memorable events, both positive and negative, are highlighted below.

Positive emotions/feelings

> *"I mean it's memorable, that meeting that we had, where we could see everybody's data. That was very memorable to me too because I like to be involved, and it gave me a feeling, you know, "Oh, well, yeah, I'm part of something that's bigger, so yeah, 'cause she didn't only have our data there. She showed some pictures or some representation on a graph of where all – her people came from that reported, and so it was the whole area in Central Pennsylvania." (Adam, ALLARM)*

> *"And I got a call from a lady who lives over in Canyon Lakes, she drives about 30 miles one way to monitor. And she's now entering all the data. She slowly getting her to run a project and administrate the project. But she called me and she was so excited and she said, "You won't believe this." But she said, "Can you go over to the Cibolo nature center and take a photograph?' She said, "I'm there and I monitoring, "And she said,*

"And there are three-fifth instars on one milkweed." And she said, "Not only did I forget my camera." She said, "But I forgot my cell phone so I couldn't call you from there." This is back before there were cell phones and people have a lot of cell phones and cameras. And she said, "Could you do that?" So I ran over there. And she said, "I mark the plant." Ran over there and there were the three monarchs, three caterpillars, big dudes, fifth instars munching down on this one milk - lots of ___ on the leaves, so I took on number of pictures. One of which I always use in my presentations which I call the trifecta because Caterpillar. So that was a memorable day." (Ken, MLMP)

"Most memorable day? I think, yeah. It was probably last year – I mentioned the full moon. So we usually catch about 100 eels a day but on the full moon we can catch 2,000. They're tiny little things and so the kids know that so they're excited on the full moon days when we go out there. So when they open the net and they see these 2,000 little clear squiggly things they get very excited and the next day you see them and they're all posting online photos and stuff like that. So it's nice to see all of that excitement." (Reuben, EELS)

Negative emotions/feelings

"Well, I really like it when the Killdeer eggs hatch. And it's surprising, because I'll be observing the Killdeer eggs and they have a kind of, they have a consistent nesting time but sometimes they nest a little earlier and a little late. And I remember one time that I was walking and I was coming into observe them, and I don't even think it had been a month yet, and all of a sudden, the eggs were gone. And we were like, "Oh no, the eggs are gone." And I think the dad Killdeer was hanging around. So I went down, I heard some Killdeer down by the lake shore, and I went down there because I was all like, "Oh no." Because they had crows and everything that were hanging out where the eggs were. And the crows had gotten to a nest earlier and destroyed another couple nests." (Delilah, NW)

"You know, it was probably, we got a three week freeze here in Southern Oregon that started a very unexpected snowstorm. And we were supposed to go camping on the coast....And we got turned around and when got back home, I went, "Oh, you know I didn't even check for snow." And that's when I learned that you can't really measure the snow with the little rain gauge that they give you because it was all on top. It wasn't inside. So it was like I couldn't, I'm not even sure I'm doing that right. I didn't check to see it. Until it melted I didn't record it. Plus, we're having a freeze and I'm not sure how they know that because all I do is report rain. So I'm not sure how that works with them. And again, I'm sure I could figure it out on their website but I haven't done that." (Rhianna, *CoCoRHaS)*

"Most memorable day, I would definitely say it was that ________ gas leak evacuation. Unfortunately, I was present during the time the families were being evacuated. Like I said, I'm not sure if I mentioned it or not, but the day those families got evacuated was the day I took the air sample inside the home....it was a Tuesday, there was a ________ city council meeting that happened – that started at 7:00. I decided to go just to see if they were to mention the ________ gas leak. The department of public health was there, the director of the department of public health and also the county supervisor that represents ________. They were both there. Them knowing that there was explosive

levels of gas in that home a day before, it was kind of sad that they didn't – they had to wait till the camera was rolled out, till there was already a city council meeting for them to say, "Okay, we're going to evacuate the city." At that time, they were not evacuated, so I went back to that neighborhood just to see if I could talk to more people. While I was there, there was fire truck after fire truck coming into the neighborhood, there was local police coming into the neighborhood, and they were walking door to door and as I was documenting people's conversations of the odor of gas for the long period of time, the authorities were essentially knocking on every door asking them – or letting them know that it was a volunteer – or a mandatory evacuation at that time, because the county supervisor decided at that time that it was a mandatory evacuation. So I was there with the families while they had to evacuate, could have their – so this community is a large farm working community. So they were gathered – they were getting their chickens, there were getting their ducks, they were getting their dogs, they were getting their families into their trucks. They were not getting their electronics, they were not getting clothes, they were essentially getting their kids and their animals and they were kind of wandering around lost, not knowing what was going to happen. So that day there was, I believe, a very memorable day and something that gives me kind of a direction, if you will." (Gabriel, GCM)

That fact that most of the participants were so open with their feelings during this first interview highlights the importance that these projects had in their lives. Emotions while often strong and passionate, were overwhelmingly positive. The diversity and strength of these emotions suggest that for almost everyone, these experiences were about much more than simply collecting data.

Social and Project Connections

In coding for social dimensions of engagement, Lave and Wenger's (1991) discussions of situated learning and legitimate peripheral participation were particularly helpful for examining social interactions that facilitate relationship building (coded as "relations"), expanding one's role in the project, using mutual resources and sharing knowledge. All 72 participants described social relationships that were important to them with respect to the project, for a total of nearly 1,700 references (See Table 3.7). What was most surprising in the interviews was the consistency with which relations were described across all projects.

Table 3.7: Sub-nodes coded for Social/Project connections

	Sources	References
Social or community of practice	72	1684
Relations	67	764
Using mutual resources	62	395
Using shared knowledge	44	162
Role expansion	22	191

All but 5 of the 72 interviewees described the importance of relationships that they had established, in particular with the project leader or organization, but sometimes with other project participants. The fact that relations was referenced 764 times also points to the depth and value that interviewees placed on these social relationships. For example, a MLMP participant writes:

> *They asked for letters of recommendation when Karen got the scientific – when she got that scientific award. They apparently put them into a pool, pulled out some of the top letters and they went out and sent out those letters of recommendation. The people whose letters were selected got an invitation to the White House. I sit there and looked at it and I got an invitation to the White House.* (David, MLMP)

Another example of the importance of connecting with the program leaders comes from the EELS project:

> *"The folks that work in ____________, it's my feeling that they consider me to be one of them, somewhat of a peer type of feeling. Certainly not a colleague and I'm not employed by the state. I'm not a paid intern. I'm just an old man who loves standing in a creek on rainy days and counting eels."* (Dion, EELS)

Dozens of interviewees also described relationships formed between the participants:

> *"We have a little kinship. Especially those of us that go through winters together... When I say 'we,' we all function within some type of a discipline and some type of approach and things like that. It's easy to make a 'we' out of that." (Mark, CoCoRHaS)*

Likewise, an ALLARM participant explains:

> *So, again, the social interactions of all those people form a synergy that makes initiatives just keep kind of happening, and keep getting born out of this energy that happens when*

> *you bring people together. And then people want to be a part of it. You don't want to get left out.* (Madeline ALLARM)

Using mutual resources was described by 62 of 72 interviewees, evidence of the important role that training materials, web sites, and publicly available data have in making participants feel part of a scientific practice:

> *"They had a diagram showing the different instars and I was trying to print it out and I couldn't. So I just sent in an email saying, "Look, can you –" It just showed the different stages of the caterpillars, so I could make copies, hand them out to the students. They would each have a laminated copy so we could use them from year to year. And so I sent in an email saying, "Look, can you get me a copy of this?" And they replied right away. Like they're very good about getting back to you if you're involved."* (Grace, MLMP)

> *"We are on our own out here, and it is an individual project, and you do do it yourself, and you rely on yourself. But, boy, if there's something you don't know, there's a well-maintained website and things like that....but so that when I did join up, I really felt like I was joining a solid organization. Yeah, and that was important to me. I can do it by myself, but I don't want to. Yeah, that was important, good to know that I didn't have to discover everything on my own or start from scratch, and if I was having a problem, that there was somebody to go to*." (Lacey, CoCoRaHS)

The importance of using shared knowledge to enhance their engagement was described by two-thirds of interviewees:

> *"I think it started out really to do more with my role as a teacher and bringing my students. And always, I always was interested because of my love of animals, getting me to do this particular project. But I think it really expanded to become a community of volunteers that, we socialize together sometimes. I feel like people would do anything for the other person. It is just a warm, sharing, interesting group of people. We had said things to each other that are interesting. Like, one lady who comes to the site found this article about eels in the Chesapeake Bay about big numbers, so we were expecting big numbers at our site this year. And stuff like that. I think… I didn't expect to broaden my own social network, you know. That was unexpected when it happened."* (Jade, EELS)

About a third of interviewees also described some form of role expansion, where projects helped them expand their role from a more peripheral to a more core member:

> *"Well, I would say that because of GCM introducing me to this whole citizen science issue and activism and affecting change and since we had such success here in Tonawanda, it's just opened up this new door of opportunity for me. I mean, they were*

the beginning of all of this for us here in Tonawanda. GCM is a part of the whole change that happened but it all started with GCM so there's been a number of people and organizations throughout the whole Tonawanda Coke campaign that changed my life. But I would say that GCM was the initial organization that sort of spearheaded all the chain of events." (Juliann, GCM)

"I never thought of myself as a trainer. But I feel like it's a – it's been a good thing for me, as a retiree, I'm getting old enough that I think about what's my legacy, what do I leave behind, what do – I have no children, so what is my contribution to the world and humanity or whatever. So I think training other people is one way to pass on skills that can go further than just me looking in boxes and enjoying the birds for myself." (Abby, NW)

A project comparison of the frequency of references for the four sub nodes of social/project interactions is shown in Figure 3.3. Relations seemed universally consistent, with EELS participants slightly more likely to discuss relationships, very likely because of their charismatic leader. NestWatch and CoCoRaHS participants mentioned the use of mutual resources, likely reflecting the wealth of information in their respective websites. GCM participants were more likely to use shared knowledge and share more examples of role expansion, but otherwise there were no definitive trends by project type or project structure.

Collectively, these findings remind us that whether participants are working alone or alongside others in a stream, having strong, respectful relationships can elevate trust between participants and project leaders. These sentiments also draw out the strong need for individuals to feel part of something bigger than themselves, to feel valued, and to have a stake in the process. Leveraging social and project connections and the tools of scientific practice also help to reinforce notions of a community of practice, even if an intentional community of practice is not the goal of such efforts.

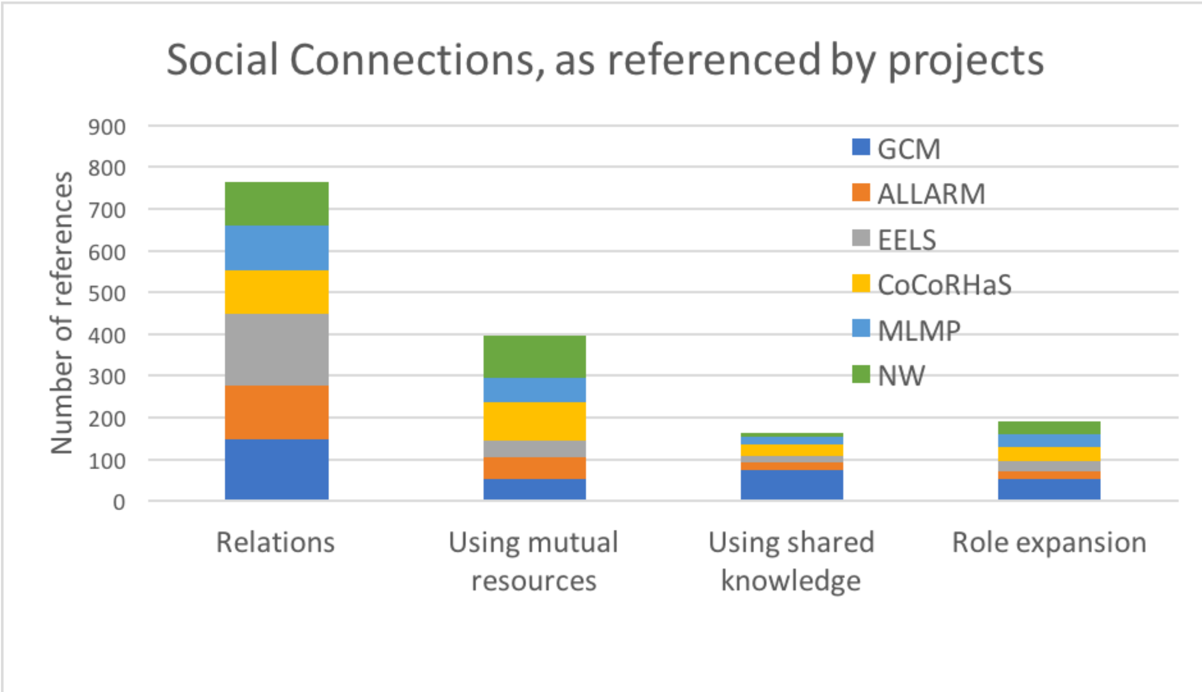


Figure 3.3: Social connections referenced by project interviewees.

Project Activities (Behavioral)

Recall that before initial synthesis, the raw data set contained more than 30 different project activities, which through convergence and divergence techniques, were then reduced to a list of 20 activities. Project activities were basically made up of two broad categories: data collection and "extra" activities. Data collection was referenced over 1,500 times and included the following aspects: classification, counts, equipment usage/setup, identification, measures, observation, gathering samples, site selection, life stages, timing, and other. Using equipment was heavily referenced, as was observation, taking samples, and other, which could include non-project tasks such as driving to sites, taking photos, etc. Extra activities were all the other non-data collection forms of behavioral activities that participants mentioned such as submitting data, communicating with others, asking questions, etc. The aggregated list of activities across all projects, is shown in Table 3.8, ordered by the most to least number of sources describing that activity.

Table 3.8: Twenty most commonly reported project activities

	Sources	References
Data collection	72	1591
Communicating with others	72	813
Learning protocols	70	271
Submitting data or reports	62	214
Communicating finding to others	55	288
Exploring data	47	157
Getting updates and feedback	47	126
Recruiting participants	44	137
Use data	33	102
Training participants	32	125
Using standardized methods	32	79
Analyzing or interpreting data	32	71
Coordinating participant activities	31	164
Asking questions	30	67
Attend meetings	29	122
Managing-compiling data	28	76
Forming hypothesis	18	35
Habitat improvement	12	33
Study design-investigations	8	32
Adapt or modify protocols	5	10

The activities are further categorized according to project, project type, and project structure in Table 3.9 and ordered from most to least common as determined by the number of people (sources) mentioning that activity. If an equal number of people mentioned the activity within a project, the activity that had the most references was deemed most common. To help visualize the different types of activities, each was color coded into one of four broad categories: science process, social interactions, learning, and stewardship.

Table 3.9: Project activities, categorized for each project, project type, and project structure, from most common to least common, indicated by number of sources in parentheses. Activities in bold were mentioned by more than half of the interviewees of each project. Green colored boxes represent science process activities; pink boxes represent social activities; blue boxes are activities related to learning; yellow boxes represent stewardship activities.

	Group Structure			Individual Structure		
	Co-created		Collaborative		Contributory	
	GCM (n=14)	ALLARM (n=10)	EELS (n=12)	CoCoRaHS (n=12)	MLMP (n=12)	NestWatch (n=12)
1	**collect data (14)**	**collect data (10)**	**collect data (12)**	**collect data (12)**	**collect data (12)**	**collect data (12)**
2	**share info others (14)**	**share info with others (10)**	**share info with others (12)**	**share info with others (12)**	**share info with others (12)**	**share info with others (12)**
3	**attend meetings (13)**	**learn protocols (10)**	**learn protocols (12)**	**submit data or reports (12)**	**learn protocols (11)**	**submit data or reports (12)**
4	**learn protocols (13)**	**communicate findings (8)**	**get updates and feedback (12)**	**learn protocols (12)**	**submit data or reports (10)**	**learn protocols (12)**
5	**communicate findings (11)**	**attend meetings (8)**	**explore data (11)**	**explore data (10)**	**communicate findings (7)**	**explore data (11)**
6	**submit data or reports (11)**	**submit data or reports (8)**	**recruit participants (10)**	**recruit participants (9)**	**explore data (7)**	**communicate findings (6)**
7	**use data (10)**	**use standardized methods (6)**	**coordinate activities (9)**	**communicate findings (5)**	**get updates and feedback (7)**	**recruit participants (9)**
8	**get updates and feedback (10)**	**train participants (5)**	**communicate findings (7)**	**get updates and feedback (7)**	**recruit participants (6)**	**train participants (7)**
9	**analyze or interpret data (8)**	**explore data (5)**	**ask questions (9)**	**use data (6)**	manage-compile data (5)	**get updates and feedback (7)**
10	**use standardized methods (7)**	**manage-compile data (5)**	**submit data or reports (9)**	coordinate activities (4)	train participants (5)	**coordinate activities (7)**
11	recruit participants (6)	**ask questions (5)**	**analyze or interpret data (7)**	manage-compile data (4)	analyze or interpret data (5)	**use data (7)**
12	train participants (6)	coordinate activities (4)	**train participants (6)**	analyze or interpret data (4)	use data (5)	**improve habitat (6)**
13	ask questions (6)	get updates and feedback (4)	**form hypothesis (6)**	use standardized methods (4)	use standardized methods (5)	**manage-compile data (6)**
14	coordinate activities (5)	analyze or interpret data (4)	use standardized methods (4)	train participants (3)	improve habitat (4)	**use standardized methods (6)**
15	form hypothesis (4)	use data (4)	manage-compile data (4)	ask questions (1)	ask questions (4)	ask questions (5)

Table 3.9 Continued

	Group Structure			Individual Structure		
	Co-created		Collaborative		Contributory	
	GCM (n=14)	**ALLARM (n=10)**	**EELS (n=12)**	**CoCoRaHS (n=12)**	**MLMP (n=12)**	**NestWatch (n=12)**
16	manage-compile data (4)	recruit participants (4)	attend meetings (3)	design investigation (1)	attend meetings (3)	form hypothesis (5)
17	explore data (3)	design investigations (1)	design investigation (2)	attend meetings (1)	form hypothesis (3)	analyze or interpret data (4)
18	adapt or modify protocols (1)	adapt or modify protocols (1)	use data (1)		design investigations (2)	design investigations (2)
19	improve habitat (1)	improve habitat (1)			coordinate activities (2)	adapt or modify protocols (1)
20					adapt or modify protocols (1)	attend meetings (1)

Without exception, the two most common activities across all six projects were data collection and communication with others. Whereas the prevalence of data collection is not surprising, as it is at the core of most citizen science projects, the significant amount of communication between participants and project leaders/scientists, other participants, and members of the public was surprising, and likely not well established in the literature, giving added emphasis to social aspects of science practice. 'Learning protocols' was either the third or fourth most common activity among all six projects. For the contributory projects and the Individual projects (MLMP, NW, CoCoRHaS), submitting data or reports rounded out the top four activities and the top fifth or sixth activities for the co-created and social projects. 'Exploring data' was much more likely to occur in the contributory (NW and MLMP) and collaborative projects (CoCoRaHS and EELS) than in the co-created (ALLARM and GCM) projects, signaling perhaps an insufficient online infrastructure for sophisticated data exploration (this was also mentioned as a common barrier for some projects). However, participants in co-created projects were more likely to share project findings (rather than simply communicate *about* the project), particularly to media, state, and federal agencies, than participants in other project types. This is likely a function of the role of co-created projects to gather and share data with their community in order to seek answers and solve problems on potentially harmful environmental issues and associated risks.

Although this work does not claim to conduct hypothesis testing, the data on project activities lends some support for the hypothesis that co-created projects engage their participants more deeply in the science process (as described in Bonney et al. 2009a). The current data set revealed that indeed more interviewees from the co-created projects - GCM and ALLARM - mentioned science process activities in the top 10 activities than the other projects. For GCM these activities included: collect data, submit data, use data, analyze or interpret data, and use standardized methods. In addition to data collection and submission, a majority of ALLARM participants also described using standardized methods, exploring data, managing/compiling data, and asking questions. EELS, CoCoRHaS, and MLMP each had four science process activities and NestWatch had three activities, in the top ten. Another interesting observation in Table 3.9 is that while there are many types of science process activities, they tend to appear at the bottom of the lists rather than being spread evenly all around. Further, the science activities on the bottom of the lists tend to be those that are considered more difficult, and requiring higher order thinking. This suggests that these citizen scientists tended to participate in more routine aspects of science processes such as collecting, submitting, and exploring data.

However, the results from the interviews also show that contributory and collaborative projects have just as much, if not more diversity, of science process activities represented, even if they are not as common. In other words, some participants in contributory projects can and do engage just as deeply in the science process as co-created projects. For instance, all six projects had at least one interviewee that 'used data' in some way. The key here is that data use looks very different among the projects, as exemplified by the following quotes:

> *"Yeah, because the bottom line for me is the bluebirds, and the ability to provide them with a place to increase their population. And any of the tools that are available to help me with – to do that, either by gaining knowledge through experience or sources like NestWatch or the data that is provided to me from NestWatch, then that's certainly good. They sort it and put it in categories and track it in an organized manner that allows me to use that data and information to better educate myself and to better educate other people about what I'm doing." (Jed, NestWatch)*

> *"And soft science is when you're sitting and saying "Well I think we saw something like this a few months ago somewhere in there around here" and so on and so forth. But hard science is where we're sitting there producing actual hard data per day in there, per visit, per whatever and you can sit there and go back to that data and watch the trends." (David MLMP)*

> *"Because the data is used in so many different ways... the National Weather Service uses it. Hydrologists, emergency management people, insurance people who have contacted me. Mosquito Control, things like that. There's so many people who use it." (Luann, CoCoRaHS)*

> *"To expose students to gathering eel data that could be used in all different areas, in climate change, and – to expose students to doing field research." (Annabell, EELS)*

> *"I mean that's a pretty – you can't argue with seeing that kind of data and something that a lot of people might not think about and how it affects your aquatic life in the stream and stuff like that." (Kayle, ALLARM)*

> *"But now that we did the research now we have the documentation to show what businesses are emitting and what exactly it is that we're smelling and how far it's travelling to the neighborhood. Now we can present it to people and say "Well look. This is the issue that we have. How are you going to help us? 'Cause before without having – unfortunately we live in a community like ours with no income. So you kind of get looked down at and they don't really want to help you. But now we have data and it's like how are they going to argue with us now with the data? You guys are gonna have to prove us wrong. Now they have to help us." (Elaine, GCM)*

The above quotes illustrate the diverse ways that data are used across the projects. The NestWatch participant uses the to make better management decisions that will help improve nesting success of his bluebirds. The MLMP participant, concerned with declining monarch numbers, uses the data to infer trends over time. The CoCoRaHS participant describes numerous uses of the data for commercial as well as public consumption. Interviewees from the EELS project routinely use the data in classrooms for students to use as part of scientific labs and inquiry exercises. The ALLARM participant uses the data to communicate about the health of local watersheds and the GCM participant uses data to lend scientific credibility to state and local agencies that have long ignored their complaints of toxic pollutants in the air they breathe.

Together these examples paint a picture of the diversity, applicability, and importance of citizen-science collected data for all participants in these projects, irrespective of project, project type, or project structure. Collectively, participants engage in learning and science and social practices in ways that are relevant and meaningful to them. Interestingly, across all projects, very few participants engage in what might be considered higher order science process activities such as forming hypotheses or designing original investigations. Yet, across the projects, participants expressed great understanding of their role in citizen science and the science process. Moreover, they expressed great satisfaction with their engagement in science and the science community.

Research Question 3.2: What are the motivations for and barriers to engaging in citizen science across different projects?

Motivations

Interviewees were asked specific questions about why they began participating in citizen science and what their expectations were for the project. In all, there were more than 2,700 references to motivation among the 72 individuals. Aggregated across the six projects, the most commonly mentioned motivators were environmental concerns (20%

of all *references*), contribution (12%), interest (10%), and community concerns (9%). Looking at the total percent of *sources*, the order changes slightly with 85% of interviewees describing environmental concerns, 81% mentioning contribution, 77% describing a specific place, 72% citing interest, and 71% social connections. Other important drivers such as learning, enjoyment, scientific credibility, education, political distrust, and career are listed in Table 3.10, for each project and sorted by the most to least number of references. Taking into account the nodes with both the highest proportion of references and sources, the three main drivers remain environmental concern, contribution, and interest. It should be noted however that GCM

Table 3.10: Motivations, sorted by number of aggregated references from highest to lowest and across individual projects

		Project Structure:	Group Structure			Individual				
		Project Type:	Co-created		Collaborative		Contributory			
Motivations, sorted by # total references	**Total # Refs**	**Total # Sources**	**GCM (14)**	**ALLARM (10)**	**EELS (12)**	**CoCoRaHS (12)**	**MLMP (12)**	**NW (12)**	**% of Refs**	**% of Sources**
Environmental concern	533	61	243	86	67	57	30	50	20%	85%
Contribution	316	58	18	36	62	55	76	69	12%	81%
Interest	271	52	13	22	55	78	50	53	10%	72%
Community concern	225	26	184	12	20	7	0	2	9%	36%
Education	207	28	16	30	74	13	28	46	8%	39%
Place - specific	206	56	25	62	49	28	8	34	8%	77%
Enjoyment	204	45	3	22	66	28	56	29	8%	63%
Learning	191	47	37	23	40	23	39	29	7%	65%
Social connections	169	51	28	26	37	31	32	15	6%	71%
Scientific credibility	105	38	39	9	18	16	14	9	4%	53%
Place-nature	73	24	0	0	19	3	41	10	3%	33%
Political distrust	68	11	63	5	0	0	0	0	3%	15%
Career	67	17	16	0	21	18	7	5	3%	24%

disproportionately represents the environmental concern node with 243 references, nearly triple the amount of references than the next project, ALLARM, also a co-created project. This highlights the incredible depth of importance that environmental concern was to the GCM interviewees, as shown in quotes below.

Looking at motivation through the SDT and functional approaches, in general, across all projects, there are both intrinsic and extrinsic factors driving engagement in citizen science. Intrinsic factors included statements related to interest, enjoyment, contribution, and learning; many of these can also be considered in the functional approach to motivation. Extrinsic factors were those related to general concern or worry, and issues related to the environment such as conservation for particular species, environmental health, air quality, water quality, conservation of a particular habitat, weather, and climate change. Many interviewees mentioned other drivers related to a specific place or social factors. Without more intense analyses, it is difficult to determine whether these were extrinsic or intrinsic factors. To examine whether there were trends among the projects, motivations were sorted from more extrinsic on top to more intrinsic on bottom and displayed in Figure 3.4.

Among the three different project types, there were some definitive trends. For example, in the co-created project ALLARM, every interviewee reported concern for water quality as a main motivator; likewise, every GCM interviewee mentioned concern for the community (82% of all references) and air quality as the primary drivers. This suggests strong extrinsic factors at work for co-created projects. The opposite was true for the contributory projects, NestWatch and MLMP, both of which mentioned contribution, interest, and enjoyment as primary drivers for engagement. In general, interviewees from the collaborative projects mentioned mostly intrinsic factors such as interest, enjoyment, learning, and contribution, but 75% of CoCoRaHS participants also mentioned issues related to the environment and weather. Similarly, 75% of EELS participants mentioned concern over the American Eel as a primary driver. Another interesting finding was that only co-created projects mentioned "political distrust" as a driver for participation. Similarly, GCM had a disproportionate number of interviewees (10 of 14) mention the need for scientific credibility as a strong motivator for participation. Collectively, these results confirm previous work that has shown motivation for citizen science is multi-faceted, with participants often having several motivations to engage with projects (Raddick et al. 2010). In Table 3.11, select quotes from interviewees are presented that show the depth and breadth of the diversity of motivations.

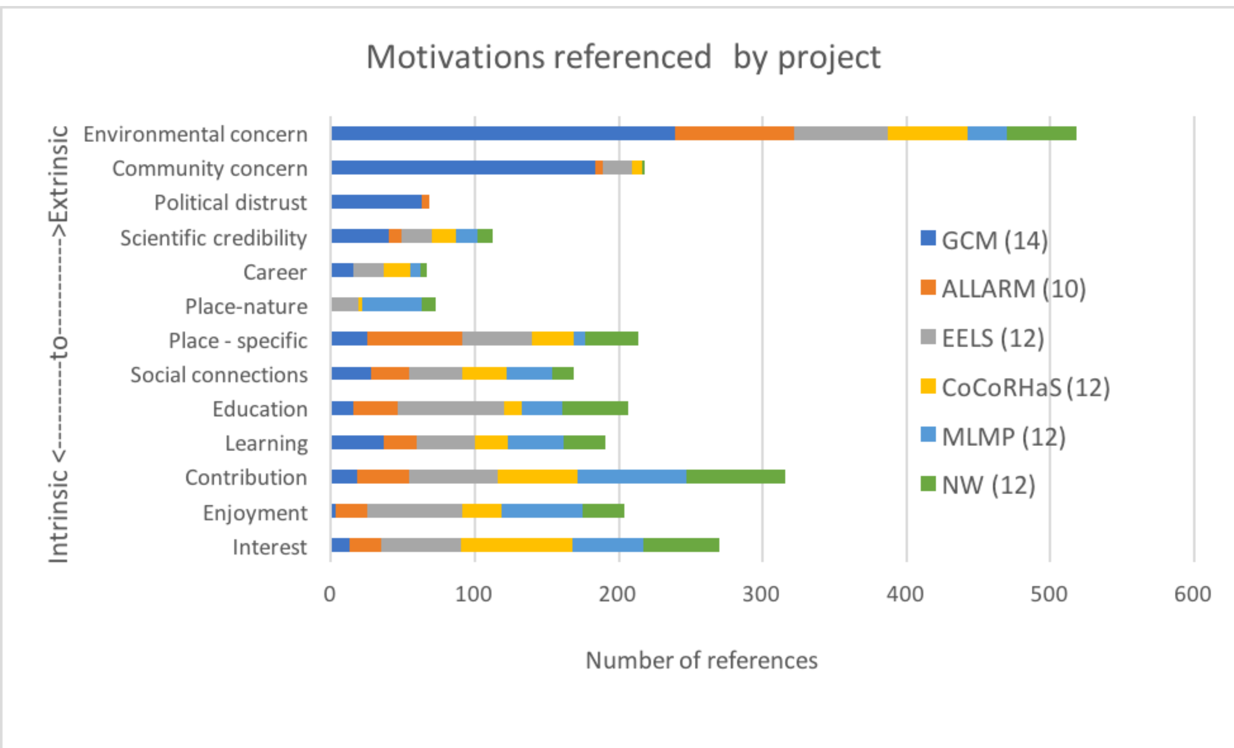


Figure 3.4: Motivations to engage in citizen science are diverse and represent a range of extrinsic to intrinsic factors and functional approaches across all projects.

Table 3.11: Example quotes representative of different motivations

Motivation Category (% of sources, n=72)	Participant ID, Project	Example quote
Contribution (81%)	Abby, NestWatch	*"I was intrigued that this information was going to a bigger purpose, that it could be used by researchers in some fashion, and I - it just seemed to make the whole process a little bit more rewarding and help drive my diligence in staying on track and doing the monitoring, knowing that it was important enough, that it was possibly going to be used for research."*
Environmental concern (water quality). (85%)	Bart, ALLARM	*"The motivation factor had to be those two injection wells west of Bear Lake, Pennsylvania in Columbus Township. And we were very concerned that there'd be spills, there'd be pipeline leaks and stuff like that."*
Political distrust (15%)	Dot, GCM	*"But now I'm involved in just these legislative items that make me really turn inside out, because I'm having a real issue with where I live. And the state representative we had said that we're gonna introduce legislation; I said, "What do you wanna introduce legislation for? You don't even enforce the legislation we have." Come on, give me a break, you know? It just – it sounds like the people that are running our government don't know one end from the other, and it's just a source of prestige for them, and as far as I'm concerned, they've got no prestige at all. None at all, because they're not effective, they're not listening to their constituent – oh, I could run off at the mouth about this, but this isn't Global Community Monitoring. [Laughs]"*
Community concerns (36%)	Gabriel, GCM	*"There's a lot of working class population that lives here, so they would – some are not willing to take up a fight of environmental issues because they fully depend on their employers and sometimes their employers are the ones that are polluting, they are here locally, so I decided I could be a voice and maybe a voice of concern that the community has that maybe they're not willing to share with others. I think that's who I'd like to be."*
Scientific credibility (53%)	Madeline, ALLARM	*"We had also heard through several resources including the Pine Creek Water Dog group that if we had received ALLARM training any concerns we might have or anything that we might discover would perhaps have more credibility, because we had received a science based training."*
Place – specific (81%)	Penelope, MLMP	*"And oh, I'll tell you what actually made me decide to work on it partly was their maps. There were maps of all these sites where people were monitoring and there wasn't one single site in Nevada where anybody was monitoring but one of the rewards I found of working in one area is getting to know an area. For field biologists, that area becomes – because there's other things there too besides what you're actually looking that – it sort of becomes your own little private place in way."*

Table 3.11 Continued: Example quotes representative of different motivations

Motivation Category (% of sources, n=72)	Participant ID, Project	Example quote
Interest (72%)	Stanley, MLMP	*"Well I was mainly interested in the plant itself because I have a lot of antelope horn milkweed on my property. And it's very difficult to eradicate 'cause of I think the deep roots system. I'm really interested in that particular plant and the fact that the monarchs like it and queen and all the other ecosystems of spiders and the beetles and all of that it – I find it fascinating. And also the monarch butterfly itself is of course of great interest as well."*
Social/project Connections (71%)	Lea, EELS	*"Well, you know, I feel like I'm something – I feel like I'm involved in something larger than just our site. So, you know, I feel connected to people that I haven't even met in the Hudson Valley because they're also volunteering at their field site, so that makes me feel part of a larger community of concerned people who are also trying to do everything they can to, you know, not only promote this particular species, but getting outdoors and celebrating the natural world and learning as much as possible."*
Learning and interest (65%)	Tai, EELS	*"I think the expectations were to learn about the eels that we had always known existed in the Hudson River but didn't really have the facts as to their habitats, their lifecycle, how they survived in the Hudson River or in the streams nearby and have really awareness of the fact that they had such a unique lifestyle. So, we learned a lot about them. I learned a lot about them, and I just find the whole eel life very interesting."*
Enjoyment (63%)	Charlotte, NestWatch	*"I guess, overall it's just something that I have a passion for and I enjoy doing. Some women like to go out shopping and – or out to a night club. That's not who I am, I really enjoy the outdoors."*

Barriers

Understanding what prevents participation may be as important as understanding what drives participation. During each of the interviews, participants were asked about barriers or limitations that negatively impacted their ability to participate in a given project. "Barriers" was referenced more than 500 times from 65 of 72 individuals, with nearly two-thirds stating "time" as a limiting factor. Other barriers in the aggregated dataset from more common to less common include: weather, cost, health or age-related issues, data transparency, technical requirements, recruiting/retaining volunteers, travel distance, access to sites or liability issues, commitment requirements, transportation logistics, lack of confidence, going on vacation, lack of immediate threat, disease such as ticks, health/safety concerns, no data to report, concern for flora and fauna, harassment from other people, loss of interest, interference from wildlife, feeling isolated, and loss of a trusted leader. Barriers, aggregated across projects, are listed in Table 3.12.

Table 3.12: Barriers, aggregated across projects.

	Total Sources	Total Refs
Barriers	65	511
Time	41	129
Weather	24	36
Cost	15	30
Old age - health	15	21
Data transparency	14	39
Technical	13	45
Recruiting or retaining volunteers	10	19
Travel distance	9	11
Access or liability	8	12
Commitment requirements	8	13
Transportation - logistics	8	13
Lack of confidence, inadequate	7	14
Going on vacation	6	8
Lack of immediate threat	5	8
Disease - ticks	4	6
Health or safety risks	4	6
No data to report	4	7
Concern for flora, fauna	3	13
Harassment from other people	3	11
Amotivation	2	3
Lack of in-person contact	2	3
Other wildlife interference	2	4
Feeling isolated	1	2
Lack of representation	1	1
Loss of trusted leader	1	1

With the exception of time, the individual project data reveal barriers that are generally unique to each project. For instance, NestWatch participants described technical barriers related to data entry as the most significant barrier, followed by time, data transparency, and concern for flora and fauna. The concern for other wildlife is exemplified in the following quote:

> *"But after chasing the birds off a few times and making them very anxious about their nest, I just couldn't do it anymore. So, I pretty much abandoned the project. I just could not bring myself to disturb those birds." (Lucy, NW)*

Main barriers for MLMP were old age, no data to report, and concern over ticks/disease. These limitations speak to the level of activity required for MLMP that may limit some seniors, and to the growing concern about monarch population declines, something heard repeatedly from several of the interviewees. CoCoRaHS participants described weather, old age, and going on vacation as barriers. These limitations speak to the frequency of the suggested data collection protocol, which recommends that weather data be collected and submitted every day. Participants in the EELS project described weather, transportation issues, and access or liability as barriers, reflecting the logistical challenges of getting to waterways, often with school-age children, as presented here:

> *"The only barrier is that we – our budget has been cut so much with the transportation. When I started there, we could get buses for after school, now we can't. So, a barrier would be that the kids have to provide their own transportation, and that's hard, that we meet at 4:00 and a lot of parents are working at that time." (Annabell, EELS)*

ALLARM participants most often described weather (especially in winter), data transparency, and lack of an immediate threat as barriers. The data transparency issue was described as a frustration for not being able to see or access the data they collected or fully understand how they were being used. For example, Madaline, an ALLARM participant states:

> *"I would say the big thing that needs to be done in order for us to attract participation or to keep people engaged is that communication factor of seeing how the data is used and seeing the data ourselves. Access to the data and understanding how it's being used if at all."*

Lastly, GCM participants described cost, recruiting volunteers and weather as barriers to participation. Here cost could reflect the cost needed to get to sites or receive technical support and equipment, especially in economically depressed areas. Recruiting community members to regularly maintain the effort of air quality monitoring was also described as a constant challenge.

Aside from lack of time, little is known of field-wide, and perhaps, project-specific barriers. These interviews provide a rich understanding of the unique and varied barriers that participants in these different projects face. Understanding barriers may be an important first step to recruitment of new participants, and is a recommended strategy for influencing behavior change (McKenzie-Mohr 2000).

Research Question 3.3: How can engagement in scientific practices be quantified and measured within the context of citizen science?

While an argument can be made that all of the dimensions of engagement noted above should be quantified, emphasis here is on the behavioral practices because of the need to understand what scientific practices participants conduct, not only to define different project types, but also to influence learning outcomes.

Recall that project leaders and expert reviewers were asked to rate the list of 20 project activities in an effort to reduce the list to regularly occurring activities that were common and important to all six projects. Project leaders were also asked to provide alternate language for each item. The edits and modifications of the 20 activities, along with the project leader rating data is presented in Table 3.13. Several of the activities such as "forming hypotheses" and "tool building" were not consistently relevant across all projects or had very low rankings and thus, were removed. Although “learn protocols” was frequently mentioned by the participants and rated high by project

Table 3.13: Project leader rankings of activities, and subsequent changes to generate the PEM

Mean ratings of importance by project leaders	List of coded project activities		Edits used to create the PEM
5.00	collect data	→	Gathered data and/or samples as often as suggested by the project protocol
4.75	communicate project finding to others	→	Communicated project data or findings to politicians, decision makers, or media outlets
4.63	submit data	→	Submitted data or reports as often as suggested by the project protocol
4.63	learn protocols	→	REMOVED
4.38	use standardized methods	→	REMOVED (included in data collection/submission)
4.38	communicate about project with others	→	Shared information about the project to the general public
4.00	ask questions	→	Sought answers to questions about a project or protocol
4.00	analyze or interpret data	→ →	Used statistics and probability to interpret project data Created graphs and maps of project data
3.88	use data	→	Used project data to make or defend a scientific claim
3.86	explore data	→	Explored publicly available project data
3.75	form hypothesis	→	REMOVED
3.71	get updates and feedback	→	REMOVED
3.50	train participants	→	Trained new participants
3.50	recruit participants	→	Recruited other participants
3.13	design investigations	→	REMOVED
3.00	attend meetings	→	Used social media to communicate with project staff or other participants (email, listserv, Facebook, Twitter, blog posts, etc.)
2.88	improve habitat	→	REMOVED
2.88	coordinate participant activities	→	REMOVED
2.88	manage/compile data	→	REMOVED
2.17	adapt or modify protocols	→	REMOVED

leaders, it too was removed because it was considered mostly a one-time event rather than a re-occurring activity that could be detected over time. Some activities required slight editorial changes, while others became completely rewritten. For example, through conversations, it was noted that "attend meetings" was not something that typically happened for the individual projects, and that the use of social media was more likely across all projects, thus, the activity morphed into "use social media to communicate with project staff or other participants (email, listserv, Facebook, Twitter, blog posts, etc.)." One item, "analyze or interpret data" was split into two items: "Use statistics and probability to interpret project data" and "Create graphs and maps of project data."

Together, the importance rating data by project leaders as well as the discussions and edits, and the participant source and reference data, were analyzed together to create a reduced list of 12 salient and relevant activities, which collectively became known as the Participant Engagement Metric (PEM). The PEM is a frequency-based measure used to quantify the behavioral aspects of engagement in citizen science, reflecting both the scientific *and* social aspects that were emphasized by both participants and project leaders. To measure frequency of behaviors, item responses were worded as: "never," "rarely," "sometimes," "often," and "very often". The PEM is shown in its entirety in Appendix F and used in the quantitative analyses in Chapter 4.

LIMITATIONS

Limitations of this work center around its qualitative focus, which is highly subjective and can threaten overall construct validity. Most of these limitations were addressed in the methods section. For example, Maxwell (1992) describes interpretative validity, or researcher bias, where data are selectively chosen or interpretations of meaning subjectively formulated that are consistent with researcher expectations. While efforts were made to minimize researcher bias through peer debriefing and inter-rater reliability, it can never be completely eliminated. Another limitation is generalizability to external communities, which is not recommended in qualitative studies. Internal generalizability, i.e, making inferences about the participant's life that were not expressed during the interview is also a common limitation in qualitative research.

DISCUSSION

To date, much of the focus on field-based or environmental monitoring across projects has been on the scientific outcomes (Follett et al. 2105, Kullenberg and Kasperowski 2016, Theobald et al. 2015). Examinations of learning outcomes are growing, but most are focused on a single project (Bonney et al. 2016, Brossard et al. 2005, Crall et al. 2012, Jordan et al. 2011, Trumball et al. 2000). More recently, comparative studies of multiple projects that occur primarily online have examined various engagement levels relative to contribution patterns often to create behavioral profiles of participants (Sauermann and Franzoni 2015, Ponciano et al. 2014, Curtis 2015, Jennett et al. 2014). Motivations for participation have largely been studied atheoretically, (McCaffrey 2005, Hobbs and White 2012, Bell et al. 2008) with notable exceptions (Raddick et al. 2010, Reed et al. 2013, Nov et al. 2011). Few, if any, studies have attempted to comprehensively characterize and operationalize engagement and motivation across multiple field-based projects and from the perspective of the participants themselves.

The current research builds on pertinent literature to empirically operationalize engagement in citizen science through analysis of qualitative interviews of 72 participants in six different environmentally-based projects. The robustness and volume of interviews allowed for examination of three broad research questions, the results of which have been summarized and depicted as a proposed framework to operationalize engagement, illustrated in Figure 3.5 below.

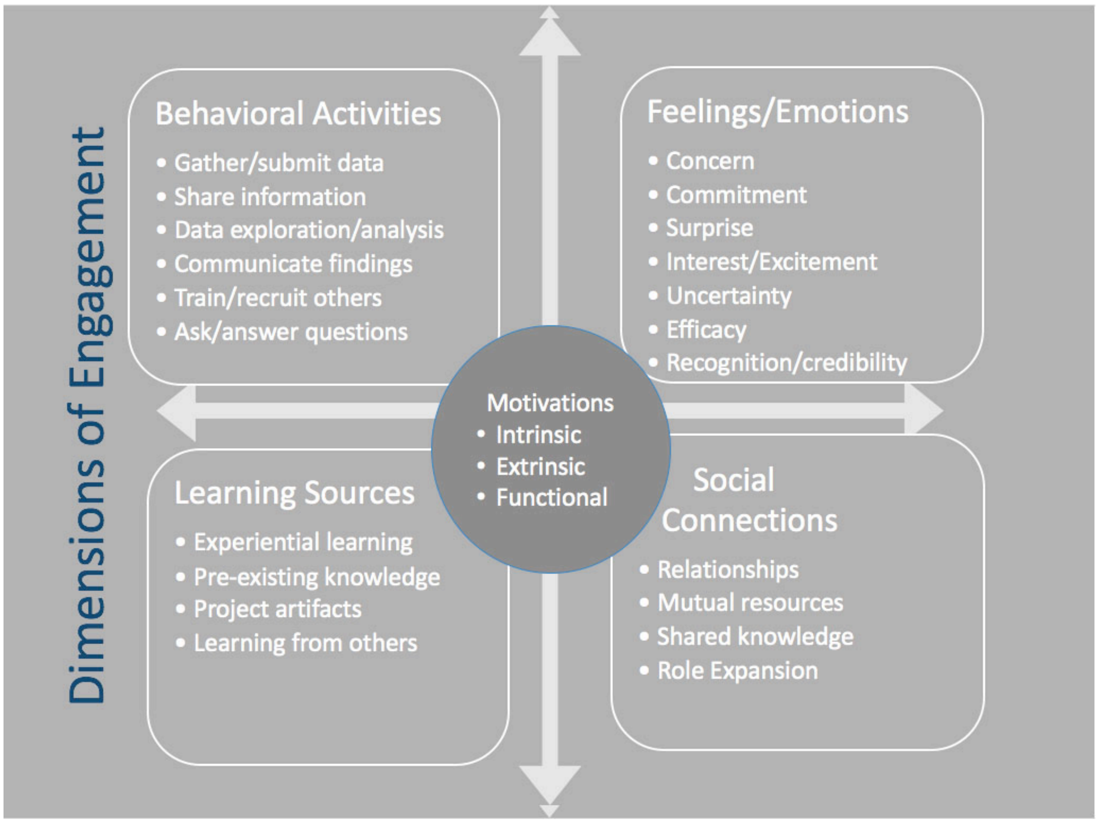


Figure 3.5: Proposed Dimensions of Engagement Framework

The goal for Research Question 3.1 was to understand how dimensions of engagement described in the literature (cognitive, affective, social, and behavioral) are characterized in citizen science. Starting with the learning/cognitive dimension, the findings highlighted the resources that participants used to support or enhance their learning and engagement. The vast majority of interviewees (60 of 72) described experiential learning as a main component of their engagement. These results are not surprising given the hands-on nature of citizen science. Participants also brought in a great deal of pre-existing knowledge into the projects, lending support to the importance of stimulating interest in science topics as a way to engage learners (Hidi and Renninger 2006, Freidman et al. 2008, National Research Council 2009). As has been described elsewhere, citizen science is a natural conduit to learning new content-specific knowledge and increasing awareness of ecological principles and connections. Many participants described an acute understanding of their role in citizen science, and in some cases to science writ large. While there was much discussion by participants about how they think about their engagement, this work is being analyzed separately in a collaborative investigation of the relationship between citizen science and science identity.

In the absence of thoughtful articulation, citizen scientists are sometimes disparagingly referred to as human sensors (Eitzel et al. 2017) or worse "data slaves," as if they are robots lacking emotion. In examining the affective dimension, data from these interviews reveals just the opposite. Citizen scientists are extremely committed individuals who care very deeply about their local environment, their community, and the quality of the data they collect. They experience positive and negative emotions throughout their lived experiences including interest, excitement, surprise, efficacy, and uncertainty. However, the analysis provided here on emotions was at a very coarse level, lacking a theoretical frame. Future work should dig deeper to better understand the ways in which emotions contribute to engagement, and subsequently learning.

One of the most surprising results of this study was the importance of social relationships for sustaining and enhancing engagement. Every project had interviewees that spoke warmly of the project and its organizers. These projects are likely not unique in this regard. Charismatic leaders certainly add to the appeal of the relationships, but what was heard most often was a sense of mutual respect, the importance of being heard, and the value of timely feedback. These are not new ideals to citizen science, but the results here serve as excellent reminders that relationships take continued work to maintain over the long term, and should not be taken for granted. Participants are clearly paying attention to communication channels or lack thereof! Another surprising finding was the number of participants that described an expanding role in the project. Role expansion could signal increased responsibility such as volunteering to take notes at a meeting or compiling data or training new participants. These types of role changes could be further explored in the context of Lave and Wenger's description of legitimate peripheral participation (1991), where group members share tools and practices that over time support transitions from peripheral/novice members to core/expert membership.

The last dimension in Figure 3.5 includes the behavioral, or project activities; essentially the things that participants actually do on behalf of the project. To say that these citizen scientists are far more than data collectors is an understatement. Within each project, interviewees described a multitude of tasks ranging from data collection to communicating with others about the project, to using data to back scientific claims. Here again, there was a great deal of discussion about the ways in which interviewees communicated about the project or its findings to others, reiterating the social nature of engagement. Although the co-created projects did have slightly more people describing more science process activities, the contributory projects had all of those same activities represented, just not as often. Importantly, these findings leave us wondering about the utility of the co-created/collaborative/contributory typology (Bonney et al. 2009, Shirk et al. 2012) that is based on involvement with the science process since few obvious patterns were detected among the project types or even the project structures with respect to science activities.

Also, across the field of citizen science, there appears to be growing emphasis on getting people to do more. However, this also begs the questions, why should they? Many participants, especially in the contributory and collaborative projects expressed satisfaction with their current role and we know satisfaction is an important consideration for volunteer motivation (Ryan and Deci 2000a), which directly links back to engagement. This begs another question, mainly, why should projects that aren't developed to support higher order process skills be expected to deliver on such lofty goals? Perhaps this is more probable in the Irwin (1995) tradition of citizen science, or the 'activist' form of citizen science as described by Cooper and Lewenstein (2016), but there are doubts here too. Across the interviews, participants described being happy in their niche as "data collectors;" most had little desire to conduct statistical analyses or read technical papers, let alone conduct their own investigations – they were happy to leave that to the scientists. It was enough for them to know that their data were being gathered and stored in a central location, and most importantly, being used to answer important questions that were personally relevant and meaningful to them.

Results from Research Question 3.2 on motivation revealed that similar to previous research, motivation to participate is complex and multi-faceted, but aggregated, was mostly driven by environmental concern, contribution, and interest. One notable trend was the prevalence of extrinsically-leaning motivations among co-created projects, versus intrinsically-leaning motivations in contributory projects. Research suggests that behaviors driven by intrinsic motivations (pleasure, interest, enjoyment) are more likely to be sustained over time than behaviors that are driven by extrinsic motivations such as fear, guilt, or worry (Ryan and Deci 2000a). This notion was in fact heard from the co-created projects when asked what might prevent them from participating; they answered that a lack of an immediate threat might cause them to stop participating. To avoid this type of project attrition, projects should repeatedly emphasize the importance of year-round monitoring to obtain baseline data. Although further testing is needed to fully understand the role of motivation in engagement, data from these interviews suggests that motivation is a key facet of engagement, and likely influential to all the other dimensions; hence its central location in Figure 3.5. The centrality of motivation in engagement has also been described by Raddick et al. (2013) who suggest that deeper involvement may be driven by different motivations.

Other than time limitations, barriers to participation were unique to each project. While some barriers such as weather and personal health cannot be easily addressed by projects, other barriers such as data transparency, technical issues, commitment requirements, lack of confidence, and lack of immediate threat can be dealt with relatively easily with targeted campaigns or communication messages. For example, project leaders can and should emphasize the importance of negative data to encourage continued participation. Similarly, very few projects require any form of prior knowledge or experience; with proper training, anyone can successfully participate and this should be clearly communicated to potential or existing participants. The lack of data transparency in some projects seemed to be the most frustrating barrier, and one that all projects should strive to overcome.

CONCLUSION

This research has attempted to fill some critical knowledge gaps about what engagement looks like across environmentally-based citizen science projects. Examination of the vast literature base on student engagement was used to frame the dimensions for affective, cognitive, and behavioral engagement. Despite the current study's emphasis on behavioral engagement, all three of these dimensions had extremely high relevance and are worthy of future research in their own right. Wenger's work on Communities of Practice (1998) provided structure for understanding the important social project interactions including relationships, using mutual resources, sharing knowledge, and role expansion. The social dimension seems especially rich for a deeper and more nuanced examination, particularly with studies using social network analysis to understand online interactions.

Research Question 3.2 relied mostly on Self Determination Theory (Ryan and Deci 2000a), to examine intrinsic and extrinsic motivations. The analysis revealed one of the few clear and apparent differences between different project types, i.e., concern being a main driver for co-created projects, and interest for contributory projects. The current study also hinted at the important role that motivation has in potentially influencing all other dimensions. Results from this study should also inform our understanding of key barriers to citizen science and inform modification of existing projects to reach new audiences or retain current participants.

In answering Research Question 3.3, this research sought to develop an empirically grounded and easy to use metric to quantify and measure scientific practices. Understanding what participants do as a function of their engagement may be a critical first step to understanding learning in citizen science. To that end, the Participant Engagement Metric, a frequency based 12-item scale was developed with input from participants and project leaders and will be tested on a large scale study during the quantitative phase of this dissertation.

Finally, this research is intended to build on existing literature to create a more clearly defined framework that operationalizes citizen science engagement. If nothing else, the Dimensions of Engagement framework emphasizes the fact that ordinary citizens find personal relevance in the work of scientists, enough so to contribute themselves emotionally, socially, cognitively, and behaviorally to the collective endeavor. The framework also may facilitate the innovation of improved methodologies for continued systematic study of citizen science globally. Future work should continue to expand or modify the dimensions of engagement in a larger population so that generalizations across the field can be inferred and utilized.

REFERENCES

Appleton, J. J., Christenson, S. L., and Furlong, M. (2008). Student engagement with school: Critical conceptual and methodological issues of the construct. *Psychology in Schools*, 45, 369–386. doi:10.1002/pits.20303.

Azevedo, R. (2015). Defining and measuring engagement and learning in science: conceptual, theoretical, methodological, and analytical issues. *Educational Psychologist*, 50:1, 84-94, DOI: 10.1080/00461520.2015.1004069.

Bell, S., Marzano, M., Cent, J. Kobierska, H., Podjed, D., Vandzinskaite, D., Reinert, H., Armaitiene, A., Grodzinska-Jurczak, M., and Mursic, R. (2008). What counts? Volunteers and their organizations in the recording and monitoring of biodiversity. *Biodiversity Conservation* 17: 3443-3454.

Bohnert, A., Fredricks, J., and Randall, E. (2010). Capturing unique dimensions of youth organized activity involvement: Theoretical and methodological considerations. *Review of Educational Research*, 80, No. 4, pp. 576–610 DOI: 10.3102/0034654310364533.

Bonney, R., Ballard, H., Jordan, R., McCallie, E., Phillips, T., Shirk, J., and Wilderman, C. C. (2009a). Public Participation in Scientific Research: Defining the Field and Assessing Its Potential for Informal Science Education. *A CAISE Inquiry Group Report*. Washington, D.C.: Center for Advancement of Informal Science Education (CAISE). Retrieved from http://eric.ed.gov/?id=ED519688.

Bonney, R., Cooper, C. B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K. V., and Shirk, J. (2009b). Citizen science: A developing tool for expanding science knowledge and scientific literacy. *BioScience*, *59*(11), 977–984. https://doi.org/10.1525/bio.2009.59.11.9

Bonney, R., Phillips, T. B., Ballard, H. L., and Enck, J. W. (2016). Can citizen science enhance public understanding of science? *Public Understanding of Science*, *25*(1), 2–16. https://doi.org/10.1177/0963662515607406.

Bonney, R., Shirk, J. L., Phillips, T. B., Wiggins, A., Ballard, H. L., Miller-Rushing, A. J., and Parrish, J. K. (2014). Next steps for citizen science. *Science*, 343(6178), 1436–1437. https://doi.org/10.1126/science.1251554.

Brossard, D., Lewenstein, B., and Bonney, R. (2005). Scientific knowledge and attitude change: The impact of a citizen science project. *International Journal of Science Education*, *27*(9), 1099–1121. https://doi.org/10.1080/09500690500069483.

Christenson, S. L., Reschly, A. L. and Wylie, C. (Eds.). (2012). *Handbook of Research on Student Engagement*. New York, NY: Springer.

Clary, E. G., Snyder, M., Ridge, R. D., Copeland, J., Stukas, A. A., Haugen, J. and Miene, P. (1998). 'Understanding and assessing the motivations of volunteers: A functional approach'. *Journal of Personality and Social Psychology*, 74, 1516-30.

Clary, E. G., and Snyder, M. (1999). The motivations to volunteer: Theoretical and practical considerations. *Current Directions in Psychological Science,* 8, 156-159.

Cleary, T. J., and Zimmerman, B. J. (2012). A cyclical self-regulatory account of student engagement: Theoretical foundations and applications. In S. L. Christenson, A. L. Reschly, and C. Wylie (Eds.), *Handbook of Research on Student Engagement* (pp. 237–258). New York, NY: Springer.

Cooper, C. B. and Lewenstein, B. V. (2016). Two meanings of citizen science. In: Cavalier, D., (ed.), *The Rightful Place of Science: Citizen Science*. Tempe, AZ: Arizona State University Press, 51–62.

Crall, A., Jordan, R., Holfelder, K., Newman, G., Graham, J. and Waller, D. (2012). The impacts of an invasive species citizen science training program on participant attitudes, behavior, and science literacy. *Public Understanding of Science* 22(6): 745–764.
Creswell, J. W. (2003). *Research Design: Qualitative, Quantitative and Mixed Methods Approaches*. Thousand Oaks, CA: Sage Publications.
Crick, R. D. (2012). Deep engagement as a complex system: Identity, learning power, and authentic enquiry. In S. L. Christenson, A. L. Reschly, and C. Wylie (Eds.), *Handbook of Research on Student Engagement* (pp. 675–694). New York, NY: Springer.
Curtis, V. (2015). Online citizen science projects: an exploration of motivation, contribution and participation. PhD thesis, The Open University.
Deci, E. L., and Ryan, R. M. (2000). The "what" and "why" of goal pursuits: Human needs and the self-determination of behavior. *Psychological Inquiry,* 11, 227-268.
Eitzel, M. V., Cappadonna, J. L., Santos-Lang, C., Duerr, R. E., Virapongse, A., West, S. E., Kyba, C. C. M., Bowser, A., Cooper, C. B., Sforzi, A., Metcalfe, A. N., Harris, E. S., Thiel, M., Haklay, M., Ponciano, L., Roche, J., Ceccaroni, L., Shilling, F. M., Dörler, D., Heigl, F., Kiessling, T., Davis, B. Y., Jiang, Q. (2017). Citizen science terminology matters: Exploring key terms. *Citizen Science: Theory and Practice*, 2(1): 1, pp. 1–20, DOI: https://doi.org/10.5334/cstp.96.
Evans, C., Abrams, E., Reitsma, R., Roux, K., Salmonsen, L., and Marra, P. (2005). The Neighborhood Nestwatch program: Participant outcomes of a citizen-science ecological research project. *Conservation Biology*, 19(3): 589–594.
Falk, J.H. (2001). Free-choice science learning: Framing the issues. In: Falk J., (Ed.), *Free-choice science education: How people learn science outside of school* (pp. 2–9). New York: Teacher's College Press.
Falk, J.H. and Dierking, L.D. (2002). *Lessons without limit: How free-choice learning is transforming education*. Walnut Creek, CA: AltaMira.
Farrell, J. M., Johnston, M. E., and Twynam, G. D. (1998). Volunteer motivation, satisfaction, and management at an elite sporting competition. *Journal of Sport Management, 12*(4), 288-300.
Finn, J. D., and Voelkl, K. E. (1993). School characteristics related to student engagement. *Journal of Negro Education*, *62*, 249–268.
Finn, J. D., and Zimmer, K. (2012). Student engagement: What is it? Why does it matter? In S. L. Christenson, A. L. Reschly, and C. Wylie (Eds.), *Handbook of Research on Student Engagement* (pp. 97–132). New York, NY: Springer.
Follett, R., and Strezov, V. (2015). An analysis of citizen science based research: Usage and publication patterns. *PLoS ONE* 10(11): e0143687. doi:10.1371/journal.pone.0143687.
Fredricks, J. A., Blumenfeld, P., and Paris, A. (2004). School engagement: Potential of the concept, state of the evidence. *Review of Educational Research*, *74*, 59–109. doi:10.3102/00346543074001059.
Fredricks, J. A. (2011). Engagement in school and out-of-school contexts: A multidimensional view of engagement. *Theory into Practice*, 50:4, 327-335, DOI:10.1080/00405841.2011.607401.
Friedman, A. J., Allen, S., Campbell, P. B., Dierking, L. D., Flagg, B. N., Garibay, C., … Ucko, D. A. (2008). Framework for Evaluating Impacts of Informal Science Education Projects. *InformalScience.org*. National Science Foundation Workshop. Retrieved from

http://www.informalscience.org/framework-evaluating-impacts-informal-science-education-projects.
Furrer, C., and Skinner, E. (2003). Sense of relatedness as a factor in children's academic engagement and performance. *Journal of Educational Psychology, 95*(1), 148–162.
Gerring, J. (2004). What is a case study and what is it good for? *American Political Science Review,* (98) 2: 341-354.
Griffiths, A., Liles, E., Furlong, M. J., and Sidhwa, J. (2012). The relations of adolescent student engagement with troubling high-risk behaviors. In S. L. Christenson, A. L. Reschly, and C. Wylie (Eds.), *Handbook of Research on Student Engagement* (pp. 563–584). New York, NY: Springer.
Hatch, J. A. (2002). *Doing Qualitative Research in Education Settings*. Albany: SUNY Press.
Haythornthwaite, C. (2009). Crowds and communities: Light and heavyweight models of peer production. *Hawaii International Conference on Systems Science*. Big Island, Hawaii. IEEE.
Hidi, S., and Renninger, K. A. (2006). The four-phase model of interest development. *Educational Psychologist*, *41*(2), 111–127. https://doi.org/10.1207/s15326985ep4102_4.
Howe, J. (2006). The rise of crowdsourcing. *Wired Magazine*, *14*(6), 1-4.
Jennett, C., Blandford, A., Brohan, P. and Cox, A. (2014). Designing for dabblers and deterring drop-outs in citizen science. *Computer Human Interaction Conference*, Toronto.
Jordan, R., Gray, S., Howe, D., Brooks, W. and Ehrenfeld, J. (2011). Knowledge gain and behavioral change in citizen-science programs. *Conservation Biology*, 25(6): 1148–1154.
Kullenberg C. and Kasperowski D. (2016). What is citizen science? – A scientometric meta-analysis. *PLoS ONE*, 11(1): e0147152. doi:10.1371/journal.pone.0147152.
Lam, S., Wong, B., Yang, H., and Liu, Y. (2012). Understanding student engagement with a contextual model. In S. L. Christenson, A. L. Reschly, and C. Wylie (Eds.), *Handbook of Research on Student Engagement* (pp. 403–420). New York, NY: Springer.
Lave, J., and Wenger, E. (1991). *Situated Learning: Legitimate Peripheral Participation*. Cambridge University Press.
Leech, N. L. and Onwuegbuzie, A. J. (2007). An array of qualitative data analysis tools: A call for data analysis triangulation. *School Psychology Quarterly*, (22) 4: 557–584.
Lawrence, A. (2006). 'No Personal Motive?' Volunteers, Biodiversity, and the False Dichotomies of Participation. *Ethics, Place and Environment: A Journal of Philosophy and Geography*. 9(3) 279-298.
Lawson, M. A., and Lawson, H. A. (2013). New conceptual frameworks for student engagement research, policy, and practice. *Review of Educational Research, 83(3):432–479. DOI: 10.3102/0034654313480891.*
Lewandowski, E. V., and Oberhauser, K. S. (2017). Butterfly citizen scientists in the United States increase their engagement in conservation, *Biological Conservation*, 208: 106-112. ISSN 0006-3207, http://dx.doi.org/10.1016/j.biocon.2015.07.029.
Lewenstein, B. V. (2015). Identifying what matters: Science education, science communication, and democracy. *Journal of Research Science Teaching*, 52: 253–262. doi:10.1002/tea.21201.

Macey, W. H., and Schneider, B. (2008). The meaning of employee engagement. *Industrial and Organizational Psychology, 1*, 3–30. doi:10.1111/j.1754-9434.2007.0002.x.
Mahoney, J. L., Cairns, R. B., and Farmer, T. (2003). Promoting interpersonal competence and educational success through extracurricular activity participation. *Journal of Educational Psychology*, *95*, 409–418. doi:10.1037/0022-0663.95.2.409.
Martin, A. J. (2007). Examining a multidimensional model of student motivation and engagement using a construct validation approach. *British Journal of Educational Psychology, 77* (413–440).
Martin, A. J. (2012). Part II commentary: Motivation and engagement: Conceptual, operational, and empirical clarity. In S. L. Christenson, A. L. Reschly, and C. Wylie (Eds.), *Handbook of Research on Student Engagement* (pp. 303–313). New York, NY: Springer.
Maslow, A. H. (1943). A theory of human motivation. *Psychological Review, 50(4)*, 370-96.
Maxwell, J. A. (1992). Understanding and validity in qualitative research. *Harvard Educational Review,* 62 (3): 279-300.
McCaffrey, R. E. (2005). Using citizen science in urban bird studies. *Urban Habitats*, *3*(1), 70–86.
McCallie, E., Bell, L., Lohwater, T., Falk, J. H., Lehr, J. L., Lewenstein, B. V., and Wiehe, B. (2009). Many experts, many audiences: public engagement with science and informal science education*. A CAISE Inquiry Group Report*. Washington, D.C.: Center for Advancement of Informal Science Education (CAISE).
McKenzie-Mohr, D. (2000). Promoting sustainable behavior: An introduction to community-based social marketing. *Journal of Social Issues*, 56: 543-554.
National Research Council. (2009). *Learning Science in Informal Environments: People, Places, and Pursuits*. National Academies Press.
Nielsen, J. (2006). Participation inequality: The 90-9-1 rule for social features. Nielson Norman group. Available online: https://www.nngroup.com/articles/participation-inequality/.
Newman, F. M., and Wehlage, G. G. (1993). Five standards of authentic instruction. *Educational Leadership*, *50* (7), 8–12.
Nevid, J. S. (2013). *Psychology: Concepts and Applications*. Wadsworth Cengage Learning, Belmont.
Nov, O., Arazy, O. and Anderson, D. (2011). Dusting for science: Motivation and participation of digital citizen science volunteers. *iConference*. Seattle, Washington.
Nov O., Arazy O., and Anderson, D. (2014). Scientists@Home: What drives the quantity and quality of online citizen science participation? *PLoS ONE* 9 (4): e90375. doi:10.1371/journal.pone.0090375.
Patton, M. Q. (2002). *Qualitative Research and Evaluation Methods*, 3rd Edition. Sage Publications Inc., Thousand Oaks, CA.
Phillips, T., Bonney, R., and Shirk, J. (2012). What is our impact? Toward a unified framework for evaluating outcomes of citizen science participation. In J. L. Dickinson and R. Bonney (Eds.), *Citizen Science: Public Participation in Environmental Research* (pp. 82–95). Ithaca, NY: Cornell University Press.
Ponciano, L., Brasileiro, F., Simpson, R. and Smith, A. (2014). 'Volunteers' engagement in human computation astronomy projects'. *Computing in*

Science and Engineering. IEEE computer Society Digital Library. IEEE Computer Society, http://doi.ieeecomputersociety.org/10.1109/MCSE.2014.4.
Preece, J., and Shneiderman, B. (2009). The reader-to-leader framework: Motivating technology-mediated social participation. *AIS Transactions on Human-Computer Interaction,* 1 (1): 13-32.
Raddick, M., Jordan, G., Bracey, P. Gay, P., Lintott, C., Murray, P., Schawinski, K., Szalay, A. and Vandenberg, J. (2010). Galaxy zoo: Exploring the motivations of citizen science volunteers. *Astronomy Education Review*, 9, http://doi 10.3847/AER2009036.
Raddick, M. J., Bracey, G., Gay, P. L., Lintott, C. J., Cardamone, C., Murray, P., ... and Vandenberg, J. (2013). Galaxy Zoo: Motivations of citizen scientists. *arXiv preprint arXiv:1303.6886*.
Reed J. T., Raddick M. J., Lardner A., and Carney K. (2013). An exploratory factor analysis of motivations for participating in Zooniverse, a collection of virtual citizen science projects. In: *Proceedings of the 46th annual Hawaii international conference on systems sciences*, Wailea, Hawaii.
Reeve, J. (2012). A self-determination theory perspective on student engagement. In S. L. Christenson, A. L. Reschly, and C. Wylie (Eds.), *Handbook of Research on Student Engagement* (pp. 149–172). New York, NY: Springer.
Rotman, D., Hammock, J., Preece, J., Hansen, D., Boston, C., Bowser, A., and He, Y. (2014). Motivations affecting initial and long-term participation in citizen science projects in three countries. *In iConference 2014 Proceedings* (110 - 124). doi:10.9776/14054.
Rowe, G., and Frewer, L. J. (2005). A typology of public engagement mechanisms. *Science, Technology and Human Values*, 30, (2): 251–290.
Rumberger, R. W., and Rotermund, S. (2012). The relationship between engagement and high school drop-out. In S. L. Christenson, A. L. Reschly, and C. Wylie (Eds.), *Handbook of Research on Student Engagement* (pp. 491–514). New York, NY: Springer.
Ryan, R. M., and Deci, E. L. (2000a). Intrinsic and extrinsic motivations: Classic definitions and new directions. *Contemporary Educational Psychology*, *25*(1), 54-67.
Ryan, R. M., and Deci, E. L. (2000b). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American Psychologist, 55*(1), 68-78.
Sauermann, H. and Franzoni, C. (2015). Crowd science user contribution patterns and their implications. *Proceedings of the National Academy of Sciences,* 112 (3): 679–684.
Schaufeli, W. B., Salanova, M., Gonzalez-Romá, V., and Bakker, A. B. (2002). The measurement of engagement and burnout: A confirmative analytic approach. *Journal of Happiness Studies, 3*, 71-92.
Schaufeli, W. B., Bakker, A. B., and Salanova, M. (2006). The measurement of work engagement with a short questionnaire: A cross-national study. *Educational and Psychological Measurement*, 66(4), 701-716.
Schrock, D. S., Meyer, M., Ascher, P., and Snyder, M. (2000). Reasons for becoming involved as a master gardener. *Horticulture Technology*, *10*(3), 626–630.
Schwan, S., Grajal, A., and Lewalter, (2014). Understanding and engagement in places of science experience: Science museums, science centers, zoos, and aquariums. *Educational Psychologist*, 49:2, 70-85, DOI: 10.1080/00461520.2014.917588.

Skinner, E. A., Furrer, C., Marchand, G., and Kindermann, T. (2008). Engagement and disaffection in the classroom: Part of a larger motivational dynamic. *Journal of Educational Psychology*, *100*, 765–781. doi:10.1037/a0012840.
Skinner, E. A., and Pitzer, J. R. (2012). Developmental dynamics of student engagement, coping, and everyday resilience. In S. L. Christenson, A. L. Reschly, and C. Wylie (Eds.), *Handbook of Research on Student Engagement* (pp. 21–44). New York, NY: Springer.
Sonnentag, S. (2003). Recovery, work engagement, and proactive behavior: A new look at the interface between non-work and work. *Journal of Applied Psychology*, 88, 518-528.
Strauss, A. and Corbin, J. (1997). *Grounded Theory in Practice*. Thousand Oaks: CA: Sage Publications.
Theobald, E., Ettinger, A., Burgess. H., DeBey, L., Schmidt, N., Froehlich, H., et al. (2015). Global change and local solutions: Tapping the unrealized potential of citizen science for biodiversity research. *Biological Conservation* 181: 236–244.
Trumbull, D., Bonney, R., Bascom, D. and Cabral, A. (2000). Thinking scientifically during participation in a citizen science project. *Science Education*, 84: 265–275.
Viera, A. J. and Garrett, J. M. (2005). Understanding inter-observer agreement: The Kappa statistic. *Family Medicine*, 37(5): 360-3.
Voelkl, K. E. (2012). School identification. In S. L. Christenson, A. L. Reschly, and C. Wylie (Eds.), *Handbook of Research on Student Engagement* (pp. 193–218). New York, NY: Springer.
Wenger, E. (1998). *Communities of Practice: Learning, Meaning, and Identity*. Cambridge University Press, MA.
Wright, D. R., Underhill, L. G., Keene, M., and Knight, A. T. (2015). Understanding the motivations and satisfactions of volunteers to improve the effectiveness of citizen science programs. *Society and Natural Resources*, *28*(9), 1013–1029. https://doi.org/10.1080/08941920.2015.1054976.
Yeung, A. B. (2004). The octagon model of volunteer motivation: Results of a phenomenological analysis. *Voluntas: International Journal of Voluntary and Nonprofit Organizations*, 15 (1):21-46.
Yin, R. K. (2003). *Case Study Research, Design and Methods* (3rd ed., vol. 5). Thousand Oaks: Sage.
Zoellick, B., H. Webber, K. James, A. Miller-Rushing, and M. Marion. (2015). Measuring participant engagement in short-duration citizen science events. Paper presented at the *Citizen Science Association Conference*, San Jose, CA, Feb. 11-12, 2015.

CHAPTER IV

QUANTITATIVE EXAMINATION OF ENGAGEMENT AND LEARNING IN CITIZEN SCIENCE

"For the things we have to learn before we can do them,
we learn by doing them."
--Aristotle

INTRODUCTION

Understanding the relationship between engagement in science activities in informal contexts and how that affects science learning is a growing area of interest for science education research. This growth is due in part, to the recognition that over a lifetime, 95% of learning occurs outside of formal K-12 structures (McEver 2010). Informal learning initiatives are often developed and supported at state, regional, and national scales to nurture lifelong science learning, yet we know little of their net effect (Lin and Schunn 2016). As such, there is a need for more evidence-based research to not only fill knowledge gaps about what works in what contexts, but also to better inform educational policy.

In a policy statement addressed to the Board of the National Association of Research in Science Teaching (NARST), Dierking et al. (2003) describe six aspects related to conducting research on or in informal science learning settings. First, since learning outside of formal classrooms is often guided by learners' interests or needs, research in these contexts must include the role that motivation and interest play in the process of learning. Second, the context and physical settings where learning happens, must be considered. Third, social and cultural factors that include both individuals and groups as the unit of analysis are important to consider. Fourth, research that utilizes a "learning ecosystems" approach where the experience of learning is considered across time and space are encouraged. Fifth, investigations should emphasize both the process and product of learning. Lastly, informal science learning research should use a variety of designs, methods, contexts, and analyses, reflective of these dynamic learning experiences.

To a great extent, the ideals put forth in this policy statement provide the milieu for the current study, which examines the relationship between engagement in citizen science and science learning outcomes, and takes into account motivation, context, social and cultural factors, process, and diverse analytical methods. Citizen science — whereby members of the public intentionally engage in scientific research — typically occurs in informal settings such as private residences, nature centers, museums, and community centers. Over the past two decades, citizen science has seen exponential growth, both in terms of number of projects and numbers of participants (Bonney et al. 2014). Moreover, the growth in peer-reviewed publications using citizen science data has increased more than 10-fold since the 1990s (Follett and Strezov 2015). In addition to the production of new science knowledge, many citizen science projects also seek to influence learning outcomes such as those aimed at improving knowledge, skills, and attitudes toward science and the scientific process, and promoting environmental stewardship practices (Phillips et al. 2012).

In an attempt to codify various forms of citizen science projects to better understand learning outcomes, Bonney et al. (2009a) hypothesized a continuum of learning outcomes that increased from less engagement in the scientific process to more engagement. According to Bonney et al. (2009a), participants in "*contributory*" projects are primarily engaged in data collection and submission, and learning here is thought to be somewhat limited. "*Collaborative*" projects, where participants engage in other aspects beyond data collection and submission and may work more integrally with scientists, result in more learning than *contributory* projects. The deepest learning outcomes, however, are said to come from "*co-created*" projects where participants are engaged in nearly all facets of the scientific process from asking the questions, to data collection, submission, analysis and interpretation, to using data as evidence and communicating findings.

Despite the apparent logic of this argument, there is little empirical evidence to examine the hypothesis. Although some projects have successfully demonstrated an increase in participants' understanding of science content and process (Trumbull et al. 2000, Trumbull et al. 2005, Phillips et al. 2006, Bonney et al. 2009a, Trautman et al. 2012), there are few, if any, studies that look across multiple projects using the same measurement tools. Moreover, few studies have examined more complex outcomes such as self-efficacy, skill acquisition, environmental stewardship, or increases in participant science identity, all of which can result from engagement in citizen science (Rowe and Frewer 2000, Lawrence 2006, Bonney et al. 2009a).

RESEARCH QUESTIONS

The current cross-programmatic research is aimed at testing the hypothesis put forth by Bonney et al. (2009a) by quantifying and comparing engagement in the scientific process across six different citizen science projects spanning the contributory to co-created continuum. The six projects include: NestWatch (NW), Monarch Larva Monitoring Project (MLMP), Community Collaborative Rain, Hail, and Snow (CoCoRaHS), Hudson River Eels Project (EELS), Alliance for Aquatic Resource Monitoring (ALLARM), and Global Community Monitor (GCM).

The present study uses theoretical perspectives from Situated Learning (Lave and Wenger 1991), and Communities of Practice (Wenger 1998), and builds off previous work (see Phillips, Dissertation Chapter 3) that identified five unique dimensions of engagement (motivation, behavioral activities, affective/emotions, social connections, and cognitive/learning). This chapter relies on descriptive and correlational analyses to examine a variety of factors associated with engagement and how they relate to learning outcomes. Specifically, the following research questions and hypotheses are addressed:

1. How are dimensions of engagement (motivation, affective/emotions, social connections, behavioral, and cognitive/learning) characterized and described across the six projects?
2. How do behavioral aspects of engagement (measured via the Participant Engagement Metric, PEM) relate to outcomes of citizen science such as science efficacy, science skills, and environmental stewardship?
    a. H1: Participants' involvement with more aspects of the scientific process will be positively correlated with outcomes related to science efficacy, skills, and environmental stewardship.
3. How do the relationships in RQ 2 differ across the six projects, three project types (contributory, collaborative, co-created), and project structure (individual vs. group-based)?
    a. H2: Projects that involve people in more aspects of the scientific process (Co-created) and support peer-peer interactions (group structures) will be more positively correlated with outcomes related to science efficacy, skills, and environmental stewardship.
4. What role, if any, does motivation play in the relationship between behavioral engagement and learning?
    a. H3: Higher intrinsic motivations will be positively correlated with behavioral engagement and learning outcomes.

This study has four overarching goals. First, to gather data through an online survey to provide descriptive analyses of the six different projects (RQ1), Second to test the hypotheses about engagement, motivation, and learning (RQ2-RQ4). Third, to apply several of the constructs and instruments within the DEVISE framework (NSF DRL-1010744; see Phillips Dissertation, Chapter 2) that were created for and validated in citizen science contexts. Fourth, to validate another instrument called the Participant Engagement Metric (PEM), a newly developed scale that measures the behavioral aspects of engaging in the science process through citizen science. It is expected that results from this research will fill critical gaps in our understanding of the relationship between engagement in citizen science and learning. The variety and number of projects being studied also will provide a window into the collective impacts that are purported to occur from participation in citizen science.

Organization of this paper is as follows: first, a literature review on aspects of engagement as they relate to learning in citizen science. Next, a description of the six projects involved in the study, followed by methodology, including data collection and analysis techniques. Descriptive and inferential results of the online survey will be presented in the order of the research questions. Lastly, interpretation of the findings and limitations of the study are discussed.

LITERATURE REVIEW

The stated importance of lifelong learning through ISE has reached a critical point in recent years, not only as an effective means of communicating science to vast segments of the population, but also as a potential pipeline for fostering lifelong engagement with and support for the scientific enterprise (National Research Council, 2009). Many citizen science projects are developed within the context of Informal Science Education (ISE) sometimes referred to as "free-choice learning," a type of voluntary, open-ended, and often unstructured learning that happens outside of school (Falk and Dierking 2002). A nagging question for ISE and citizen science however, is what do participants learn through such experiences and how do we measure this learning? "Public engagement in science" (PES) initiatives[2] such as citizen science are thought to improve science and environmental literacy among the general public through participation in genuine scientific research (Crall et al. 2012, Jordan et al. 2011, Kloetzer et al 2013, Lee and Roth 2003, Masters et al. 2016). The main assertion by developers of citizen science projects is that through engagement with the scientific enterprise, citizens will have a better understanding of the nature and process of science and therefore be able to make more informed decisions regarding science and technology issues (Bonney et al. 2009b, Newman et al. 2012). Additionally, since many of these projects occur in natural outdoor settings, it is inferred that engaging with the natural world will increase knowledge and improve attitudes toward the environment and lead to environmental concern and stewardship behaviors (Dickinson and Bonney 2012). Collectively, these outcomes can have cumulative impacts across science and society, resulting in a healthier democracy and a sustainable natural world (Cooper et al. 2007).

---

[2] The study of public engagement in science encompasses many different approaches to increasing science literacy among the populace. Some approaches aim to directly involve the public in policy and decision making related to science and technology. Other approaches simply aim to increase public interest and engagement in science, particularly in informal settings, and still other approaches attempt to engage the public in ongoing research, typically in partnership with a scientific institution and sometimes referred to as "public participation in scientific research" or "citizen science."

It can be argued therefore, that citizen science engagement can support what Lave and Wenger (1991) describe as *Situated Learning Theory* (SLT). Also referred to as *Legitimate Peripheral Participation*, Situated Learning is the process of co-participation in knowledge production and meaning making, where learning is distributed among participants and the learner acquires skills to engage in the process through repeated practice. Learners create meaning from the everyday contexts and activities of daily life. The hands-on and experiential nature of citizen science provides many opportunities to study how people 'learn by doing' in everyday contexts, and in particular by engaging in scientific practices such as data collection, submission, data analysis, etc. Here, learning is situated, meaning that it places the learner in the center of the **conten**t and the **context.** The collaborative nature of citizen science is often regarded as a collective social activity involving many actors (Wiggins and Crowston, 2011) and thus provides a **community** or group with which the learner creates and negotiates meaning of the situation. Perhaps most obvious, citizen science lends itself quite readily to **participation**, the interchange of ideas and active engagement of learners with each other and with tools and materials. These components – content, context, community, and participation – provide central pillars for examining learning in citizen science through the SLT lens, i.e., learning that is embedded within the lived experiences of the individual as part of social practice. Practice plays a central role in knowledge creation, which according to Lave and Wenger (1991) is socially construed and mediated. Additionally, increasing practice of an activity within a community using similar tools and procedures leads to changes in practice, and changes in participation from novice or peripheral, to expert or core participation. In a comparison between SLT and Activity Theory, Arnseth (2008) notes that in SLT, "Practice is given a primary role in shaping and constituting knowledge and knowing. As such, their turn toward practice should be conceived as an attempt to formulate a new epistemology for studies of learning, an epistemology where practice is given a primary role and learning is seen as an integral part of practice" (p. 295).

Although numerous studies have looked at learning outcomes from citizen science (see Phillips Dissertation Chapters 2 and 3), only a few studies have examined the centrality of practice or experience on learning. For example, developers of the Monarch Larva Monitoring Project examined engagement between youth and adult mentors more deeply through short surveys and interviews (Kountoupes and Oberhauser 2008). They found that these experiences encouraged opportunities for deep immersion in the natural environment as well as hands-on science (Kountoupes and Oberhauser 2008), although they don't differentiate on the quality or quantity of practice. In an examination of how eBird participants use data retrieval tools, Thompson and Bonney (2007) used quantitative surveys and data analysis scenarios to determine understanding of appropriate tools to answer specific questions. While their findings showed that "active users" who recorded data in the past month were more engaged, i.e., recorded more data, visited more locations, and identified more species, than non-users, they did not relate these practices to learning.

Recent work in online citizen science projects have begun to examine the role of practice or participation as it relates to learning. Controlling for scientific knowledge, Masters et al. (2016) measured participation rates in Zooniverse using data analytics such as length of time since first and last clicks, number of days with recorded classifications, or total number of classifications submitted in a specific time frame. They found that participants that are more active also did better on project-specific content measures, but not necessarily on general science knowledge. They also suggest that successful projects able to retain a greater number of sustained participants tend to have more social media opportunities such as blogs, chats, and Twitter feeds. In another cross-programmatic examination of online citizen science projects, Kloetzer et al. (2013) used qualitative interviews and online observations across three projects to define six types of learning outcomes related to how participants learn. The "how learning happens" include: contributing to the task, interacting with others online, using external resources, using project documentation, and personal creations. Kloetzer et al. (2013) report on learning outcomes related to task/game mechanics, pattern recognition, on-topic learning, scientific process, off topic knowledge and skills, and personal development. The off-topic skills include computer and web literacy and communication skills. Personal development outcomes comprised increased self-confidence, interest in science, and expansion of social networks and individual roles in the online community. They also suggest that much of the observed learning outcomes were more related to the social aspects of participation rather than the difficulty of the task.

Other research is also revealing the positive physical and psychological benefits of nature experiences through environmental volunteering in adult populations (Pillemer et al. 2010). In a study of citizen scientists conducting local nest monitoring, Evans et al. (2005) suggests that environmental awareness by individuals' connections to place may lead to conservation-related actions. In another study examining the effect of different types of engagement in conservation monitoring projects, Eveyl et al. (2010) found that across all project types, participants learned about conservation issues. However, learning tended to be greater in self-mobilization and interactive projects (analogous to co-created and collaborative projects in the current study, respectively) where engagement was considered more robust than functional projects (analogous to contributory projects). They found that duration in the project did not have an influence on learning. Further, participants in functional projects tended to take longer to achieve the same level of understanding as individuals in interactive and self-mobilization projects. Functional participants also lost confidence over time as compared to self-mobilization participants. The authors suggest that factors such as autonomy, sharing of information, involvement in decision making, and motivation to learn may be partially responsible for the greater learning outcomes. Eveyl et al. (2010) also emphasize the need to understand the processes of participation that may lend themselves to enhanced learning.

The role of motivation may also play a key role on informal science experiences. Using Self Determination Theory and social movement participation models Nov et al., (2014), found that intrinsic motivation was one of four drivers that influenced quantity of participation, but that it did not affect quality of participation in an examination of three digital citizen science projects. Examining the role of motivation in the online project OldWeather, Eveleigh et al. (2014) found higher intrinsic motivation to be positively associate with greater numbers of transcriptions and posts to online forums. They also found a similar positive relationship between the number of contributions and forum posts, suggesting a link between high contributors and the desire or motivation to engage socially. Interestingly, Eveleigh et al. (2014) et al. also found that high contributors have significantly higher intrinsic *and* extrinsic motivations than low contributors, suggesting a more complex picture of motivation and engagement for super users.

PROJECT DESCRIPTIONS

As described earlier, using SLT as a lens for examining everyday learning requires an understanding of the context, content, community interactions, and participation characteristics of such experiences. Below, each of the six projects is described using information gathered through interviews and conversations with the project leaders. The project descriptions provide information about content, context, community, and participation such as where the project takes place, who participates, what are the perceived motivations, and typical activities undertaken by participants. The information in Table 4.1 summarizes the six project descriptions and their alignment with SLT characteristics.

NestWatch (NW) is a nest monitoring project that began as the Nest Record Card Program in the 1960's. The goal of NestWatch is to examine changes in bird breeding biology and reproductive rates throughout the US and Canada. NestWatch participants tend to be female, mostly well-educated, and over the age of 45. Participants typically are individual homeowners or families or belong to a conservation group, golf course or community trail of nest boxes. Most individuals join the project because of a conservation ethic, attraction to charismatic fauna like the Eastern bluebird *(Sialia sialis)*, and also because they are intrigued to watch the intimate life stages of breeding birds. The NestWatch protocol suggests that after finding a nest, participants monitor it every 3-4 days for the remainder of the nesting cycle. Participants put up any number of nest boxes, ranging from 1 to more than 100. The NestWatch web site allows participants to download their own personal data to track nesting success, and access data from across the country. The NestWatch database currently houses more than 300,000 nesting records.

The **Monarch Larva Monitoring Project (MLMP)** occurs anywhere in the US, Canada, and Mexico, wherever there is the favored milkweed plant of monarch butterflies (*Danaus plexippus)*. These spaces can include backyards, nature centers, or parks of various sizes. The majority of MLMP participants are adults, although about half of the participants monitor with children and use it as educational activity in and out of school. According to interviews and surveys conducted by MLMP staff (Oberhauser, personal communication), the main reason for participation is to help monarch conservation, followed by a desire to be outdoors in nature. The main activity participants engage in is measuring monarch density on milkweed plants by examining a set number of plants and counting the number and life stage of caterpillars on them. They also take into account weather and other factors. Some MLMP participants collect caterpillars and rear them indoors to see if they are afflicted with parasites. While the majority of participants monitor on a regular basis, there is opportunity for people to monitor on a more sporadic basis. MLMP data are submitted online and can be retrieved individually or aggregated among sites. There are currently more than 1,300 MLMP active sites.

The **Community Collaborative, Rain, Hail and Snow (CoCoRaHS)** project started out as a small community-based organization in northern Colorado following an epic rainfall event in 1998, resulting in an 'accidental network' (personal communication, Noah Newman), but now operates throughout the US and in Canada. CoCoRaHS gathers precipitation data year-round to track weather across time and space, receiving upwards of 10,000 observations daily, much of the which are shared with meteorologists, local, state, and federal agencies. The majority of participants are middle-aged to retired, mostly college educated white males, although efforts are underway to engage a younger, more diverse audience. Many CoCoRaHS participants are self-described "weather nerds," who track weather anyway, but like the ability to have their weather observations permanently stored for them. Others join because they were asked by someone else and/or were told it was important. Participating in CoCoRaHS typically involves less than 5 minutes per day checking a rain gauge and entering the data online. Some participants do more, taking extra measurements of water content in snow, evaporation, and drought impacts. Although most participation is done individually, CoCoRaHS provides monthly educational webinars through YouTube and other forms of social media. Personal and project wide data are accessible and downloadable via the website.

The **Hudson River Eel Project (EELS)** started in 2008 and operates regionally along a 150-mile stretch of 12 tributaries along the Hudson River in New York state, between Staten Island and Albany. The EELS project has more than 500 volunteers, mostly made up of high school students and teachers, college interns, watershed groups or small family groups. According to Chris Bowser, the EELS project leader, participants join because they feel they are contributing to science and conservation of American eels (*Anguilla rostrate*), which are born in the Sargasso Sea and then swim upstream all the way to the Hudson River to eventually spawn. The American eel and its life history are considered mysterious and charismatic, resulting in a high participant retention rate. Once or twice a week between March and May, a group of volunteers coordinated by the New York State Department of Environmental Conservation (DEC), don waders and carry buckets to large fyke nets positioned in tributaries, to catch and count thousands of juvenile "glass eels." The eels are then transported and released above the dams that obstruct their migration. Some participants have taken on leadership roles, modifying or adapting protocols to specific sites or spearheading the inclusion of new sites along the Hudson. Data are recorded on paper forms and left in a secure location where the DEC collects and then uploads them to an online site. Data are compiled by the DEC and then available for download for each site.

The **Alliance for Aquatic Resource Monitoring (ALLARM)** is a stream monitoring program that began in 1986 and is run out of Dickinson College to provide technical assistance for monitoring the health of watersheds throughout Pennsylvania. Originally developed for helping communities deal with acid rain, ALLARM now focuses on shale gas fracking and watershed protection and restoration. Typically, communities self-organize over a local issue or concern and turn to ALLARM for help in training to develop and implement water quality monitoring protocols. Most volunteers are adult retirees who live in rural farming/hunting communities and may be already involved with a local watershed group. ALLARM organizes trainings throughout the state to help groups develop their goals for monitoring, create study designs, develop protocols for data collection, analysis, and interpretation. ALLARM also provides decision trees for communicating and disseminating data to local municipalities. Participants typically make monthly visits to their site(s) throughout the year, conducting visual, biological, and/or chemical assessments of watersheds. A variety of data collection tools are used including syringes, pipettes, water conductivity meters, and calibration solutions. Although ALLARM provides rigorous QA/QC training, it is their philosophy that communities have full ownership of how their data are used and shared. Currently, there is a central database that gathers information on sites being monitored for shale gas fracking, where participants can view, submit, and download statewide or local data.

Global Community Monitor (GCM) began in 2001 in California as a grass roots effort to monitor local air pollution. Since then, GCM quickly spread to other states in the US and other areas such as the Philippines, India, and South Africa. GCM, sometimes referred to as "Bucket Brigades" teaches communities how to collect air samples, lobby elected officials, meet with local, state, and federal agencies, and essentially empower communities to have a voice through the air quality data they collect. GCM participants tend to be people who live on the fence line of heavy industry such as fracking, oil refineries, steel mills, etc., Participants tend to be working

Table 4.1: Summary of project description, aligned with SLT characteristics.

Project Name (Content)	Description (Context)	Project Type & Structure (Community)	Tools/materials (Participation)
NestWatch (Nestwatch.org)	Contributory; Monitoring bird nest boxes	Individual, some peer to peer interactions online	Nest boxes, binoculars, field guide; paper and online data collection, online data submission, online data retrieval, online materials and training
Monarch Larva Monitoring Project (mlmp.org)	Contributory; Counting monarch larvae on milkweed plants	Individual and group, some peer to peer interactions online	Hand magnifying lens, field guide, ruler, paper and online data collection, online data submission, online data retrieval, online and in-person materials and training
Community Collaborative, Rain, Hail, and Snow Network (cocorahs.org)	Collaborative; Measuring precipitation events	Individual, most peer to peer interactions online	Rain gauges, measuring sticks, online data entry and retrieval, online materials and training
Hudson River Eels Estuary Project (dec.ny.gov/lands/49580.html)	Collaborative; Counting glass eels	Group, most peer-to-peer interactions in person	Waders, fyke nets, buckets; paper data collection; online data retrieval, in-person training
Alliance for Aquatic Resource Monitoring (www.dickinson.edu/allarm)	Co-created; Monitoring water quality	Group, most peer-to-peer interactions in person	Water bottles, yard sticks, water conductivity meters, paper and online data collection; online data retrieval, in-person training
Global Community Monitor (gcmonitor.org)	Co-created; Monitoring air quality	Group, most peer-to-peer interactions in person	Air monitoring buckets; paper data collection, in-person training

class and communities of color, but there are also many older, white, highly educated individuals impacted by fracking across the country. Most communities join after becoming aware of emissions because of localized health issues and reach out to GCM for assistance with gathering defensible air quality data. GCM teaches communities how to choose siting of air collection buckets, collect data, send data to certified air quality labs, and then use results of analyses as an organizing tool to open lines of communication with industry to either improve regulations or in some cases, cause the industry to shut down. Participants may choose to engage in some or all aspects of the GCM protocol. GCM data are maintained within the communities and it is up to those communities to determine how best to share and use the data.

METHODS

Study Design

The quantitative phase of this dissertation builds off of qualitative research from the previous chapter, which was aimed at understanding various aspects of engagement in citizen science. During the qualitative phase, 72 interviews from participants across the six projects described above were transcribed and analyzed and coded. The relative frequencies of themes across the six projects were synthesized to develop a draft model of Dimensions of Engagement (DoE) for citizen science (see Chapter 3). According to Creswell (2009), this type of study design is considered *a sequential exploratory study*, in which qualitative data collection and analysis informs the development of quantitative data collection. These dimensions included: motivation, behavioral activities, cognitive/learning, social/project interactions, and feelings and emotions. Each of these dimensions informed the development of question blocks for the online survey on engagement and learning from a larger pool of participants across the six projects.

The following Dimensions of Engagement and their associated set of indicators serve as independent variables for the current study:

- Motivation
- Social and Project Connections
- Behavioral Activities (PEM) and Effort
- Demographic data

Dependent variables for measuring learning outcomes were chosen from the conceptual model of individual learning outcomes for citizen science described in Chapter 2 of this dissertation. The six project leaders were asked to examine the constructs in the conceptual model (Interest in science/environment; Self-efficacy for science/environment; Motivation for science/environment; Knowledge of the Nature of Science/science process; Skills of Science Inquiry; and Environmental Stewardship) and choose three learning outcomes that had the most relevance and importance to their project goals (Table 4.2).

Table 4.2: Learning outcomes chosen by project leaders as most relevant.

	Interest in science and environment	Self-efficacy	Motivation	Skills Science Inquiry	Knowledge of Nature of Science	Environmental Stewardship
NestWatch	✓	✓		✓		
MLMP				✓	✓	✓
CoCoRaHS		✓	✓	✓		
EELS			✓	✓		✓
ALLARM		✓		✓		✓
GCM		✓			✓	✓

Although none of the projects chose the same three constructs, there was much overlap in their choices. Of the six learning constructs, Skills of Science Inquiry was chosen by 5 of 6 leaders; Environmental Stewardship and Self-efficacy were both chosen by 4 of 6 leaders. Motivation and knowledge of Nature of Science were chosen by two leaders, and one leader chose interest. The three learning outcomes that were most common, relevant, and attainable by at least half of the six projects, also serve as common dependent variables for the study, and are listed below with an *:

- Skills of science inquiry (5/6)*
- Self-efficacy (4/6)*
- Environmental Stewardship (4/6)*
- Motivation – 2/6
- Knowledge of Nature of Science – 2/6
- Interest – 1/6

Measures

The final survey consisted of 29 questions; 20 of these were individual questions. The remaining nine questions were grouped into blocks relating to distinct constructs. Time and resource limitations prevented validation of four of these nine question blocks: (Interest, Social interactions, Learning, and Barriers). Five of these question blocks however, underwent typical procedures for valid and reliable scale development (Participant Engagement Metric, Motivation, Self-efficacy, Skills of Science Inquiry, and Environmental Stewardship), according to basic principles as outlined by Clark and Watson (1995), and recommendations from Cronbach and Meehl (1955) and Shadish, et al. (2002). A summary of these efforts for each of the five scales is presented in Table 4.3.

To begin gathering evidence of construct validity, before being used in the online survey, all five scales underwent content validity checks by first clearly defining the construct based on prior research and then obtaining written and oral feedback from

Table 4.3: Summary of efforts for achieving valid and reliable scales prior to use in online survey

Scale & Type	Validity and Reliability	Psychometric Properties – GBBC	Psychometrics – NW pilot Test
Motivation for Doing and Learning Science **16 items, Likert-type** **5 pt. scale**	Expert review; in-person focus groups; online feedback; pilot test (5); test-retest (2); field test	EFA: 2 Factors (Intrinsic/Extrinsic Motives) all items load at >.50 on their factor. (N=249) Internal Consistency: (Cronbach's α =.80) Intrinsic = .81/ Extrinsic = .85; (N=249) Test-Retest Reliability: all Pearson's *r*'s > .33, all p's < .05, except Internal Engage item 5 (N=72)	*Sample size too small for FA* Internal Consistency: (Cronbach's α = .781) (N=114) Split half reliability (Intrinsic/Extrinsic) =.791/.839 (N=114)
Participant Engagement Metric (PEM) **12-item frequency type scale**	Synthesis from 72 interviews, expert review and ranking; online feedback	*Not developed as of yet*	*Sample size too small for FA* Internal Consistency: (Cronbach's α = .859); (N = 114)
Self-Efficacy for Doing and Learning Science **8 items, Likert-type** **5 pt. scale**	Expert review; in-person focus groups; online feedback; pilot test (5); test-retest (2); field test	5pt best fit EFA: unidimensional all items load at >.70**;** (N=460) Internal Consistency (Cronbach's α) = .92**;** (N=460) Test-Retest Reliability: all Pearson's r's > .30, all p's < .05 (N=72) (results excluding negatively worded items)	*Sample size too small for FA* Internal Consistency (Cronbach's α) = .825**;** (N=129)
Skills of Science Inquiry **12 item, 5 pt. Likert-type**	Expert review; online feedback; field test (3), pilot test, IRT analysis	EFA: 2 Factors (Protocol, Data Use) all items load at >.40 on their factor. (N=1,030) Internal Consistency: (Cronbach's α = .893) Protocol =.82/Data Use = .837**;** (N=1,030)	*Sample size too small for FA* Internal Consistency: (Cronbach's α = .917; (N = 114)
Environmental Stewardship Scale **24 item, Frequency-type scale**	Concept mapping; brainstorm; expert review; multi-hierarchical analysis	EFA: 5 Factors 19/24 items load at >.50 on their factor. (N = 387) Internal Consistency: (Cronbach's α = .881) (N=387)	*Sample size too small for FA* Internal Consistency: (Cronbach's α = .925; (N = 114)

experts regarding content, format, and audience appropriateness; revising as necessary. All instruments were also tested for face validity with small numbers (8-12) of individuals similar to the target audience, where they were asked about suitability, utility, clarity, and length of the instrument. In some cases, the field tests were done in person, in other cases feedback was solicited online and revised as necessary. Establishing face and content validity is a first step toward achieving construct validity in social science research (Drost 2011).

To provide further evidence of construct validity, factor analyses were conducted on all five scales with at least one of three populations: The Great Backyard Bird Count (GBBC), the NestWatch pilot, or with participants of the current study. Factor Analysis is a statistical tool used to discover simple patterns in the structure of the data and to determine the smallest number of factors to explain the observed variables. A widely used statistical technique in factor analysis is Kaiser's eigenvalue which is the total variance of the factors and provides guidance for "retaining only factors that explain more variance than the average amount explained by one of the original items" (DeVellis, 1991). To determine the minimum number of factors to keep, I looked at the scree plots and factors with eigenvalues greater than one. The scree plot is a graphical representation of the number of factors or components, based on the total variance in the data, and plotted in a descending order of magnitude (Costello and Osborne 2005). Factors to the right of the "elbow," indicated by a sharp drop in the plot typically explain little variance in the data and can be ignored.

Lastly, all scales underwent reliability testing to determine how much a variable influences a set of items to confirm the internal consistency of the measures. When variables such as those related to attitudes and motivation are not directly observable, the use of latent variables that can infer or estimate the phenomenon of interest is required (DeVellis, 1991). A set of items representing a latent variable are said to have some relationship to one another, thereby demonstrating correlation. In survey instruments for example, items in a single scale with high reliability or internal consistency are said to be measuring a single construct (DeVellis, 1991). Measuring internal consistency is typically done using Cronbach's alpha coefficient (Cronbach, 1951), which describes how well a group of items hold together and assumes unidimensionality, i.e., measurement of one latent variable. A reliable measurement will help to minimize Type I errors, where a relationship is inferred when none actually exists. Standard reliability estimates seek to obtain an alpha coefficient of .70 or higher. However, a high alpha does not necessarily mean that a scale is unidimensional. To determine unidimensionality factor analysis is conducted using the correlation coefficients to determine the number of factors or dimensions in the data set (Field 2009). Another measure of a scale's reliability is its consistency across time, sometimes referred to as temporal stability or test-retest reliability (DeVellis, 1991). A scale displaying temporal stability will show high correlation at multiple points in time, but when examining this kind of reliability, it is important to also establish the stability of the phenomenon in question from time 1 and time 2.

Reliability of measures for the current study was conducted in multiple ways. In some cases, test-retest reliabilities were conducted where a small number (30-40) of citizen scientists complete the instrument twice, roughly two weeks apart. Pair scores from the first and second administration looking for a high percentage of correlation (> 0.70). Questions with lower than 70% agreement should be removed and the instrument revised and tested again as necessary. Some scales also underwent split-half reliability where the consistency of a scale is measured by splitting it in two, and comparing scores for each half with one another. The scores from each half should be similar to establish reliability.

Presented next is a description of each of the five scales and the additional efforts that were conducted to establish reliability and validity.

Motivations

The Motivation for Participating in Citizen Science scale is a 14-item scale with a 1-5 range, based on the Motivation Toward the Environment Scale (Pelletier et al. 1998, Villacorta et al. 2003), which reflects the types of motivation specified by Self Determination Theory (i.e., innate psychological needs for competence, autonomy, and relatedness). The Motivation for Participating in Citizen Science scale has been adapted using customization principles described at http://selfdeterminationtheory.org/questionnaires/ and is intended to measure the degree of intrinsic and extrinsic motivations for engaging in citizen science. Engagement with citizen science can be driven by intrinsic motivations such as interest, enjoyment, and pleasure. Motivations based on values or importance are considered intrinsic and labeled 'identified regulation'. Engagement with citizen science can also be driven by extrinsic motivations such as concern, avoidance of negative feelings (e.g. guilt) or to gain recognition (e.g. respect from others). While different motivations may prove more effective in various situations, in general, research suggests that the more intrinsically motivated a person is, the more effort and persistence they will have for a particular activity (Ryan and Deci 2000a, 2000b). The Motivation for Participating in Citizen Science scale provides information about the *type* of psychological motivation participants have for engaging in citizen science, i.e., either intrinsic or extrinsic; this is different than the reasons for participation (e.g. to contribute data, to socialize, to learn, etc.). The Motivation for Citizen Science scale was pilot tested with 114 NestWatch participants and found to have good internal consistency (Cronbach's α = .781) as well as a split half reliability analysis of intrinsic and extrinsic items (Cronbach's α = .791/.839, respectively).

Participant Engagement Metric (PEM)

The Participant Engagement Metric (PEM) was developed during the qualitative phase of this study to measure the frequency and diversity of social and scientific project activities and described in its entirety in Chapter 3 of the dissertation. Briefly, coded data from 72 interviews resulted in 4,800 references describing tasks performed on behalf of projects, and categorized into a list of 30 "Project Activities". Via input from the six project leaders and an expert review panel, the 30 activities were then each ranked on their relative importance for the respective project, with 1 being "not at all important" and 5 being "extremely important". Subsequent analysis of the importance ranking data involved both rewording some activities to enhance clarity and removing some activities that were not deemed important by project leaders or that had very low relative frequencies in the initial interviews. Activities that were referenced in greater frequency by participants and rated as most important by project leaders and the expert review panel were prioritized as most common and important.

Using the above criteria, the list of 30 activities was then further reduced to 12, and renamed the "Participant Engagement Metric," i.e., the PEM, (behavioral components of what participants did as part of project tasks). The PEM measures the frequency and diversity of project activities undertaken by participants using a summed score for each item. Item responses for the PEM were scored as follows: "Never" = 0, "Rarely" = 1, "Sometimes" = 2, "Often" = 3, and "Very often" = 4. The scores for individual items within the PEM are summed to provide an overall index ranging from 0 (never do any of the activities) to 48 (very often do all of the activities). The final items that comprise the PEM are presented in Table 4.4 below.

Table 4.4: PEM scale items grouped according to factors.

Factor	Item
Basic Engagement	• Gathered data and/or samples as often as suggested by the project protocol • Submitted data or reports as often as suggested by the project protocol
Data Driven	• Explored publicly available project data • Created graphs and maps of project data • Used statistics and probability to interpret project data • Used project data to make or defend a scientific claim
Socially Driven	• Shared information about the project to the general public • Communicated project data or findings to politicians, decision makers, or media outlets • Used social media to communicate with project staff or other participants (email, listserv, --Facebook, Twitter, blog posts, et • Recruited other participants • Trained new participants • Sought answers to questions about a project or protocol

In addition to being informed by the 72 interviews and an expert review panel, the PEM scale was tested for reliability with 114 NestWatch participants during the pilot test of the survey and obtained a good internal consistency (Cronbach's α = .859).

Self-efficacy

Self-efficacy refers to an individuals' beliefs about their capabilities to learn specific content and perform particular tasks (Bandura 1982, 1997). Self-efficacy can positively influence one's effort and persistence at doing certain tasks, but it is also influenced by several factors, including an individual's past experiences, good or bad, with a specific activity. The measure used to assess self-efficacy for the current research is based on the Self-Efficacy for Learning and Doing Science (SELDS), an 8-item scale (range 1-5) that underwent a series of validity tests with citizen scientists in the Great Backyard Bird Count (GBBC, an annual bird count hosted by the Cornell Lab of Ornithology) and various water quality monitoring projects (Porticella et al. in prep). The Cronbach's alpha coefficients assessing the internal consistency of the SELDS was 0.92, indicating high internal consistency. The two-week test-retest reliabilities for the total averaged items were r = .82 and .89 indicating the SELDS scale could achieve stable responses from a single sample over time. Item-total correlations measured by Pearson's correlation between each item and the total scale ranged from .54 to .83, indicating all items measure consistently with the total scale, and suggesting a positive item discrimination power. The SELDS scale also showed positive correlations with a different scale measuring interest in science and motivation for learning and doing science, suggesting concurrent validity. Lastly, an exploratory factor analysis was conducted and showed a unidimensional scale with all factor loadings above. 0.70.

The SELDS items and question statements were slightly modified in the NestWatch pilot test of the current study to contextualize the items for the 'learning' content (i.e., breeding bird biology), and the 'doing' activity (i.e., monitoring breeding birds through participation in NestWatch). Table 4.5 provides the documentation of changes made for the pilot test. Internal consistency for the pilot study was (Cronbach's α = .825, N=129), suggesting good reliability. No further modifications to the scale were made for the final survey other than contextualizing the content and activity to each of the six projects.

Skills of Science Inquiry

Science inquiry skills as a learning outcome can include practices such as those outlined by the Next Generation Science Standards (NGSS Lead States 2013): asking questions and defining problems, designing scientific investigation, developing and using models, and analyzing and interpreting data. The Skills of Science Inquiry (SSI) scale is a 12-item self-report (range 1-5) on perceived skills of science inquiry, contextualized for specific citizen science activities. Initial validation efforts for establishing content/face validity included expert review, online feedback, and in-person think alouds. Statistical tests were conducted with 1,030 participants of the Great Backyard Bird Count, and included Item Response Theory (IRT) analysis (all items discriminate > 0.40); exploratory factor analysis (all items load > .40); internal consistency (Cronbach's α = .893), and split/half reliability (.82 and .837). For the current study, the SSI was tested for internal consistency in the pilot test with 134 NestWatch participants (Cronbach's alpha = .917). No changes were made to the SSI when used across the six projects other than customizing the object of the scale items to refer to the specific project name.

Environmental Stewardship

The Environmental Stewardship Scale (ESS) measures 24 different behaviors that are typically associated with behaviors aimed at helping the environment (Phillips et al. in prep). The ESS was originally conceived using a methodology known as concept mapping. Concept mapping is a participatory, mixed-methods approach used to structure and organize concepts and ideas from a pre-defined group (Rosas and Kane 2012, Trochim and Donnelly 2008, Kane and Trochim 2007). The data are collected from

Table 4.5: Revisions to original SELDS scale for pilot test and final survey of the current study.

Original Scale Item Wordings for Self-efficacy for Learning and Doing Science (SELDS)	Revised Scale Item Wordings (underlined)
These statements are about how you feel about learning and understanding science topics.	**These statements are about how you feel about learning and understanding science content <u>(e.g., breeding bird ecology).</u>**
I think I'm pretty good at understanding science topics.	I think I'm pretty good at understanding science-<u>related</u> topics.
Compared to other people my age, I think I can quickly understand new science topics.	Compared to other people my age, I think I can quickly understand new science topics.
It takes me too long to understand new science topics. (reversed)	It takes me <u>a long time</u> to understand new science topics. (reversed)
I feel confident in my ability to explain science topics to others.	I feel confident in my ability to explain science topics to others.
These statements are about how you feel about doing scientific activities.	**These statements are about how you feel about doing <u>citizen science activities</u> <u>(e.g., breeding bird monitoring).</u>**
I think I'm pretty good at following instructions for scientific activities.	I think I'm pretty good at following instructions for <u>NestWatch</u> activities.
Compared to other people my age, I think I can do scientific activities pretty well.	Compared to other people my age, I think I can do <u>NestWatch</u> activities pretty well.
It takes me too long to understand how to do scientific activities. (reversed)	It takes me <u>a long time</u> to understand how to do <u>NestWatch</u> activities. (reversed)
I feel confident about my ability to explain how to do scientific activities to others.	I feel confident about my ability to explain how to do <u>NestWatch</u> activities to others.

groups or individuals in qualitative form and using nonmetric multidimensional scaling, the data are represented visually as a two-dimensional map showing the relatedness of concepts and ideas. Concept mapping has been used in a variety of ways including theory construction, scale development, strategic planning, and product development (Kane and Trochim 2007, Rosas and Camphausen 2007, Trochim and Donnelly 2008). In a meta-analysis of 69 studies using concept mapping, Rosas and Kane (2012) demonstrated strong internal validity and very strong sorting and rating reliability across the studies.

Concept mapping is typically described in multiple steps. In the first step, participants are given a focal question specific to a domain of interest, yet general enough to obtain a wide range of responses and asked to generate a series of statements to answer the question (Kane and Trochim 2009). This can happen either in person, or online. Equally important is identifying the audience for the question. One of the advantages of concept mapping is the relatively small sample size needed – typically between 10 and 25 participants. Following principles of concept mapping, development of the ESS began with the formulation of a focus using the following focus prompt: "*In your opinion, a specific activity that represents an act of environmental stewardship, whether by an individual or by a group, is …*". In June 2013, 59 people, both online and in-person, experts and non-experts, participated in a concept mapping brainstorm session (see: http://www.conceptsystemsglobal.com). Participants were encouraged to enter as many statements to answer the question as possible.

After the brainstorming session was complete and a sufficient number of statements generated, a manual idea synthesis was conducted by the researcher to eliminate redundancies and remove statements that are not relevant to the focus question. Ideally, generating around 100 unique statements should provide the conceptual foundation for understanding the answers to the focal question (Kane and Trochim 2009). From this initial brainstorm, 140 unique responses were collected online. Duplicates were removed and the list was condensed to 119 statements describing acts of environmental stewardship. Further synthesis and analysis was conducted to remove vague general statements, statements that were not obvious behaviors, or those that were too place-based or too specific to an individual behavior or issue (e.g., fracking in the Northeast). A review of other published scales that measure environmental behavior was also conducted resulting in the addition of three items to the final list, which resulted in a list of 50 acts of environmental stewardship.

In the next step, participants view the collective list of statements from the entire group and are asked to sort statements into piles (through drag and drop techniques online) based on similarity of concept (Kane and Trochim 2009). Participants are then asked to rate each statement based on some criteria, such as importance or feasibility, for example. Immediately following the sorting session, unique statements are once again presented and individuals are asked to rate the importance of each of the statements, relative to all the other statements, using a five-point Likert-type scale. In this phase, specific guidelines were provided to help individuals create a sufficient number of groups classified according to similarity of statements. 101 experts and non-experts were asked to sort and rank the list of 50 statements based on ease and importance of doing the specific tasks. This resulted in 91 “Sorts” and 98 “Ranks” being completed of the 50 statements.

Once the sorted and ranked data have been collected, multivariate statistics are conducted to create a two-dimensional map showing how statements are grouped, the relationships of each of the statements relative to each other, and the relative rating for each group. The first analysis is multi-dimensional scaling (MDS) whereby individual sorts are transformed into a binary square similarity matrix and then aggregated across all participants. Essentially what is created is a matrix that is as long and as wide as the number of statements, and a total sum of the number of individuals that placed two items in the same pile. By locating statements relative to theoretical distances of other statements, the MDS produces a point map, with similar items closer together on the map. The second analysis involves refining the MDS point map into a two-dimensional cluster map using hierarchical cluster analysis. Here, a pre-defined algorithm is used to partition the universe of statements into groups or clusters that represent the aggregated thinking of the individuals from the brainstorming session (Kane and Trochim 2009). The cluster analysis returned six issue-based clusters from the list of 50 statements: Financial/legal, Social/political activism, Habitat Restoration, Food/agriculture, Transportation, Reduce/reuse/recycle. These cluster titles were given the names based on the types of activities that grouped together.

To further reduce the list of behaviors from 50 to something more manageable, an analysis of the "Go-Zone" was conducted, which uses a bivariate plot of the ranked data to place individual items in quadrants based on ease and importance. The quadrant used in this analysis looked like Figure 1, where quadrant 1 included behaviors that were deemed unimportant and difficult; quadrant 2 were unimportant and easy behaviors; quadrant 3 included important and easy behaviors; and quadrant 4 were important and difficult behaviors.

4 Important & Difficult	3 Important & Easy
1 Unimportant & Difficult	2 Unimportant & Easy

Figure 4.1: "Go-Zone" Quadrants

The Go-zone weighting along with centrality data (mean, standard deviation, median) was analyzed to reduce the data set again. The criteria for inclusion of items was to include the majority of behaviors deemed important and easy and important and difficult (Quadrant 3 and 4, respectively). Expert review of the remaining items resulted in the addition of a few behaviors deemed unimportant such as "investing in a hybrid vehicle" to be sure that a diversity of easy and hard behaviors was included in the scale. The final scale for statistical testing included 24 items.

In March of 2015, the 24 items were included in an online Qualtrics survey with members of the GBBC audience. Item responses included: I don't do this, I am thinking about doing this, I used to do this, I intend to do this, I am currently doing this, I will continue to do this, and I can't imagine not doing this, and were developed based on the work of Prochaska's Transtheoretical Model for Action: precontemplation, contemplation, preparation, action, maintenance, and termination (Prochaska and Velicer 1997). Similar to the PEM, a summation of each item yielded an index, in this case ranging from 0 to 144.

The online pilot survey received a total of 387 complete responses to all 24 items. A factor analyses was conducted to compare Exploratory and Confirmatory Factor structures. To better understand the item relationships, a comparison of the exploratory five-factor solution and the confirmatory six-factor solution were made by item. It was determined that the 5-factor solution was a better fit, with 19/24 items loading at > .50. Reliability analysis was also applied to the entire scale (Cronbach's α = .881) as well as the subscales. Four of the five subscales held-together in satisfactory levels with one being somewhat questionable. It was noted that the factors were grouped together differently than the clusters from the concept mapping, with the factor analysis grouping factors into groups based on type of activity, rather than the type of issue. The 24-item scale was also tested for internal consistency with the NestWatch pilot group (N=132), and found to have strong reliability (Cronbach's α = .925).

Data Collection and Sample

Before administering the final survey to all six projects, in July, 2016, a pilot test of the survey was administered online to a subset of NestWatch participants using Qualtrics software. The pilot study was conducted to determine whether response rates for individual questions were consistent; whether responses were within the accepted range of values; whether questions were being answered thoughtfully; and to determine the average time to complete the survey. Time and resources prevented the inclusion of all six projects in the pilot study, therefore there may be some limitations around the homogeneity of the project, but as long as pilot study respondents are as similar as possible to the target population (van Teijlingen and Hundley 2001), this limitation should not be very concerning. Other limitations of pilot studies include issues around contamination and making erroneous predictions from pilot data. NestWatch participants who took the pilot survey were not eligible to take part in the final survey, removing the contamination issue.

For the pilot study, 178 out of 600 (28%) NestWatch participants responded and completed the online survey. After downloading and cleaning the data, initial analyses revealed that the survey took on average about 18 minutes to complete and the overall survey design was sound. Next, in consultation with the Cornell Statistical Consulting Unit, descriptive and inferential statistics were conducted to ensure that the data were of high quality and to remove extraneous questions that didn't provide novel information. This analysis resulted in the removal of several questions about change in participation over time and two questions that tried to generalize scenarios for data collection and submission across all projects. A final version of the survey was sent to all project leaders and an external review panel for feedback before being administered. IRB approval was obtained prior to any study invitations being sent.

Once project leaders approved the final revisions to the survey, they were asked to provide a list of email addresses to be included in the sampling frame for the study. The target population for this survey was a population of citizen scientists who had been considered "active" (e.g., submitted data) within the last two years. Only two projects (NestWatch and CoCoRaHS) provided the email contacts as requested. The other four projects cited privacy concerns and instead chose to send the survey invitations and reminders through their mail systems, rather than through the Cornell Qualtrics system. In these four cases, project leaders were instructed to send the emails and reminders on the same dates as the Cornell invitations. The first email invitations were sent starting on August 02, 2016, with three weekly reminders thereafter. The email invitations described the nature of the study, risks, benefits, and contact information. Participants were also told that completing the survey would allow them to be entered into a drawing for one of five $50 Amazon gift cards. The survey was closed on September 06, 2016. Table 4.6 below provides the sample size and response rates across the six projects. In addition to the 1,469 project participants who completed the survey, there were an additional 181 people who completed the survey that had not engaged in citizen science in the past year and responded only to questions about barriers and outcomes. The total number of surveys collected from the six projects (including non-participants) was 1,526. The final survey in its entirety is available in Appendix G.

Data Analysis

All survey data were downloaded from Qualtrics and cleaned in Excel to check for accuracy and inconsistencies before being imported into SPSS. Data were organized

Table 4.6: Survey sample and response rates by project

Project Name	Sample	Submitted Responses	Response rate	Clean/complete responses
NestWatch	1,981	482	24%	412
MLMP	418	195	47%	181
CoCoRaHS	1,979	622	31%	587
EELS	153	67	44%	64
ALLARM	283	88	31%	88
GCM*	n/a	15	n/a	12
TOTAL	4,814	1,469	31%	1,344

**At the beginning of the survey administration phase, GCM announced it would no longer be operational, and that communication channels to participants would no longer be available, hence the small, incomplete sample size. Overall sample and response rates do not include GCM.*

with unit of observations in rows and variables in columns. A codebook housing the metadata was developed and stored within the dataset. Variable codes included label, units, description, measurement scale (i.e., variable type), range of possible values, format (character or numeric), number of decimal places, and codes for missing values. The dataset included continuous, ordinal, categorical, and string variables. In according with the plans submitted for IRB approval, the raw data is stored on a password-protected desktop PC and saved online to a private password-protected Dropbox account. A summary of the methods and statistical approaches for this chapter is presented below in Table 4.7. All data analyses were conducted in SPSS version 23 and Excel for Mac 2017.

For RQ 1 (characteristics of engagement across projects), much of the descriptive analyses included basic frequencies describing valid and missing cases, means, median, range, minimum, and maximum values. For all variables, the data were summarized to

Table 4.7: Matrix of research questions, methods, and statistical approaches

Research Question	Target Sample & Unit of Analysis	Analytical Approach	Specific Statistical Technique
Q1: How are dimensions of engagement (motivation, affective/emotions, social connections, behavioral, and cognitive/learning) characterized and described across the six projects?	Aggregate of data from approximately 1,300 individuals who completed the full survey.	(Descriptive) Univariate data summaries for each variable	• Continuous: histogram, box plot, and descriptive statistics (mean, median, range, SD) • Categorical: bar charts, pie charts, counts, frequency and percent
Q2: How does engaging in behavioral aspects of the scientific process relate to commonly sought after outcomes of citizen science such as science efficacy, science skills, and environmental stewardship?	Grouped data from approximately 1,300 individuals who completed the full survey.	(Inferential) Bivariate analyses (Two or more variables)	• 2 continuous variables – scatter plot, line graph, correlation table, simple linear regression • 1 continuous, 1 categorical – summary stats for each variable via side by side box plot, t-test for 2 groups, ANOVA to test for significance for more than three groups
Q3: How do these relationships differ across the six projects, three project types (contributory, collaborative, co-created), and project structure (individual vs. group-based)?	Comparisons of means between subject groups; tests of significance between groups; Significance test of between subject effects	(Inferential) Bivariate analyses (Two or more variables)	• One-way Anova and multiple comparisons
Q4: What role, if any, does motivation play in the relationship between behavioral engagement and learning	Grouped data from approximately 1,300 individuals who completed the full survey.	(Inferential) Bivariate analyses (Two or more variables)	• 2 continuous variables – scatter plot, line graph, correlation table, simple linear regression

assure assumptions of normality were met. This included graphical distributions of frequency using histograms, as well as tests to measure skewness and kurtosis values. Reliability tests of internal consistency were conducted for the PEM, motivation, and dependent variables to determine the overall consistency of results across scale items, presented as Cronbach's Alpha. According to George and Mallery (2003) the following guidelines can be used to assess internal consistency using the coefficient alpha: "$\alpha > .9$ = Excellent, $\alpha > .8$ =Good, $\alpha > .7$ = Acceptable, $\alpha > .6$ = Questionable, $\alpha > .5$ = Poor, and $\alpha < .5$ = Unacceptable" (p. 231).

Exploratory factor analysis, a multivariate statistical tool, was conducted to analyze a large number of potentially highly correlated variables and determine the underlying dimensions in a group of latent variables with certain common factors (DeVellis 1991). Factor analysis can be used for summarization of data to describe smaller "sub-scales" of the original data and it can also be used to reduce data. Subscales were created for "Efficacy", "SciEfficacy", (specific to general science efficacy learning) and "CitSciEfficacy" (specific to efficacy for doing citizen science). The motivation scale also had two subscales: "Intrinsic" and "Extrinsic." Exploratory factor analyses were conducted to achieve best model fit, according to recommendations by Costello and Osborne (2005): "After rotation...compare the item loading tables; the one with the "cleanest" factor structure – item loadings above .30, no or few item cross loadings, no factors with fewer than three items – has the best fit to the data" (p.3).

For RQ 2, 3, and 4, correlational statistics were heavily relied on to examine relationships between engagement and learning outcomes across the various units of analysis. Correlational statistics are a widely-used tool in social science research to examine strengths and relationships between variables (Samuel and Okey, 2015). Measured using the correlation coefficient (*r*), correlations range from -1 to +1. For each of the relationships examined, scatter plots were created to visually assess whether the relationships were linear or non-linear. The following cutoff criteria from Terrell (2012) were used for determining strength of relationships:

- Weak positive/negative: values between 0 and 0.3 (0 and -0.3)
- Moderate positive/negative: 0.3 and 0.6 (-0.3 and -0.6)
- Strong positive/negative: 0.7 and 1.0 (-0.7 and -1.0)

Although correlation does not imply causality, it can help set the stage for predictive studies examining directionality between independent and dependent variables (Samuel and Okey 2015). Given the large sample size and high incidence of ordinal data, and to minimize Type 1 errors (i.e., false detection of an effect that is not present), Spearman's rank difference correlation (Spearman's rho) was used with p value significance set = <.01.

One-way ANOVA was used to determine if there were statistically significant differences between the six projects, the three project types, and the two project structures (all considered independent variables) on the three dependent variables, as well as motivation and the PEM.

RESULTS

General Statistics/Normality Tests

The full dataset from the online survey contained 1,655 respondents; however, after cleaning, the final dataset used for this analysis comprised responses from 1,526 individuals across the six projects and including 181 individuals that did not participate in any citizen science projects in the past year but still answered questions about learning outcomes. Not all questions were answered by all participants; thus, sample sizes vary among questions. Response rates from the online survey varied from a low of 24% for NestWatch to a high of 47% for MLMP (see Table 4.6).

Tests of Normality: With two exceptions, all variables or sets of variables, appear to be normally distributed, as measured by the skewness and kurtosis values (Table 4.8). The number of hours per year was highly skewed to the right because of several outliers where participants entered more than 600 hours per year. Also, the total number of participants ranging from 0 to 8 was also skewed, likely due to numerous respondents who engage in multiple projects.

Table 4.8: Descriptive summaries of all variables, or groups of variables.

	N	Min	Max	Mean	Std. Dev.	Skewness (±2)	Kurtosis (±7)
Age_2016	1503	18	100	58.39	14.471	-0.633	0.200
Education	1480	1	8	5.35	1.724	-0.311	-0.997
Gender	1476	1	3	1.53	0.501	-0.103	-1.949
Participant_index	1293	0	48	16.98	8.356	0.635	0.513
Number_PEM	1336	0	12	3.13	2.326	1.116	1.507
Intinsic_Motiv_Mean	1324	2.57	5.00	4.42	0.48321	-0.614	-0.298
Extrinsic_Motiv_Mean	1324	1.00	5.00	2.26	0.79956	0.244	-0.373
Efficacy_Mean	1510	1.38	5.00	4.17	0.52998	-0.433	0.418
SciEfficacyMean	1510	1.00	5.00	4.09	0.62929	-0.527	0.528
CitSciEfficacyMean	1510	1.75	5.00	4.26	0.55901	-0.479	0.084
Skills_Mean	1509	1.42	5.00	3.98	0.63040	-0.382	-0.052
Env_Behavior_Score	1446	0	138	74.54	29.059	-0.180	-0.672
Stewardship Mean	1508	0.00	6.00	3.32	1.23833	-0.210	-0.614
Interest_mean	1322	1.00	5.00	4.04	0.63341	-1.408	2.900
Connect_mean	1334	1.00	5.00	3.26	0.81690	-0.062	-0.233
Social activity index	1236	0	28	8.55	4.711	0.724	0.623
Total Projects	1341	0	8	1.39	0.802	2.835	11.807
Years_range	1339	1	6	2.84	1.179	0.143	-0.601
Hours/yr	1304	0.0	1200.0	48.74	75.5975	6.431	67.844

Demographic Summary: Basic demographic information revealed that the average age was 58.4 years (Figure 4.2), with youngest participants on average in GCM (48), and oldest in CoCoRaHS (62). Over a third of respondents had either masters or doctorate degrees (Figure 4.3), and gender was almost evenly split with 51% female. Roughly 42% of respondents lived in rural or farming communities (Figure 4.4). The most common occupation was listed as "retired"; other occupations included K-12 education, medical/healthcare, farming/fishing/forestry/ranching, and computer and information technology. As is typical of most citizen science projects, the vast majority of respondents (87%) were white. Demographic data for each of the projects is provided in Table 4.9.

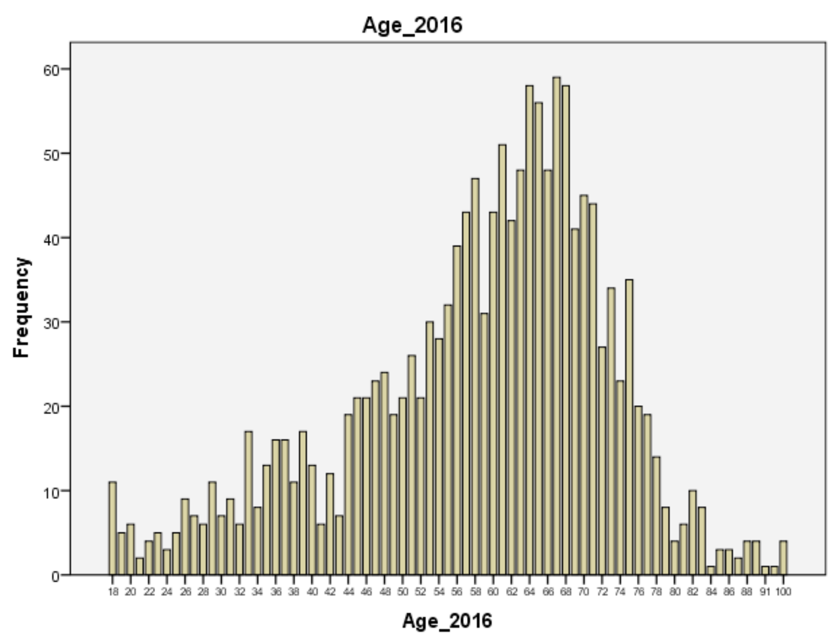


Figure 4.2: Frequency distribution of age of respondents in 2016.

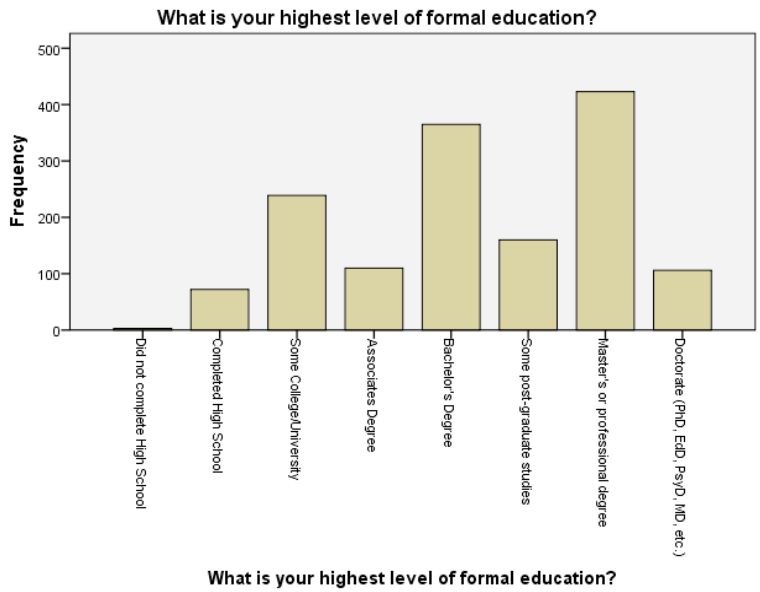


Figure 4.3: Frequency distribution of education levels.

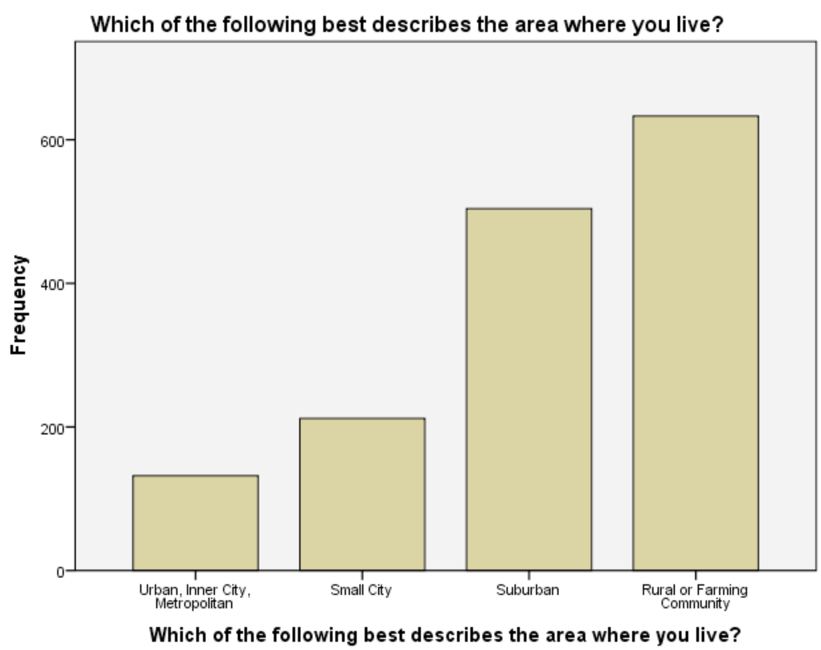


Figure 4.4: Frequency distribution of area of residence.

Table 4.9: Demographic data for each project

Project Name	% Female	Mean Age	Most Common Education	Most Common Residence
NestWatch	66%	55.45	28% Bachelors	45.2% Suburban
MLMP	80%	56.34	32% Masters	38.9% Suburban
CoCoRaHS	34%	62.25	29% Masters	49.6% Rural
EELS	63%	49.56	42% Masters	47.4% Suburban
ALLARM	55%	61.53	28% Masters	71.8% Rural
GCM*	50%	48.34	38% Bachelors	37.5% Metropolis

T-Tests: Several independent-samples t-tests were conducted to compare the independent demographic variables of gender, education and age on the dependent variables related to efficacy, skills, and environmental stewardship. Starting with gender, Environmental Stewardship scores were significantly higher for females (M = 81.97, SD = 27.57) than males (M = 66.32, SD = 28.513); t (1405) = -10.462, p = 0.001. Skills were significantly higher for males (M = 4.034, SD = .612) than females (M = 3.940, SD = .638); t (1465) = 2.874, p = 0.004. No other significant interactions based on gender were noted.

Age was split into two groups: over age 50 (N = 1,137) and under age 50 (357). Significant differences between the two groups were found for nearly all the dependent variables. For instance, younger respondents (<50) had significantly higher self-efficacy (M = 4.720, SD = .510) than older respondents (M = 4.147, SD = .535); t (1492) =-3.905, p = 0.001. Younger respondents (<50) had significantly higher Science self-efficacy (M = 4.237, SD = .592) than older respondents (M=4.046, SD = .535); t (1492) = -3.905, p = 0.001. Respondents less than 50 years of age had significantly higher Skills (M = 4.114, SD = .617) than older respondents (M = 3.944, SD = .627); t(1492) = -4.491, p = 0.001. Finally, younger respondents had significantly higher Environmental Stewardship scores (M = 77.98, SD = 29.35) than older respondents (M = 73.46, SD = 28.906); t(1432) = -2.518, p = .012).

Education was split into two groups: those with Associates college degrees or higher (N = 1,398), and those without a degree (N = 73). Respondents with higher levels of education had significantly higher results for all the dependent variables. For instance, college graduates had significantly higher Self-efficacy (M = 4.193, SD = .528) than non-graduates (M = 3.838, SD = .488); t(1469) = 5.626, p = .001. The same was true for Science Self-efficacy for graduates (M = 4.109, SD = .627) and non-graduates (M = 3.744, SD = .551); t(1469) = 4.842, p = .001 and for Citizen Science Self-efficacy for graduates (M = 4.279, SD = .551) than non-graduates (M = 3.93, SD = .582); t(1469) = 4.842, p = .001. College graduates had significantly higher Skills (M = 3.995, SD = .631) than non-graduates (M = 3.792, SD = .583); t(1469) = 5.022, p = .007. Lastly, college graduates had significantly higher Environmental Stewardship scores (M = 75.11, SD = 29.013) than non-graduates (M = 63.71, SD = 28.132); t(1469) = 3.167, p = .002.

The T-test results suggest that the demographic variables age, gender, and education levels may have an effect on efficacy, skills, and stewardship and need to be taken into account when interpreting results. In particular, t-test results could provide alternative hypothesis for some of the subsequent results described below.

Reliability and factor analysis: The internal consistency estimate, or coefficient alpha, was calculated for several of the scales and subscales. As illustrated in Table 4.10, all reliability estimates for full scales were .8 or above, suggesting good internal consistency. Inter-item correlations are available for each of the scales in Appendix H. Exploratory factor analyses for all the scales loaded on at least .4 (Table 4.10), and there were minimal examples of cross-loading. However, for both the PEM and the

Environmental Stewardship Scale, each contained a factor structure with only two items, suggesting additional testing may be needed. The complete rotated factor loading tables are presented in Appendix I.

Table 4.10: Summary of Reliability and Factor Analysis results from online survey

	Scale	**Number of Items**	**Cronbach's Alpha**	**Factor Analysis**
MEASURES USED IN THE STUDY	Motivation (full) • Intrinsic Motivation • Extrinsic Motivation	14 7 7	.800 .828 .855	EFA: 3 Factors (Intrinsic, Identified Regulation, Extrinsic); all items load at >.50 on their factor; Eigenvalue = 3 .9, 3.5, 1.1 (N = 1,301)
	Participant Engagement Metric (PEM)	12	.847	EFA: 3 Factors (Basic, Social, and Data); all items load at >.40 on their factor; Eigenvalue = 4.6, 1.7, 1.1; (N = 1,310)
	Self-efficacy (full) • Learning science • Doing citizen science	8 4 4	.836 .793 .728	EFA: 3 Factors (Learning, Doing, negatively worded items); all items load at >.60 on their factor; Eigenvalue = 3.8, 1.1, 1.0; (N = 1,510)
	Skills of science inquiry	12	.912	EFA: 2 factor (Protocol, Data Use) explains 65% variance; all items load at >.50 on their factor.; Eigenvalue = 6.2, 1.5; (N = 1,509)
	Environmental Stewardship	24	.928	EFA: 5 factor structure all items load at >.4 on their factor; Eigenvalue = 9.2, 1.7, 1.3, 1.2, 1.0; (N = 1,508)

<u>Research Question 4.1: How are dimensions of engagement (motivation, affective/emotions, social connections, behavioral, and cognitive/learning) characterized and described across the six projects?</u>

Motivations: The Motivations for Engaging in Citizen Science scale contained 14 items, seven of which were classified as Extrinsic, and seven Intrinsic (four were intrinsic and three were identified regulation, a form of intrinsic motivation dealing with value structures). A comparison of the means for the intrinsic and extrinsic items by projects is presented in Figure 4.5. While all projects had relatively high intrinsic motivations, the difference between the two types of motivations was markedly greater for NestWatch (2.49), MLMP (2.13), CoCoRaHS (2.01), and EELS (2.13), than for ALLARM (1.66) and GCM (.95). These results suggest that ALLARM and GCM (both co-created projects) have stronger extrinsic motivations (i.e., sense of guilt, worry, or concern) driving their participation than in the collaborative and contributory projects.

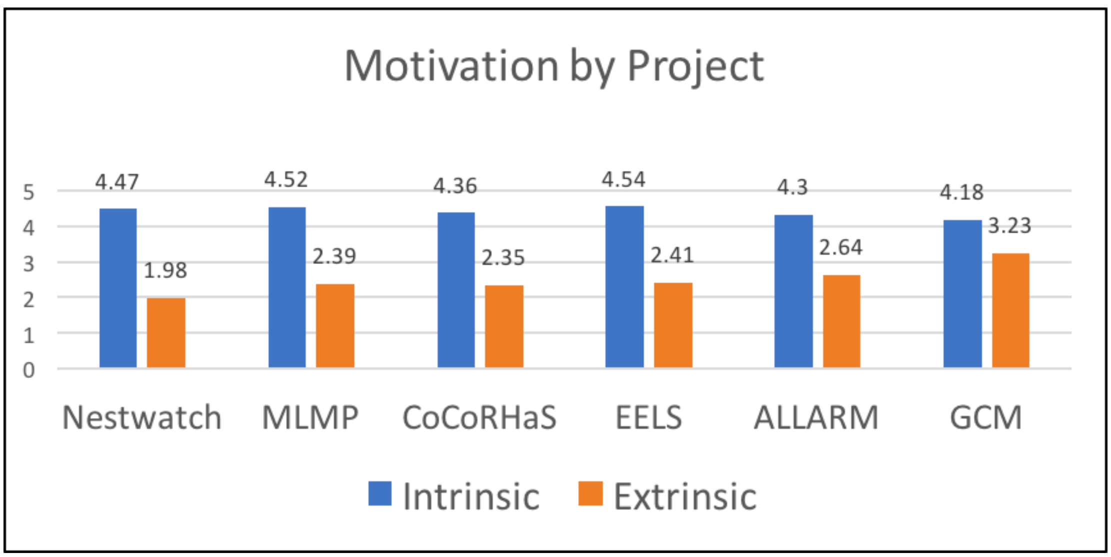


Figure 4.5: Mean intrinsic and extrinsic motivations by project.

Behavioral dimensions of engagement are characterized by overall effort (duration and number of hours/year), and project activities (measured as the Participant

Engagement Metric, or PEM). The majority of participants had participated in their respective projects on average between 3-5 years. Figure 4.6 presents the distribution of years, where 1 = less than one year, 2 = 1-2 years, 3 = 3-5 years, 4 = 6-10 years, 5 = 11-20 years, and 6 = more than 20 years. The mean number of hours per year engaging in all projects was 48.6, with a positively skewed range from 0 to 1200. EELS participants reported the smallest number of hours (37) and GCM the highest number of hours (161), Figure 4.7.

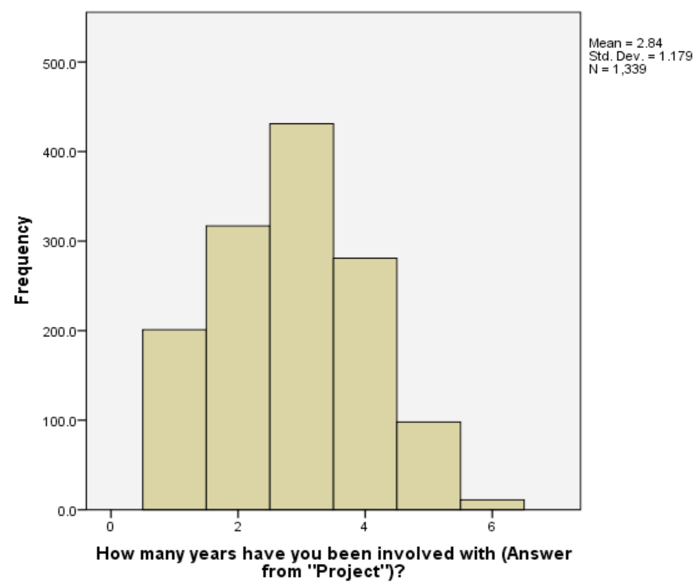


Figure 4.6: Distribution of duration in years

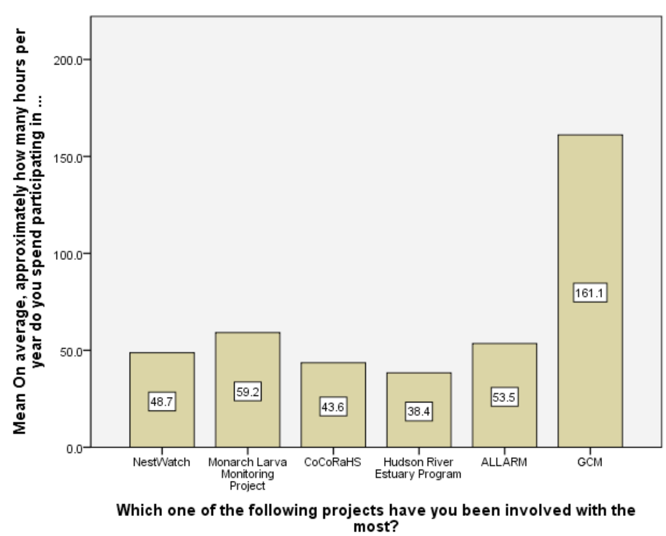


Figure 4.7: Mean hours/project

To determine the frequency with which participants engaged in project activities and calculate a PEM score, respondents were asked *"How often have you done the following activities on behalf of your project in the last year?"* The mean score for the PEM aggregated across the six projects was 16.85, with a possible range from 0 to 48. The distribution of the aggregated PEM scores is presented in Figure 4.8. Among projects, mean PEM scores increased from 14.09 for NestWatch to 28.30 for GCM (Figure 4.9).

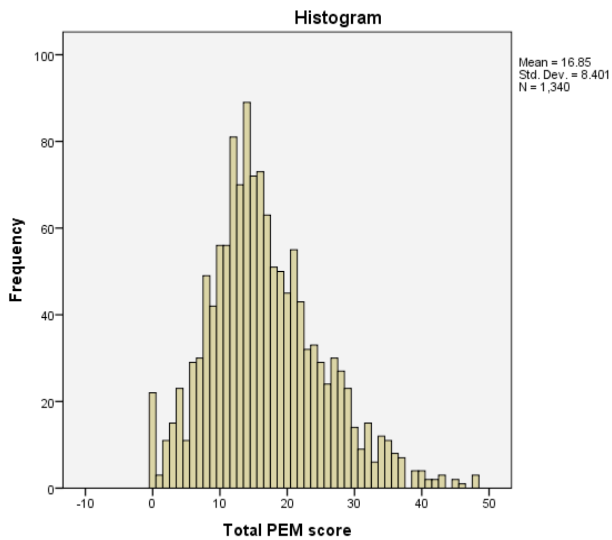


Figure 4.8: Aggregated PEM Scores

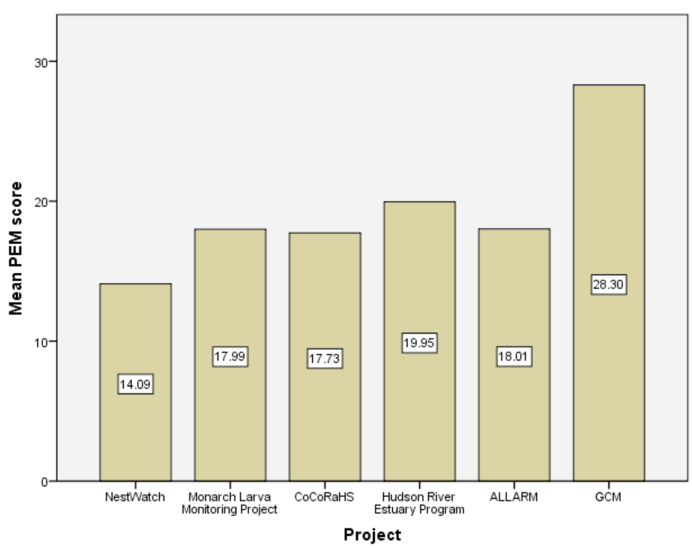


Figure 4.9. Mean PEM scores for the six projects.

Across the projects, the most commonly reported activity in the PEM was gathering data, done 'often' or 'very often' by more than 70% of respondents. Just under 70% of respondents also reported submitting data often or very often. The next most common activity reported by approximately 38% of respondents was sharing information about the project to the public. Activities that were 'never' or 'rarely' done included "used project data to make or defend a scientific claim," (80% of respondents), "used statistics and probability to interpret data" (76%), and "communicated project data or findings to politicians, decision makers, or media outlets," (75%). The frequency of PEM individual activities is presented in Figure 4.10. On average, most participants were conducted 3.13 PEM activities, aggregated across projects.

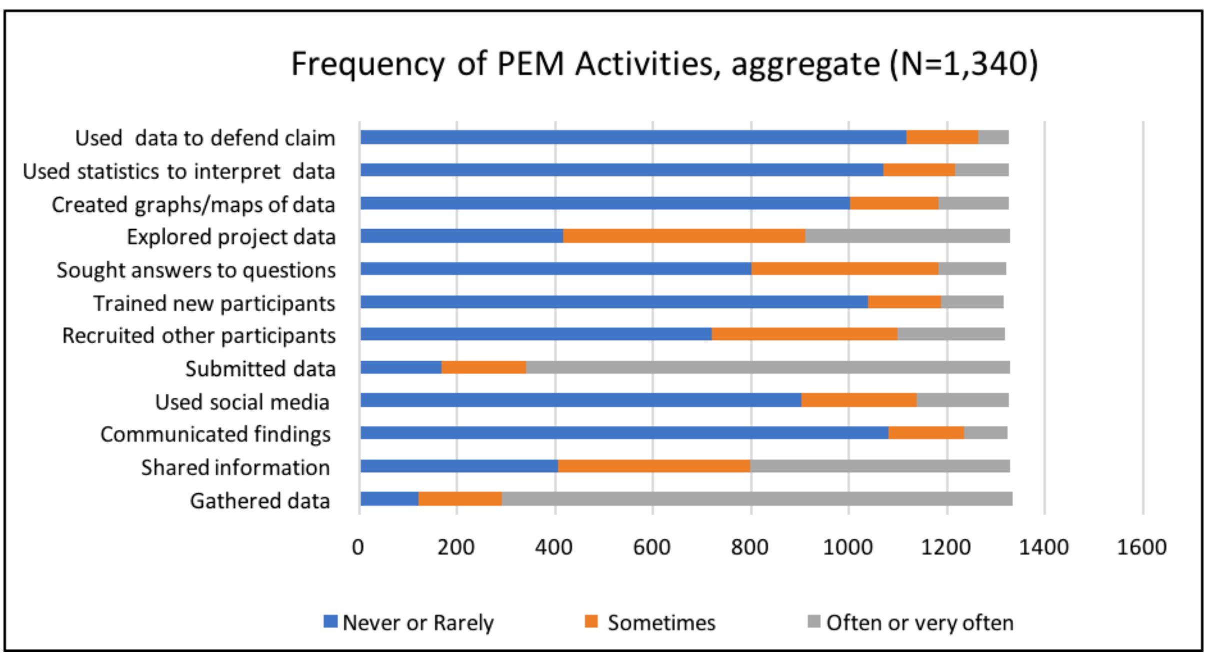
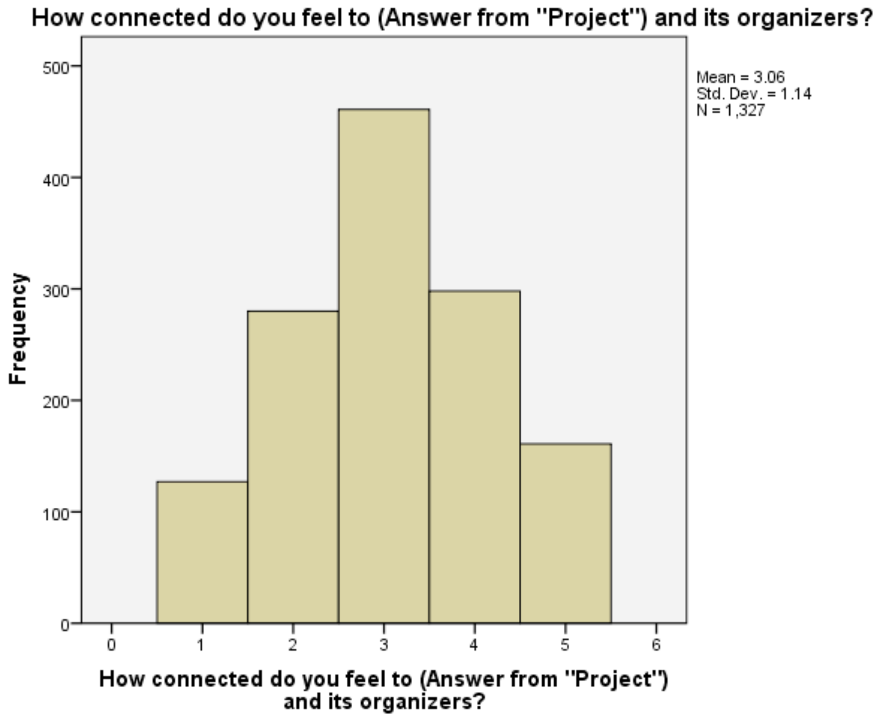


Figure 4.10: Frequency of reported project activities, aggregated across projects.

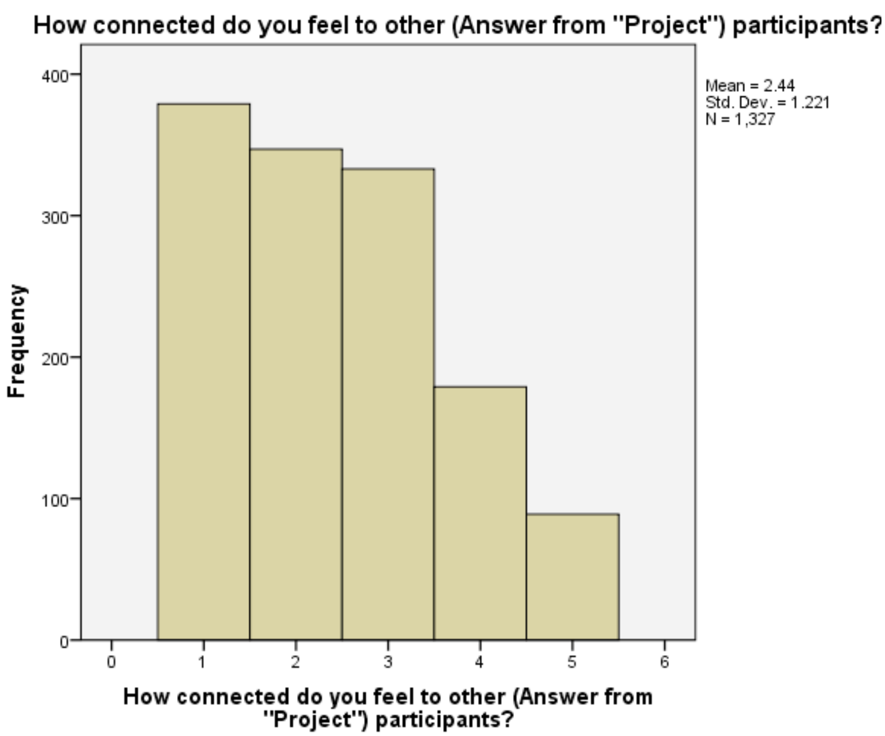
Affective dimensions: To measure affective dimensions of engagement, participants were asked three questions that gauged interest in the project (data not shown) and a set of questions about how connected they felt to certain aspects of the project. Nearly 80% of all project respondents, except those from GCM, reported being interested or extremely interested in the project. About half of GCM participants were extremely interested, while 40% reported not very or not at all interested. However, sample size for GCM was very small (12). For all projects except GCM, the majority of participants are interested in the project about the same as their other leisure activities. Roughly 40% of all respondents said that they were more interested in the citizen science project than other leisure activities. When asked the likelihood to participate in the project in the future, across all projects the vast majority were very likely, although this was lowest for GCM.

Respondents were asked how connected they felt to the project and its organizers, to other participants, to their communities as it relates to the project, to the sites they monitor, and to their local environment. Connections to projects and their organizers were evenly distributed from 1 (not at all connected) to 5 (extremely connected), with a mean = 3.06 (Figure 4.11a). There were less feelings of connections to other project participants (mean = 2.44, Figure 4.11b) and connections to their local communities as they relate to the project (mean = 2.47, Figure 4.11c). A very different pattern emerged when asked about connections to the sites they monitor, (mean = 4.34, Figure 4.11d), and their local environment (mean = 4.0, Figure 4.11e.)

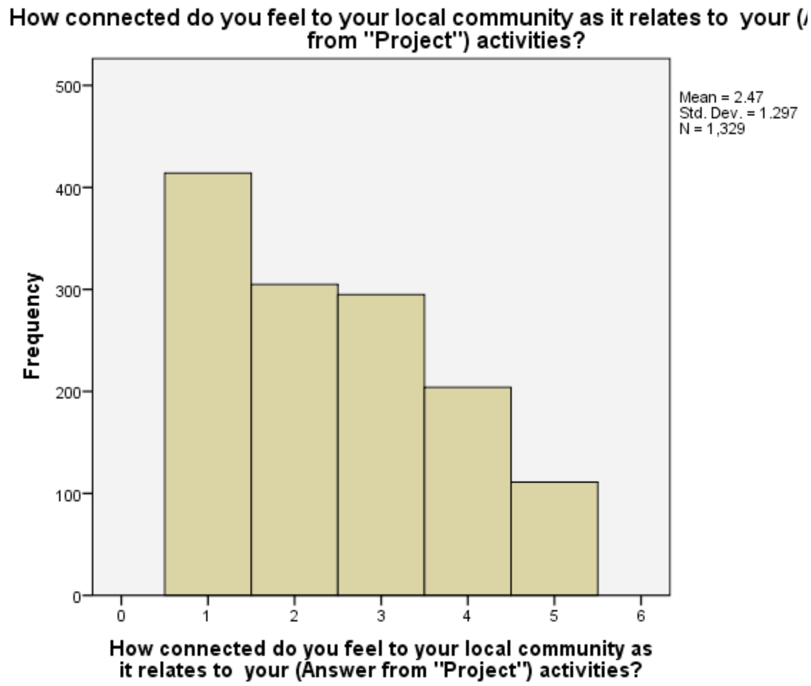
Figure 4.11a-e. Distribution of feelings of connectedness.



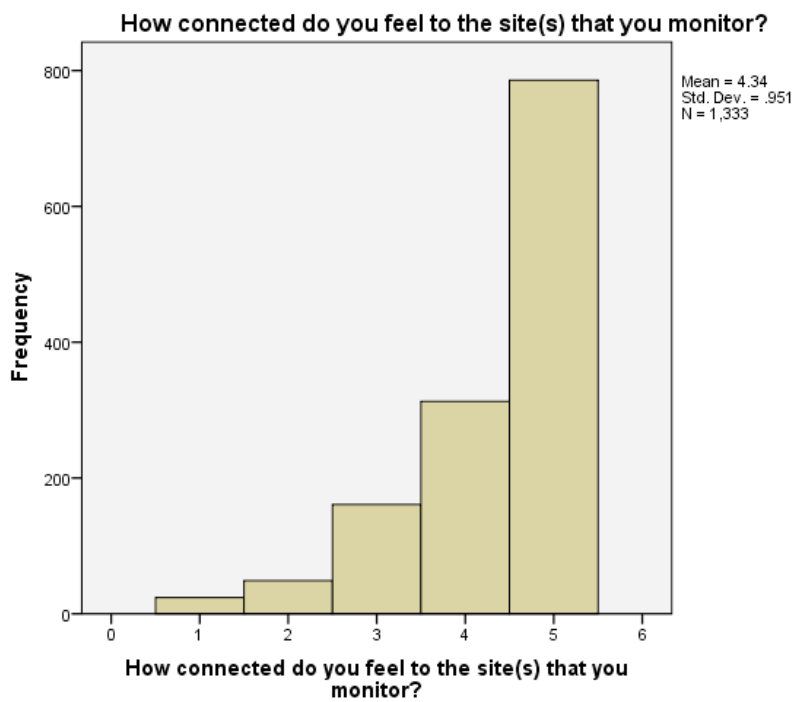
a. Connection to project organizers



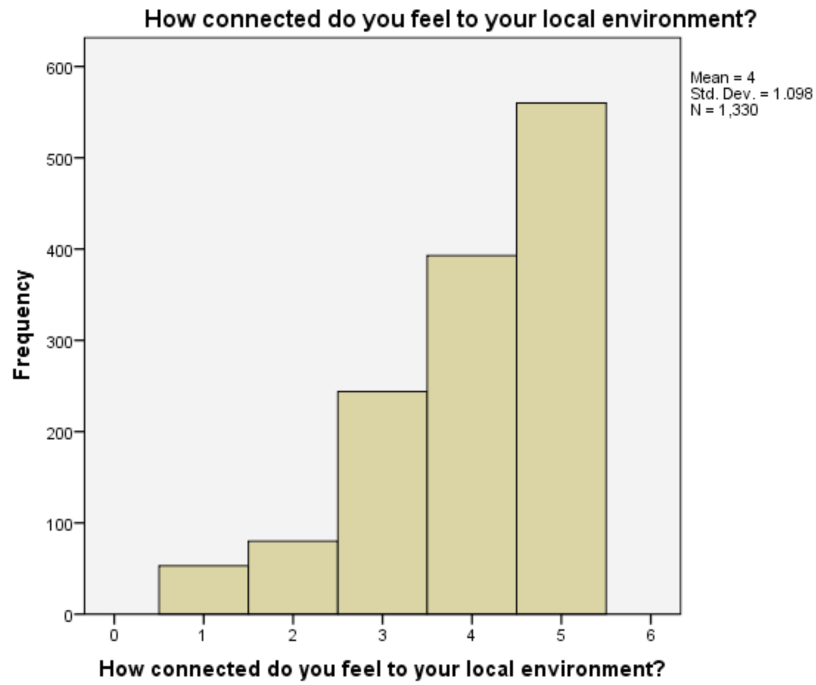
b. Connections to other project participants



c. Connection to local community and project



d. Connection to sites



e. Connection to local environment

Cognitive/learning: Only two questions asked about learning per se, although all three dependent variables (efficacy, skills, and environmental stewardship) are measuring learning outcomes. Respondents were asked to complete the sentence *"Most of what I learned while participating in this project came from…"* using a 1-5 scale where 1 = strongly disagree and 5 = strongly agree. Multiple sources of learning were reported (Figure 4.12); however, experiential learning had the highest overall mean (3.87) across the six projects, followed by external sources and previous knowledge (3.55 each), and project materials (3.52). In-person interactions (2.35) and online interactions (2.09) had the lowest overall means.

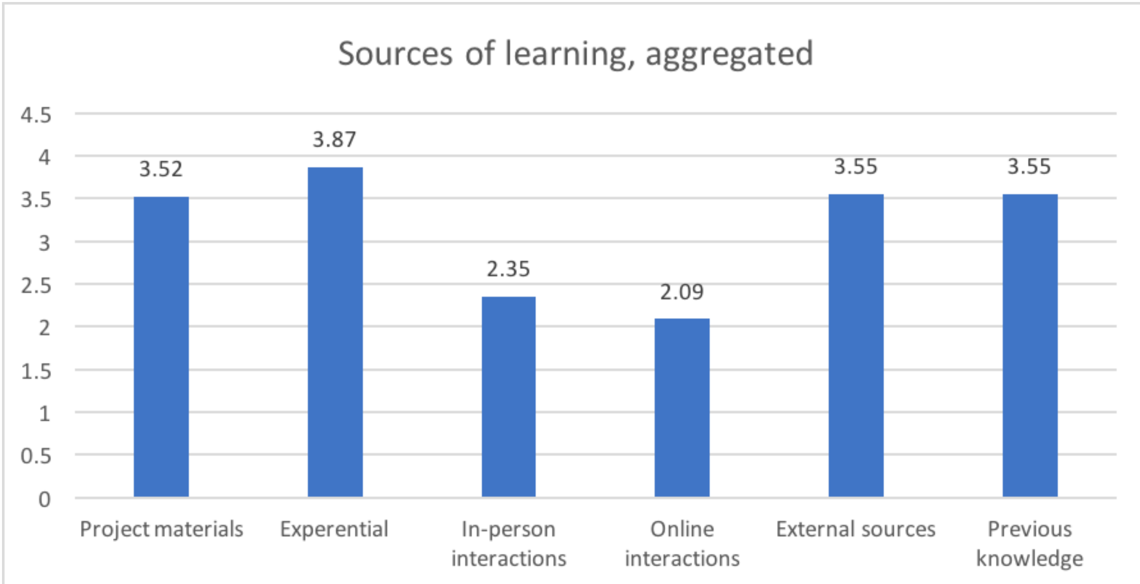


Figure 4.12: Aggregated means for sources of learning.

Comparing projects, NestWatch, MLMP, and EELS all cited experiential learning as their most frequent source of learning. Unlike most other projects, CoCoRaHS participants report previous knowledge as the most common source of learning. ALLARM participants rely heavily on the project materials and training, while GCM respondents report on in-person interactions most often. Among all projects, online interactions were the least common form of learning (Figure 4.13).

In one of the few open-ended questions in the survey, respondents were asked to describe the most beneficial aspect of participating in their respective projects. The most common key terms included "data," "learning," "helping," and "using." These terms speak to the major role that access to data has for participants. Learning and contributing to science and/or conservation appear to be not only inputs, but also meaningful outcomes for participants. The word cloud in Figure 4.14 provides the relative frequencies of coded key words.

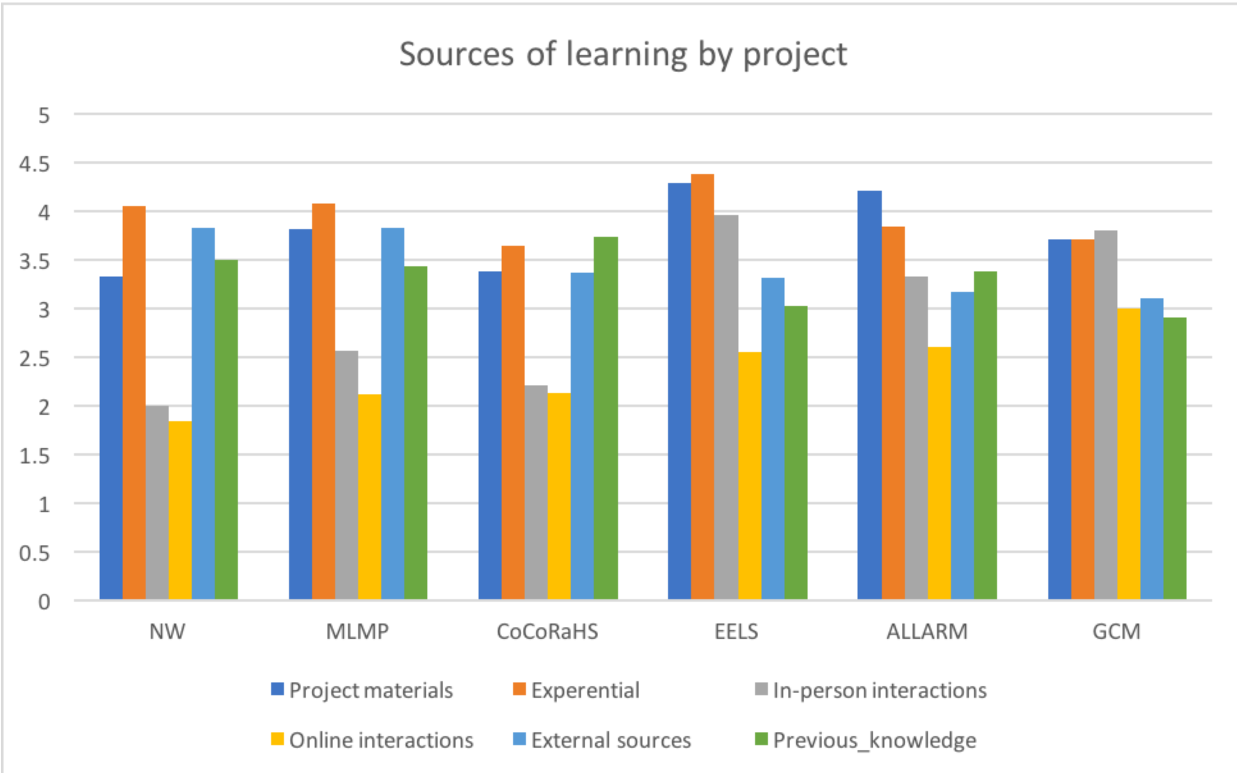


Figure 4.13: Mean scores for sources of learning by project.

Figure 4.14: Word cloud showing relative frequency of key words in response to beneficial aspects of participation.

Social Activities: Similar to the PEM, an index was created (although not validated) to provide a summed measure of social or extra activities that participants engaged in. Seven different activities were presented to respondents: Participate in meetings or conference calls; Post to Facebook, Twitter, or other social media; Communicate with other participants, virtually or in person; Take part in project webinars; Email project leaders; Visit project website; and Read project newsletters. Item responses ranged from 0=Never, 1=Rarely, 2=Sometimes, 3=Often, and 4=Very often. The range for this index was between 0 and 28.

Mean scores for the social activity index across the aggregated dataset was 8.78 (Figure 4.15). Examination of individual social activities reveal that of the seven activities, only visiting project websites and reading project newsletters were done "often" or "very often" by a majority of respondents (Figure 4.16).

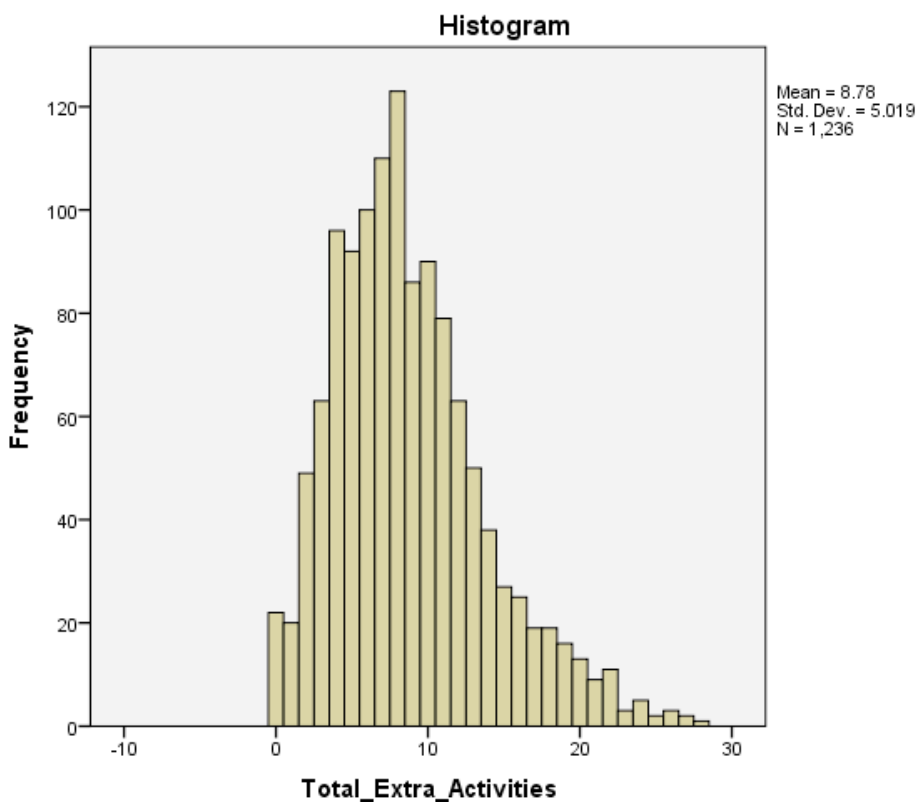


Figure 4.15: Distribution of social or extra activities index.

Figure 4.16: Frequency of reported social activities, aggregated across projects.

<u>Research Question 4.2: How do behavioral aspects of engagement (measured via the PEM) relate to commonly sought after outcomes of citizen science such as science efficacy, science skills, and environmental stewardship?</u>

To test the initial hypothesis described by Bonney et al. (2009a) correlational tests were conducted to examine how behavioral engagement in citizen science relate to science efficacy, science skills, and environmental stewardship. Here, behavioral variables include duration of effort (years), intensity (hours/year), engagement in scientific practices, (measured via the PEM), and social activity. Table 4.11 presents a correlation matrix for the behavioral variables and learning outcomes, aggregated across the data. Nearly all the relationships signified statistical significance at the $p<.01$; however, given the sample sizes (between 1,181-1,325), this is not surprising.

Table 4.11: Spearman's rho correlation matrix for aggregated behavioral variables and learning outcomes. Bold correlations indicate moderately strong relationships greater than .30.

(N=1181-1326)	1	2	3	4	5	6	7	8	9	10
1.Duration	1	.221**	**.319****	.212**	.283**	.094**	0.003	.177**	.235**	-.081**
2.Hours / Year	.221**	1	**.388****	**.345****	**.362****	.101**	0.038	.145**	.218**	0.021
3. PEM	**.319****	**.388****	1	**.847****	**.683****	.244**	.158**	.278**	**.512****	.232**
4. Number PEM	.212**	.345**	.847**	1	**.586****	.212**	.125**	.252**	**.460****	.173**
5.Social Activity	.283**	.362**	.683**	.586**	1	.145**	.079**	.182**	**.396****	.223**
6.Efficacy Mean	.094**	.101**	.244**	.212**	.145**	1	.899**	.876**	.605**	.203**
7.Sci Efficacy Mean	0.003	0.038	.158**	.125**	.079**	.899**	1	.595**	.481**	.210**
8.CitSci Efficacy Mean	.177**	.145**	.278**	.252**	.182**	.876**	.595**	1	.607**	.153**
9.Skills Mean	.235**	.218**	.512**	.460**	.396**	.605**	.481**	.607**	1	.202**
10.Env. Behavior Score	-.081**	0.021	.232**	.173**	.223**	.203**	.210**	.153**	.202**	1
**** Correlation is significant at the 0.01 level (2-tailed).**										

Examination of the *r* values in Table 4.11 indicates mostly positive relationships and some moderately to strong relationships. For example, the number of years in a project (Duration) was positively correlated with PEM scores (in other words, more years in a project relates to doing more activities). The number of hours/year was also moderately correlated with PEM, as well as the diversity of activities (Number PEM), and the amount of social activities (Social Activity Score). Not surprising the PEM was highly correlated with the diversity of PEM activities as well as the mean score for skills related to citizen science (Skills Mean). The Social Activity Score was also moderately correlated with skills but when broken down into individual activities, only reading newsletters (r=.319) and visiting project websites (r=.330) had statistically significant and moderately strong relations (table not shown for brevity). However, emailing project leaders had fairly strong associations with taking part in project webinars (r =

.419), communicating with other participants (r=.470), and participating in conference calls or meetings (r = .470). Interestingly, none of the behavioral predictors had any strong relationships to either of the efficacy or stewardship measures.

Nearly all individual PEM activities had positive, statistically significant correlations with the learning outcomes but again, the majority of these interactions are fairly weak (Table 4.12). A few moderately strong relationships are evident, however. For instance, sharing information about the project has a fairly strong relationship with nine other PEM activities as well as citizen science skills. Communicating findings and using social media also have moderately strong associations with several other PEM activities, including using data to make or defend a scientific claim. Interestingly, gathering data, the crux of most citizen science projects, only had one strong interaction with submitting data (r=.759). Similarly, recruiting and training others were strongly associated with each other (r=.609). As above, Skills was the only learning outcome that had fairly strong relationships with individual PEM activities including: sharing information, recruiting others, exploring data, creating graphs, using statistics and probability to interpret data, and using project data to make scientific claims. These data lend support to the hypothesis that engaging in more aspects of the scientific process is related to increased learning outcomes, although the strength of the relationships is variable.

Table 4.12: Spearman's rho correlation matrix for individual PEM activities and learning outcomes. Bold correlations indicate moderately strong relationships greater than .30.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16	17.
1 Gather data	1	.269**	.143**	.085**	.759**	.177**	.098**	.116**	.264**	.169**	.151**	.135**	.173**	.058*	.252**	.287**	-0.042
2 Share information	.269**	1	.444**	.365**	.271**	.440**	.322**	.301**	.353**	.316**	.323**	.344**	.140**	.101**	.154**	.361**	.145**
3 Comm. findings	.143**	.444**	1	.450**	.123**	.418**	.417**	.344**	.269**	.429**	.462**	.494**	.108**	.069*	.125**	.298**	.149**
4 Use social media	.085**	.365**	.450**	1	.088**	.368**	.375**	.381**	.224**	.304**	.302**	.325**	.068*	0.027	.093**	.216**	.201**
5 Submit data	.759**	.271**	.123**	.088**	1	.167**	0.047	.108**	.288**	.139**	.115**	.108**	.154**	0.044	.241**	.287**	-0.05
6 Recruit others	.177**	.440**	.418**	.368**	.167**	1	.609**	.391**	.298**	.373**	.344**	.375**	.156**	.084**	.203**	.323**	.238**
7 Train others	.098**	.322**	.417**	.375**	0.047	.609**	1	.420**	.169**	.368**	.332**	.373**	.173**	.118**	.190**	.278**	.221**
8 Seek answers	.116**	.301**	.344**	.381**	.108**	.391**	.420**	1	.332**	.302**	.321**	.320**	.073**	.059*	.074**	.206**	.243**
9 Explore data	.264**	.353**	.269**	.224**	.288**	.298**	.169**	.332**	1	.358**	.361**	.312**	.254**	.202**	.250**	.403**	.162**
10 Create graphs	.169**	.316**	.429**	.304**	.139**	.373**	.368**	.302**	.358**	1	.631**	.504**	.180**	.152**	.161**	.358**	.117**
11 Use statistics	.151**	.323**	.462**	.302**	.115**	.344**	.332**	.321**	.361**	.631**	1	.616**	.151**	.125**	.147**	.394**	.127**
12 Use project data	.135**	.344**	.494**	.325**	.108**	.375**	.373**	.320**	.312**	.504**	.616**	1	.181**	.158**	.163**	.381**	.164**
13 Efficacy Mean	.173**	.140**	.108**	.068*	.154**	.156**	.173**	.073**	.254**	.180**	.151**	.181**	1	.899**	.876**	.605**	.203**
14 SciEfficacy Mean	.058*	.101**	.069*	0.027	0.044	.084**	.118**	.059*	.202**	.152**	.125**	.158**	.899**	1	.595**	.481**	.210**
15 CitSci Efficacy Mean	.252**	.154**	.125**	.093**	.241**	.203**	.190**	.074**	.250**	.161**	.147**	.163**	.876**	.595**	1	.607**	.153**
16 Skills Mean	.287**	.361**	.298**	.216**	.287**	.323**	.278**	.206**	.403**	.358**	.394**	.381**	.605**	.481**	.607**	1	.202**
17 Env Behavior	-0.042	.145**	.149**	.201**	-0.05	.238**	.221**	.243**	.162**	.117**	.127**	.164**	.203**	.210**	.153**	.202**	1
** Correlation is significant at the 0.01 level (2-tailed).																	

Research Question 4.3: How do these relationships differ across the six projects, three project types (contributory, collaborative, co-created), and project structure (individual vs. group-based)?

Using the four characteristics of SLT described above as the theoretical lens, the PEM (Participation) was examined across the six projects (Content), three project types (Context), and two project structures (Community) to determine if any significant differences existed among these relationships. Table 4.13 provides the mean PEM scores and number of PEM activities, along with means for the three dependent variables across the projects, with high and low values called out. Figure 4.17a-c shows PEM scores across projects, project type, and project structure. Generally speaking, there is an increase in PEM scores and PEM activities from contributory to collaborative to co-created projects.

Table 4.13: Means for PEM, number of PEM activities, efficacy, skill, and environmental stewardship by project. Lowest values are in red, highest values are in green.

Project	N	PEM Score (0-48)	Number of PEM (1-12)	Efficacy Mean (1-5)	Skills Mean (1-5)	Environmental Behavior (0-144)
NW	401	**14.14**	**2.41**	4.174	3.8159	76.16
MLMP	176	18.11	3.22	4.253	4.0044	87.69
CoCoRaHS	580	17.85	3.29	4.197	4.1417	**65.94**
EELS	57	20.71	4.55	**4.3802**	**4.2065**	97.2
ALLARM	80	18.38	4.18	**3.8988**	3.7933	**90.61**
GCM	10	**28.30**	**6.8**	4.0938	**3.7917**	84.43

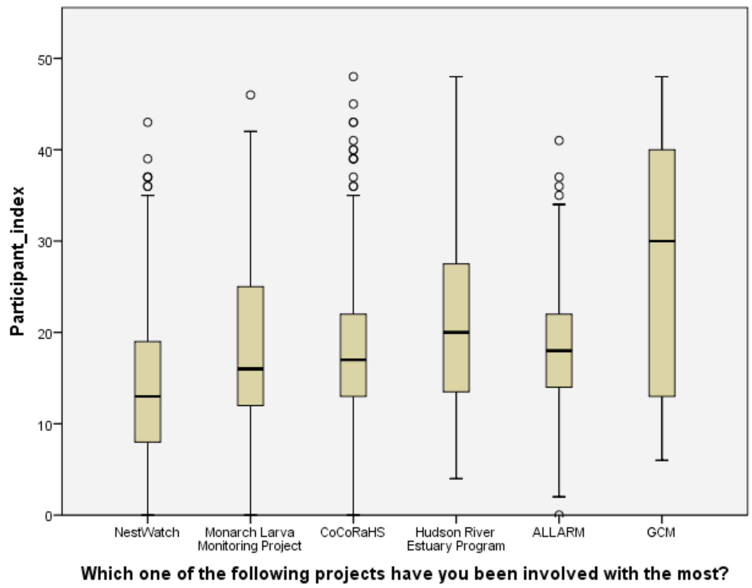


Figure 4.17a: Mean PEM scores by project.

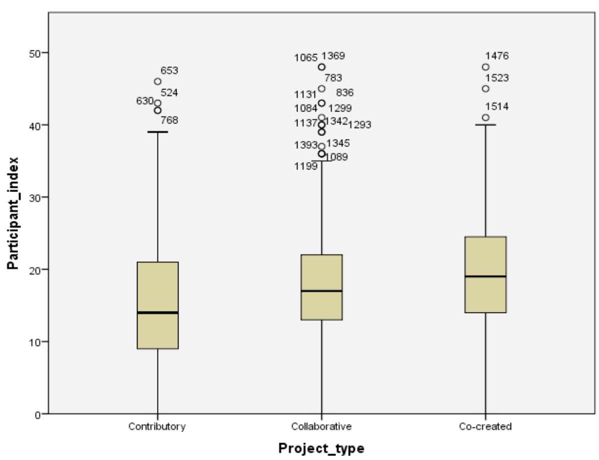


Figure 4.17b: Mean PEM scores by project type

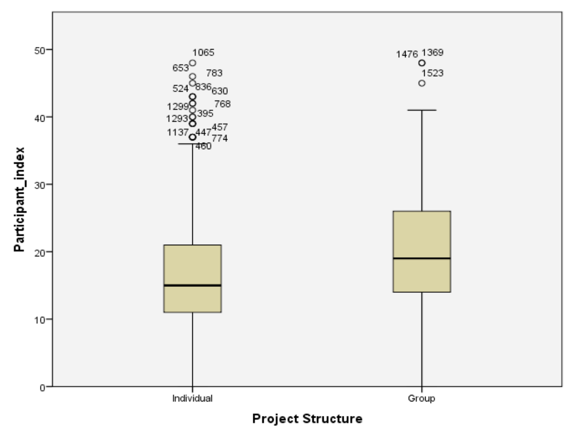


Figure 4.17c: Mean PEM scores by project structure.

Table 4.14: ANOVA: Multiple comparisons of PEM across projects

Dependent Variable: Participant_index (PEM)						
Project	Compared to	Mean Difference	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
NestWatch	MLMP	-3.973*	.729	**.000**	-6.05	-1.89
	CoCoRaHS	-3.707*	.527	**.000**	-5.21	-2.20
	EELS	-6.572*	1.127	**.000**	-9.79	-3.36
	ALLARM	-4.245*	1.000	**.000**	-7.10	-1.39
	GCM	-14.160*	2.588	**.000**	-21.55	-6.78
Monarch Larva Monitoring Project	NestWatch	3.973*	.729	**.000**	1.89	6.05
	CoCoRaHS	.266	.696	.999	-1.72	2.25
	EELS	-2.599	1.215	.268	-6.07	.87
	ALLARM	-.272	1.098	1.000	-3.41	2.86
	GCM	-10.187*	2.627	**.002**	-17.68	-2.69
CoCoRaHS	NestWatch	3.707*	.527	**.000**	2.20	5.21
	MLMP	-.266	.696	.999	-2.25	1.72
	EELS	-2.865	1.106	.100	-6.02	.29
	ALLARM	-.538	.976	.994	-3.32	2.25
	GCM	-10.453*	2.578	**.001**	-17.81	-3.09
Hudson River Estuary Program	NestWatch	6.572*	1.127	**.000**	3.36	9.79
	MLMP	2.599	1.215	.268	-.87	6.07
	CoCoRaHS	2.865	1.106	.100	-.29	6.02
	ALLARM	2.327	1.395	.553	-1.65	6.31
	GCM	-7.588	2.764	.067	-15.48	.30
ALLARM	NestWatch	4.245*	1.000	**.000**	1.39	7.10
	MLMP	.272	1.098	1.000	-2.86	3.41
	CoCoRaHS	.538	.976	.994	-2.25	3.32
	EELS	-2.327	1.395	.553	-6.31	1.65
	GCM	-9.915*	2.715	.004	-17.66	-2.17
GCM	NestWatch	14.160*	2.588	**.000**	6.78	21.55
	MLMP	10.187*	2.627	**.002**	2.69	17.68
	CoCoRaHS	10.453*	2.578	**.001**	3.09	17.81
	EELS	7.588	2.764	.067	-.30	15.48
	ALLARM	9.915*	2.715	**.004**	2.17	17.66

collaborative or co-created projects ($p<.05$, table not shown). Between individual and group projects, group projects have a significantly higher PEM scores than individual projects ($p<.05$, table not shown).

To examine relationships between PEM scores and the learning outcomes, by project, project type, and project structure, Spearman's split file correlation statistics were conducted (Table 4.15). Across all projects, with the exception of GCM, project types, and project structures, an increasing PEM score also relates to a statistically significant increase in skills. Additionally, PEM scores for CoCoRaHS and EELS (hence collaborative projects) were positively related to efficacy for learning science and doing citizen science (EfficacyMean). MLMP, EELS, CoCoRaHS, collaborative, and individual projects also had moderately strong and statistically significant associations with efficacy for doing citizen science (CitSciEfficacyMean). MLMP and Contributory projects had a statistically significant positive relationship with environmental stewardship (Env_Behavior_Score). Given that there were no clear patterns between different projects, project types, and project structures with learning outcomes, these data call on the rejection of the hypothesis that co-created and group-based projects are more likely to result in deeper learning than other types of projects.

Table 4.15: Spearman's split file correlation coefficient for PEM by project and learning outcome. Bold correlations indicate moderately strong relationships greater than .30.

		PROJECT						**PROJECT TYPE**			**PROJECT STRUCTURE**	
		NW - PEM	MLMP - PEM	CoCoRaHS - PEM	EELS - PEM	ALLARM - PEM	GCM - PEM	Contributory	Collaborative	Co-created	Individual	Group
Efficacy Mean	R	.226**	.238**	**.320****	**.323***	-0.007	0.589	.236**	**.328****	0.056	.266**	.191*
	Sig.	0.000	0.001	0.000	0.015	0.953	0.124	0.000	0.000	0.620	0.000	0.025
	N	401	177	568	56	74	8	578	624	82	1146	138
Sci Efficacy Mean	R	.149**	0.073	.242**	0.183	0.040	0.254	.147**	.247**	0.083	.169**	0.162
	Sig.	0.003	0.334	0.000	0.176	0.734	0.544	0.000	0.000	0.460	0.000	0.057
	N	401	177	568	56	74	8	578	624	82	1146	138
CitSci Efficacy Mean	R	.258**	**.348****	**.331****	**.430****	-0.071	0.289	.278**	**.344****	-0.023	**.306****	.185*
	Sig.	0.000	0.000	0.000	0.001	0.550	0.487	0.000	0.000	0.834	0.000	0.030
	N	401	177	568	56	74	8	578	624	82	1146	138
Skills_ Mean	R	**.479****	**.504****	**.503****	**.520****	**.405****	0.515	**.504****	**.507****	**.402****	**.527****	**.468****
	Sig.	0.000	0.000	0.000	0.000	0.000	0.192	0.000	0.000	0.000	0.000	0.000
	N	401	177	567	55	74	8	578	622	82	1145	137
Env_ Behavior_ Score	R	.276**	**.339****	.218**	0.077	.274*	-0.536	**.324****	.219**	0.197	.207**	.169*
	Sig.	0.000	0.000	0.000	0.589	0.022	0.215	0.000	0.000	0.086	0.000	0.049
	N	396	169	544	52	70	7	565	596	77	1145	136
**. Correlation is significant at the 0.01 level (2-tailed).												
*. Correlation is significant at the 0.05 level (2-tailed).												

<u>*Research Question 4.4: What role, if any, does motivation play in the relationship between behavioral engagement and learning?*</u>

Finally, in Table 4.16, Spearman's rho correlation for motivation related to the PEM and learning outcomes, aggregated across projects is presented. Intrinsic motivation has moderately strong association with efficacy (including for learning science and doing citizen science), skills, and environmental behavior. Extrinsic motivation has a negative statistically significant, albeit weak relationship with science and citizen science efficacy, and a positive statistically significant relationship with PEM, skills and environmental behavior. These data support the hypothesis that intrinsic motivation is positively correlated with behavioral engagement and learning outcomes, and highlight the important role that intrinsic motivation may have, particularly on learning outcomes.

Table 4.16: Spearman's rho correlation for motivation, PEM, learning outcomes, aggregated across all projects.

	PEM	Efficacy Mean	Science Efficacy	CitSci Efficacy	Skills Mean	Envir Behavior
Intinsic_	.273**	**.404****	**.314****	**.404****	**.420****	**.367****
Sig. (2-tail	0	0	0	0	0	0
N	1281	1324	1324	1324	1323	1274
Extrinsic_	.234**	-.107**	-.096**	-.108**	.090**	.132**
Sig. (2-tail	0	0	0	0	0.001	0
N	1281	1324	1324	1324	1323	1274

** Correlation is significant at the 0.01 level (2-tailed).

LIMITATIONS

The described work, although carefully conceived, is not without its limitations. One limitation influencing these results is the very small sample size for GCM (n=15), making it difficult to generalize the findings about co-created projects more broadly, and threatening both internal and external validity. Another notable limitation of this study will originate from the sampling strategy because participants are self-selected, which precludes the possibility of a truly randomized experiment and may introduce sampling bias, which threatens internal validity (Shadish et al., 2002). Additionally, there are always constraints and errors when studying human behavior related to motivation, cognition, emotions, etc., that threaten internal validity. These constraints make it difficult to account for all additional variables that could influence science and environmental learning outcomes amongst individuals and therefore impede the formation of causal generalizations that would explain relationships beyond those studied (Shadish, et al., 2002). Data collection procedures and/or instruments with low validity or reliability, or floor or ceiling effects, can pose serious threats to internal validity. This is especially true for four sets of constructs that had not been extensively validated, and as such were not used in most of the inferential analyses. The use of self-reports for developed instruments can be a threat to construct validity in particular because they introduce social desirability bias. Finally, each of these threats could influence the statistical validity of the work, which relies on the use of appropriate sampling, reliable measurements, and suitable statistical tests.

DISCUSSION

Despite the above limitations, the data from the online survey of six different citizen science projects spanning the contributory to collaborative to co-created continuum provide a wealth of information to better understand similarities and differences within these different science and environmental learning contexts. Research Question 1 was concerned with understanding the various dimensions of engagement. These data reveal clearly that citizen science engenders much interest from its participants in nearly all contexts and across different content from birds to butterflies to weather and air quality. Sources of learning also seemed to be fairly consistent, with experiential experiences being most common for all projects except GCM. Participants across the board felt very connected to the sites they monitor and their local environment, slightly less so to the project and its organizers and even less to other participants. Creating more connections to participants may present an opportunity for enhanced engagement with those seeking additional opportunities for engagement. Clear differences were noted with respect to motivations among projects. Whereas all projects had relatively high intrinsic motivations, the co-created projects also had fairly high extrinsic motivations related to worry or concern. Studies have shown that sustained participation in activities is more likely when strong intrinsic factors are at work (Deci and Ryan 2000).

Few studies have attempted to understand the practice of citizen science participation and its effect on learning, as this study did in answering Research Question 2. Engagement in scientific and social process was quantified via an index called the Participant Engagement Metric (PEM) and compared across projects, project types, and project structures. Supporting the idea of legitimate peripheral participation (Lave and Wenger, 1991), results of this study reveal that increasing duration in a project is linked to an increase in project activities. The number of hours/year was also moderately correlated with PEM, along with the diversity of activities (Number PEM), and the amount of social activities (Social Activity Index). Results showed that increasing PEM scores were also associated with increased social activity. These findings underscore the need for all projects to provide and support meaningful outlets for peer-to-peer, participant-to-scientist, and participant-to-public forms of communication, all of which sustain participant interest and engagement in the project and likely influence learning. Of the 12 possible activities in the PEM however, most participants engage primarily in data gathering, submission, and communicating about the project with others. Across the projects, increasing PEM scores had positive associations with all learning outcomes, lending support to the hypothesis that regardless of unit of analysis, engaging in more aspects of the scientific process is related to increased learning outcomes, although the strength of the relationships is variable.

Research Question 3 examined how relationships in RQ2 differ between projects, project types and project structures. The data show that the PEM score and number of PEM activities does increase from contributory to co-created projects. The results also show that activities such as exploring data online were much more likely to occur in the contributory (NestWatch and Monarch Larva Monitoring Project) and collaborative projects (CoCoRaHS and Hudson River EELS project) than in the co-created (Alliance for Aquatic Resource Monitoring (ALLARM), and Global Community Monitor (GCM) projects, perhaps reflecting insufficient online infrastructure in co-created projects for sophisticated data exploration. Although, the vast majority of survey respondents rarely take part in higher level science activities such as using data to defend scientific claims, participants in co-created projects engaged in a higher number of PEM activities and were more likely to use data and share project findings (rather than simply communicate *about* the project) than participants in other project types. This lends partial support to the hypothesis that co-created projects facilitate and support more facets of the scientific process.

Bonney et al. (2009a) also hypothesized and compiled preliminary evidence that co-created projects are likely to produce deeper learning outcomes than collaborative or contributory projects. Until now, few, if any, studies have attempted to empirically test this hypothesis. The aggregated data suggest that participating in more facets of the scientific practice (as measured by the PEM) is also associated with greater perceived Skills for conducting citizen science. This association was moderately strong across all projects (excluding GCM because of small sample size), project types, and project structures. This finding also provides some indirect evidence that with more practice, skills related to citizen science activities improve, and likely result in improved data quality. However, an alternative explanation may be due to the T-test results showing that college graduates, which made up 95% of the sample, had significantly higher self-perceptions of skills than non-graduates.

CoCoRaHS and EELS showed positive associations between PEM and the full efficacy measure and efficacy for citizen science but a weaker correlation with science efficacy in general. This finding is similar to Masters et al. (2016) who did not find an association between increasing contribution and increasing general science knowledge, lending support to SLT that contends that learning is contextualized to the project at hand, and not necessarily transferable to other contexts. Surprisingly, only one project, MLMP had a statistically significant positive relationship with environmental stewardship, likely due to the fact that stewardship activities are very much tied to MLMP project activities. However, an alternative hypothesis may be derived from the T-test results, which revealed that females had significantly higher stewardship scores than males and given that MLMP is skewed female, this could also account for these higher environmental stewardship scores.

It is also worth recalling that when project leaders were asked to choose three learning outcomes that were relevant to their project, all six chose Skills, which had the greatest overall associations with all projects and PEM scores. MLMP also chose Environmental Stewardship, which was also positively associated with MLMP activities. Similarly, CoCoRaHS PEM scores were related to Self-Efficacy, another outcome chosen for this project. Besides rejection of the hypothesis that learning outcomes are stronger for co-created and group projects than other project, these data also remind us that learning outcomes are very contextualized to the projects and are best achieved when designed for. A key take away is that any project has the ability to influence nearly any type of learning, so long as it is relevant and designed for the project, and aligned with project activities.

Lastly, the final question examined intrinsic motivation as a predictor, and had moderately strong associations with all the dependent variables, including general science efficacy. Interestingly, extrinsic motivation had a weak but negative association with all forms of efficacy, a finding that perhaps should be considered more deeply in the future. Together, these data support the hypothesis that intrinsic motivation is positively correlated with behavioral engagement and learning outcomes, underscoring the important role that motivation has in informal science learning environments.

CONCLUSION

Each year, millions of dollars are granted to develop citizen science projects that aim to promote science learning and increase environmental awareness and stewardship. In a time where accountability is ever more important, the field of citizen science must begin to provide evidence for its collective impact. This research offers a step toward that goal and fills important knowledge gaps about whether individual learning goals are being achieved given a project type or how varying levels of engagement might affect learning outcomes. Results of this study may have implications for future research on conservation action and the link between spending time outdoors and environmental stewardship practices. This research also highlights the need to better understand how to create more social spaces and tap into intrinsic motivations, which seem to relate to all measured learning outcomes in this study. Importantly, the results provided here have been boiled down by pre-conceived and socially construed categories, which may or may not reflect the true complexity of engaging in citizen science. At the very least however, this research is intended to engender new research questions, agendas, and methodologies for systematically studying this dynamic and growing field.

REFERENCES

Arnseth, H. C. (2008). Activity theory and situated learning theory: contrasting views of educational practice. *Pedagogy, Culture and Society*, *16*(3), 289-302.

Bandura, A. (1982). Self-efficacy mechanism in human agency. *American Psychologist*, *37*(2), 122–147. https://doi.org/10.1037/0003-066X.37.2.122.

Bandura, A. (1997). *Self-Efficacy: The Exercise of Control* (1st edition). New York: Worth Publishers.

Bonney, R., Ballard, H., Jordan, R., McCallie, E., Phillips, T., Shirk, J., and Wilderman, C. C. (2009a). *Public Participation in Scientific Research: Defining the Field and Assessing Its Potential for Informal Science Education. A CAISE Inquiry Group Report*. Washington, D.C.: Center for Advancement of Informal Science Education (CAISE). Retrieved from http://eric.ed.gov/?id=ED519688.

Bonney, R., Cooper, C. B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K. V., and Shirk, J. (2009b). Citizen Science: A Developing Tool for Expanding Science Knowledge and Scientific Literacy. *BioScience*, *59*(11), 977–984. https://doi.org/10.1525/bio.2009.59.11.9.

Bonney, R., Shirk, J. L., Phillips, T. B., Wiggins, A., Ballard, H. L., Miller-Rushing, A. J., and Parrish, J. K. (2014). Next Steps for Citizen Science. *Science*, *343*(6178), 1436–1437. https://doi.org/10.1126/science.1251554.

Clark, L. A., and Watson, D. (1995). Constructing validity: Basic issues in objective scale development. *Psychological assessment*, *7*(3), 309.

Cooper, C. B., Dickinson, J., Phillips, T., and Bonney, R. (2007). Citizen science as a tool for conservation in residential ecosystems. *Ecology and Society*, *12*(2), 11. https://doi.org/http://hdl.handle.net/10535/2968

Costello, A. B., and Osborne, J. (2005). Best practices in exploratory factor analysis: Four recommendations for getting the most from your analysis. *Practical Assessment Research and Evaluation*, 10(7). Available online: http://pareonline.net/getvn.asp?v=10&n=7

Crall, A. W., Jordan, R., Holfelder, K., Newman, G. J., Graham, J., and Waller, D. M. (2012). The impacts of an invasive species citizen science training program on participant attitudes, behavior, and science literacy. *Public Understanding of Science*, *22*(6), 745–764. https://doi.org/10.1177/0963662511434894

Creswell, J. W. (2009). *Research design: qualitative, quantitative, and mixed methods approaches* (3rd ed). Thousand Oaks, Calif: Sage Publications.

Cronbach, L. J., and Meehl, P. (1955). Construct validity in psychological tests. *Psychological Bulletin*, *52*, 281-302.

Cronbach, L. J. (1951). Coefficient alpha and the internal structure of tests. *Psychometrika*, (16) 3: 297–334.

Deci, E. L., and Ryan, R. M. (2000a). The "What" and "Why" of Goal Pursuits: Human Needs and the Self-Determination of Behavior. *Psychological Inquiry*, *11*(4), 227–268. https://doi.org/10.1207/S15327965PLI1104_01

Deci, E. L. and Ryan, R. M. (2000b). The "What" and "Why" of goal pursuits: Human needs and the self-determination of behavior. *Psychological Inquiry*, 11(4): 227–268.

DeVellis, R. (1991). *Scale Development: Theory and Applications*. Newbury Park, California: Sage Publication.

Dewey, J. (1938). *Experience and Education*. New York: Macmillan.

Dickinson, J. L., and Bonney, R. (2012). *Citizen Science: Public Participation in Environmental Research*. Cornell University Press.
Dierking, L. D., Falk, J. H., Rennie, L., Anderson, D., and Ellenbogen, K. (2003). Policy statement of the "informal science education" ad hoc committee. *Journal of Research in Science Teaching*, *40* (2), 108–111. https://doi.org/10.1002/tea.10066.
Drost, E. A. (2011). Validity and reliability in social science research. *Education Research and Perspectives*, 38(1), 105.
Evely, A. C., Pinard, M., Reed, M. S., and Fazey, I. (2011). High levels of participation in conservation projects enhance learning: Participation enhances learning. *Conservation Letters*, *4*(2), 116–126. https://doi.org/10.1111/j.1755-263X.2010.00152.x.
George, D., and Mallery, P. (2003). SPSS for Windows step by step: A simple guide and reference. 11.0 update (4th ed.). Boston: Allyn and Bacon.
Falk, J. H., and Dierking, L. D. (2002). *Lessons Without Limit: How Free-choice Learning is Transforming Education*. Rowman Altamira.
Field, A. (2009). Discovering Statistics using SPSS. Sage: London.
Follett, R., and Strezov, V. (2015). An Analysis of Citizen Science Based Research: Usage and Publication Patterns. *PLOS ONE*, 10(11):e0143687 https://doi.org/10.1371/journal.pone.0143687
Jordan, R. C., Gray, S. A., Howe, D. V., Brooks, W. R., and Ehrenfeld, J. G. (2011). Knowledge Gain and Behavioral Change in Citizen-Science Programs: Citizen-Scientist Knowledge Gain. *Conservation Biology*, *25*(6), 1148–1154. https://doi.org/10.1111/j.1523-1739.2011.01745.x.
Kane, M., and Trochim, W. (2009). Concept Mapping for applied social research. In L. Bickman and D. J. Rog (Eds.), *The SAGE Handbook of Applied Social Research Methods*. Thousand Oaks, CA: SAGE Publications.
Kane, M., and Trochim, W. M. K. (2007). Concept Mapping for Planning and Evaluation. In L. Bickman and D. J. Rog (Eds.), *Applied Social Research Methods Series* (Vol. 50). Thousand Oaks, CA: SAGE Publications. Retrieved from http://www.corwin.com/sites/default/files/upm-binaries/12219_Kane_Concept_Mapping_TP.pdf
Kloetzer, L., Schneider, D., Jennett, C., Lacovides, I., Eveleigh, A., Cox, A. L., and Gold, M. (2013). Learning by volunteer computing, thinking and gaming: What and how are volunteers learning by participating in Virtual Citizen Science? In *ESREA 2013: Changing Configurations of Adult Education in Transitional Times Proceedings* (pp. 73-92). European Society for Research on the Education of Adults (ESREA).
Kountoupes, D. L., and Oberhauser, K. S. (2008). Citizen Science and Youth Audiences: Educational Outcomes of the Monarch Larva Monitoring Project. *Journal of Community Engagement and Scholarship*, *1*(1), 10–20.
McEver, C. (2010). The Case for Informal Science Education. Center for the Advancement of Informal Science Education 2010 Summit. Washington DC.
Lave, J., and Wenger, E. (1991). *Situated Learning: Legitimate Peripheral Participation*. Cambridge University Press.
Lawrence, D. (2006). *Enhancing Self-esteem in the Classroom*. Pine Forge Press.
Lee, S., and Roth, W.-M. (2003). Science and the "Good Citizen": Community-Based Scientific Literacy. *Science, Technology, and Human Values*, *28*(3), 403–424. https://doi.org/10.1177/0162243903028003003

Lin, P. and Schunn, C. D. (2016) The dimensions and impact of informal science learning experiences on middle schoolers' attitudes and abilities in science. *International Journal of Science Education*, 38:17, 2551-2572, DOI: 10.1080/09500693.2016.1251631

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

National Research Council. (2009). *Learning Science in Informal Environments: People, Places, and Pursuits*. National Academies Press.

Newman, G., Wiggins, A., Crall, A., Graham, E., Newman, S., and Crowston, K. (2012). The future of citizen science: emerging technologies and shifting paradigms. *Frontiers in Ecology and the Environment*, *10*(6), 298–304. https://doi.org/10.1890/110294.

NGSS Lead States. (2013). *Next Generation Science Standards: For States, By States*. Washington, D.C.: National Academies Press. Retrieved from https://www.nap.edu/catalog/18290/next-generation-science-standards-for-states-by-states

Pelletier, L. G., Tuson, K. M., Green-Demers, I., Noels, K., and Beaton, A. M. (1998). Why Are You Doing Things for the Environment? The Motivation Toward the Environment Scale (MTES)1. *Journal of Applied Social Psychology*, *28*(5), 437–468. https://doi.org/10.1111/j.1559-1816.1998.tb01714.x

Phillips, T., Bonney, R., and Shirk, J. (2012). What is our impact? Toward a unified framework for evaluating outcomes of citizen science participation. In J. L. Dickinson and R. Bonney (Eds.), *Citizen Science: Public Participation in Environmental Research* (pp. 82–95). Ithaca, NY: Cornell University Press.

Phillips, T., Lewenstein, B. V., and Bonney, R. (2006). A case study of citizen science. In D. Cheng, J. Metcalf, and B. Schiele (Eds.), *At the Human Scale, International Practices in Science Communication* (pp. 317–334). Beijing: Science Press.

Pillemer, K., Fuller-Rowell, T. E., Reid, M. C., Wells, N.W. (2010). Environmental Volunteering and Health Outcomes over a 20-Year Period, *The Gerontologist*, (50) 5: 594-602. https://doi.org/10.1093/geront/gnq007.

Prochaska, J. O. and Velicer, W. F. (1997). The Transtheoretical Model of Health Behavior Change. *American Journal of Health Promotion*, 12(1): 38 – 48.

Rosas, S. R., and Kane, M. (2012). Quality and rigor of the concept mapping methodology: A pooled study analysis. *Evaluation and Program Planning*, *35*(2), 236–245. https://doi.org/10.1016/j.evalprogplan.2011.10.003

Rosas, and Camphausen. (2007). The use of concept mapping for scale development and validation in evaluation Evaluation and Program Planning, 30 (2): 125-135.

Rowe, G., and Frewer, L. J. (2000). Public participation methods: A framework for evaluation. *Science, Technology and Human Values*, *25*(1), 3–29.

Ryan, R. M., and Deci, E. L. (2000). Intrinsic and Extrinsic Motivations: Classic Definitions and New Directions. *Contemporary Educational Psychology*, *25*(1), 54–67. https://doi.org/10.1006/ceps.1999.1020.

Samuel, M. and Okey, L. K. (2015). The relevance and significance of correlation in social science research. International Journal of Sociology and Anthropology Research, (1).3:22-28.

Shadish, W. R., Cook, T. D., and Campbell, D. T. (2002). *Experimental and Quasi-Experimental Designs for Generalized Causal Inference*. Boston: Houghton Mifflin Company.

Terrell, S. (2012). Statistics Translated: A Step by Step Guide to Analyzing and Interpreting Data. The Gulford Press, New York, NY.
Thompson, S., and Bonney, R. (2007). Evaluating the impacts of participation in an online citizen science project: A mixed-methods approach. In J. Trant and D. Bearman (Eds.), *Museums and the web 2007: Selected papers from an international conference* (pp. 187–199). Toronto: Archives and Museum Informatics.
Trautman, N., Shirk, J. L., Fee, J., and Krasny, M. E. (2012). Who poses the question? In J. Dickinson and R. Bonney (Eds.), *Citizen Science: Public Participation in Environmental Research* (pp. 179–190). Cornell University Press.
Trochim, W. M. K., and Donnelly, J. P. (2008). *Research Methods Knowledge Base*. Atomic Dog/Cengage Learning.
Trumbull, D. J., Bonney, R., Bascom, D., and Cabral, A. (2000). Thinking scientifically during participation in a citizen-science project. *Science Education*, *84*(2), 265–275. https://doi.org/10.1002/(SICI)1098-237X(200003)84:2<265::AID-SCE7>3.0.CO;2-5.
Trumbull, D. J., Bonney, R., and Grudens-Schuck, N. (2005). Developing materials to promote inquiry: Lessons learned. *Science Education*, *89*(6), 879–900. https://doi.org/10.1002/sce.20081
van Teijlingen, E., and Hundley, V. (2001). The importance of pilot studies. Social Research Update, 35.
Villacorta, M., Koestner, R., and Lekes, N. (2003). Further Validation of the Motivation Toward the Environment Scale. *Environment and Behavior*, *35*(4), 486–505. https://doi.org/10.1177/0013916503035004003
Wenger, E. (1998). *Communities of Practice: Learning, Meaning, and Identity*. Cambridge University Press.
Wiggins, A., and Crowston, K. (2011). From Conservation to Crowdsourcing: A Typology of Citizen Science. In *2011 44th Hawaii International Conference on System Sciences (HICSS)* (pp. 1–10). https://doi.org/10.1109/HICSS.2011.207

CHAPTER V

CONCLUSION

STUDY OVERVIEW

This dissertation is the culmination of work, largely funded by the National Science Foundation, to critically examine the relationship between engagement in citizen science and science learning outcomes. The research used a mixed-methods comparative case study design to understand the intersection of engagement and learning in six environmentally-based citizen science projects. However, the nascent nature of the phenomenon required first identification of relevant learning theories to citizen science (Chapter 1) and articulation of common learning outcomes in citizen science (Chapter 2). Next, a qualitative analysis of the dimensions of engagement provided a robust framework for defining engagement in citizen science (Chapter 3). With learning and engagement sufficiently defined, Chapter 4 allowed for hypothesis testing and a quantitative examination of the relationships between these overarching constructs. This final chapter begins with a summary of the findings from the previous chapters and a summary of triangulated findings across the chapters. Significance of the work is discussed. Next, limitations of the study are addressed. Lastly, recommendations for future research and theoretical and practical implications are presented.

SUMMARY OF FINDINGS

Chapter 1 – Introduction

This first chapter provided background information on citizen science, including its explosive growth over the last few decades and the various ways it has been studied. Next, it sought to situate learning in citizen science within theories of learning that had the greatest alignment. In particular, socio-cultural theories of learning such Activity Theory, Experiential Education, Situated Learning, and Communities of Practice were called out as being useful in understanding *how* learning happens in citizen science and the mechanisms and processes that enable active learning, particularly when developing project activities and experiences. Situated Learning and Communities of Practice are used to frame the bulk of the current research. The chapter concludes with an iteration of the problem statement, identification of research questions, and a rationale for the significance of the study.

Chapter 2 - Articulating and Evaluating Individual Learning Outcomes from Citizen Science: A Conceptual Model

Chapter 2 had three main goals: first, to apply a framework for evaluating learning in informal contexts to citizen science; second, to describe the state of evaluation in citizen science; and third, to provide a conceptual model to support citizen science practitioners in articulating individual learning outcomes from their projects. Additionally, this chapter advocated for the use of program theory to carefully articulate a project's underlying assumptions about how project activities affect expected outcomes.

To test the applicability of learning frameworks developed for Informal Science Education (ISE) to citizen science, a comprehensive review of project websites was conducted to gather data on expected outcomes. An online practitioner survey was also conducted to measure observed or reported outcomes. Together, these two datasets confirm the general applicability of the ISE frameworks, albeit with modifications and contextualization to citizen science. The survey results also confirmed the value of evaluation in citizen science but a largely deficient capacity *for* evaluation in citizen science.

Comparing results from the website review and practitioner survey highlighted interesting tensions that exist within citizen science. For example, there is an overemphasis on measuring interest in science despite the fact that most participants are already positively predisposed to science and the environment. Also, many projects spend a lot of evaluation effort measuring science *content* gains through context-specific instruments, and typically at the expense of other more complex forms of understanding such as knowledge about the process or Nature of Science. The most prominent tension elucidated from comparing the two data sets is the tradeoff between the need to improve data collection skills, and the relative lack of measurement or evaluation of such skills. This was particularly true and perhaps most critical for contributory projects, which often seek to publish findings from volunteer-collected data in peer-reviewed journals. Finally, the online survey revealed that while a third of practitioners attempted to measure behavior change, the things that they regarded as behavior change included awareness and appreciation of the environment, and engaging in the project itself. These data suggest a need to better define and clarify what is meant by this term and to more thoughtfully link intended behavior changes to project-specific activities.

The conceptual model for articulating and evaluating individual learning outcomes presented in Chapter 1 was based largely on application of the NSF Framework (Friedman et al. 2008), the LSIE strands (National research Council 2009) and the findings from the website review and online practitioner survey. The fleshing out of the conceptual model to define the constructs and apply them to citizen science was conducted via an extensive literature review across multiple disciplines. The framework consists of the following constructs: Interest in science and the environment; Efficacy for science and the environment; Motivation for science and the environment; Knowledge of the Nature of Science, concepts, and process; Skills of science inquiry;

and Environmental Stewardship. Together, these constructs serve as an important, although not exhaustive, set of learning outcomes that are common across the field of citizen science.

Collectively, the findings from Chapter 1 provide much needed insight regarding the ways in which learning has been articulated, studied, and measured in citizen science, as well as the role of evaluation in general. Importantly, the chapter highlights ways in which constructs within the conceptual model have been applied and can be operationalized in the future.

Chapter 3 - A Qualitative Analysis on The Dimensions of Engagement in Citizen Science

To date, few studies have attempted to comprehensively characterize and operationalize engagement across multiple field-based projects and from the perspective of the participants themselves. Chapter 3 builds on pertinent literature from educational research, human computer interaction, and volunteer engagement to operationalize engagement in citizen science through analysis of interviews of 72 participants from six different environmentally-based projects. The six projects span the contributory to collaborative to co-created continuum and include NestWatch (NW), Monarch Larva Monitoring Project (MLMP), Community Collaborative, Rain Hail, and Snow (CoCoRaHS), Hudson River Estuary Project (EELS), Alliance for Aquatic Resource Monitoring (ALLARM), and Global Community Monitor (GCM). The chapter had three main goals. First, to characterize engagement in citizen science using cognitive, affective, social, behavioral, and motivational dimensions that are described mostly outside of citizen science. Second to examine motivations and barriers to participation. And third, to develop a tool to quantify social and scientific practices as part of behavioral engagement.

The cognitive dimension was examined in terms of sources of learning and what kind of learning occurred. Not surprisingly, most interviewees described experiential learning as a main component of their engagement. Participants also brought in a great deal of pre-existing knowledge into the projects, and relied extensively on prior knowledge, external sources of knowledge and project-related materials and training. The vast majority of participants did not rely on in-person or online interactions as a main source of learning. As has been described elsewhere, citizen science is a natural conduit to learning new content-specific knowledge and increasing awareness of ecological principles and connections. Many participants also described an acute understanding of their role in citizen science, and in some cases to science writ large.

Examining affective dimensions of engagement highlighted how committed participants are to the project, their local environment, the sites they monitor, and to data quality. Participants described positive and negative emotions throughout their lived experiences including interest, excitement, surprise, efficacy, and uncertainty. The overwhelming emotion across all projects however, was extremely positive.

Social relationships, particularly with project leaders, were seen as important sources of learning, and were critical for sustaining and enhancing engagement. These relationships fostered mutual respect and made participants feel valued and part of the scientific community. Another surprising finding was the number of participants that described an expanding role in the project beyond data collection, such as volunteering to take notes at a meeting or compiling data or training new participants.

Identified in the behavioral dimension were the activities that participants actually do on behalf of the project. Within each project, interviewees described a multitude of tasks ranging from data collection to communicating with others about the project, to using data to back scientific claims. Here again, there was a great deal of discussion about the ways in which interviewees communicated about the project or its findings to others, reiterating the social nature of engagement. Co-created projects did have slightly more people describing more science process activities, but the contributory projects had all of those same activities represented, just not as often. Across projects, there were very few examples of participants engaged in "higher order" scientific practices such as formulating hypotheses or designing their own studies, but interviewees provided rich and detailed examples of how they used data, which was very different between the projects, but personally relevant and meaningful to all of them.

Examining motivations to and barriers for engagement revealed some interesting trends. With respect to barriers, aside from time (which was universally the most common barrier), each of the project interviewees reported barriers that appeared specific to the project itself. Barriers included issues with technology, accessibility to monitoring sites, weather, travel logistics, data transparency, and cost. Similar to previous research, motivation to participate is complex and multi-faceted, but across projects, was mostly driven by environmental concern, contribution, and interest. One notable trend was the prevalence of extrinsically-leaning motivations among co-created projects, versus intrinsically-leaning motivations in contributory projects. Although further testing is needed to fully understand the role of motivation in engagement, data from these interviews suggests that motivation is a key facet of engagement, and likely influential to all the other dimensions.

The detailed analyses on the behavioral dimension of engagement from the qualitative interviews resulted in the development of an empirically grounded and easy to use metric to quantify and measure scientific practices. The Participant Engagement Metric (PEM), is a frequency based 12-item scale, developed with input from participants and project leaders and tested with a larger audience, described in Chapter 4 of this dissertation.

While building on existing literature, Chapter 3 concluded with a new framework derived from the full set of qualitative data, that attempts to operationalize citizen science engagement. The Dimensions of Engagement framework summarizes the emotional, social, cognitive, behavioral and motivational aspect of engagement and will hopefully facilitate the innovation of new methodologies for studying citizen science.

Chapter 4 - Quantitative Examination of Engagement and Learning in Citizen Science

The final research chapter utilized quantitative data to empirically examine the linkages between selected learning outcomes as articulated in Chapter 2, with engagement dimensions as described in Chapter 3. Data were collected from participants of the six different projects mentioned above, via an online survey administered in mid-2016. The overarching goal for this chapter was to generalize some of the earlier qualitative findings about dimensions of engagement to a larger audience, conducted in four parts. First, to provide descriptive analyses of the six different projects (RQ1) and second to test the stated hypotheses about engagement, motivation, and learning. Third, to apply several of the constructs and instruments from the DEVISE initiative that were created for and validated in citizen science contexts. Fourth, to test another instrument called the Participant Engagement Metric (PEM), a newly developed scale that measures the behavioral aspects of engaging in scientific and social practices related to citizen science.

Roughly 1,500 responses were collected via an online survey, which provided a wealth of data for examining the relationships between engagement and learning across different units of analysis: aggregated across the entire data set, by the six projects, by three project types (contributory, collaborative, or co-created) and by project structure (individual vs. group-based). Regardless of project, participants reported a high level of interest in the project and intention to remain in their respective project. Experiential experiences provided the most common source of learning for all but one project. In general, respondents felt very connected to the sites they monitor and their local environment, less so to the project and its organizers and even less to other participants. Clear differences were noted with respect to motivations among projects. Whereas all projects had relatively high intrinsic motivations, the co-created projects also had fairly high extrinsic motivations related to worry or concern over the environment or their local community.

Behavioral engagement in the scientific process was quantified via the PEM and compared across projects, project types, and project structures. Results revealed that increasing duration in years was linked to an increased PEM, suggesting that over time participants increase their engagement. Social activities were also measured and found to be positively associated with PEM scores. These findings underscore the need for all projects to provide and support meaningful outlets for peer-to-peer, participant-to-scientist, and participant-to-public forms of communication. Although the PEM consists of 12 activities, the vast majority of participants engage primarily in just three: data gathering, data submission, and communicating about the project with others. Three dependent variables representing learning outcomes were examined: self-efficacy (for learning science and doing citizen science), skills of science inquiry, and environmental stewardship. Across the projects, increasing PEM scores had moderately strong positive associations with skills of science inquiry, and weak but positive association with self-efficacy and environmental stewardship. This finding lends support to the hypothesis that engaging in more aspects of the scientific process is related to increased learning outcomes, although the strength of the relationships varies depending on the outcome.

Examining the data through the project type unit of analysis, reveals that the PEM score and number of PEM activities do increase from contributory to co-created projects. Difference in the kinds of activities typical of certain project types were noted. For instance, participants in contributory (NestWatch and Monarch Larva Monitoring Project) and collaborative projects (CoCoRaHS and Hudson River EELS project) were more likely to explore data online than co-created projects (Alliance for Aquatic Resource Monitoring (ALLARM), and Global Community Monitor (GCM). This latter finding may reflect the sophisticated nature of databases supported by larger-scale projects. Participants in co-created projects however, engaged in a higher number of PEM activities and were more likely to use data and share project findings (rather than simply communicate *about* the project) than participants in other project types. This lends partial support to the hypothesis that co-created projects facilitate and support more facets of the scientific process.

This study provided mixed support for the hypothesis put forth by Bonney et al. (2009a), i.e., that co-created projects result in deeper learning outcomes than collaborative or contributory projects. With the exception of GCM, which had too small a sample size, the PEM had a positive and statistically significant relationship with skills of science inquiry, regardless of project, project type, and project structure. The collaborative projects (CoCoRaHS and EELS) also showed positive associations between the PEM and the full efficacy measure and efficacy for citizen science but a weaker correlation with science efficacy in general. Surprisingly, only one project, MLMP had a statistically significant positive relationship with environmental stewardship, likely due to the fact that stewardship activities are very much tied to MLMP project activities. A key take away from this question is that projects can and do achieve a variety of learning outcomes, but content and context matter. Further, attention to relevancy and alignment of outcomes with project activities is necessary.

Finally, a quantitative examination of motivation showed it to have moderately strong associations with all the learning outcomes, including general science efficacy. Extrinsic motivation, on the other hand, had a weak but negative association with all forms of efficacy. Together, these data provide strong support for the central role that intrinsic motivation has in self-selected informal learning environments.

TRIANGULATION OF FINDINGS

A major strength of case study methodologies is the ability to triangulate findings from multiple data sources. This study was afforded the rich qualitative descriptions from 72 participants belonging to six different citizen science projects, as well as 1,500 survey responses from participants in those same projects. The online participant survey was developed largely based on the qualitative findings in an effort to generalize the qualitative findings more broadly. Additionally, this research included survey responses from nearly 200 citizen science practitioners, feedback and interviews with the six project leaders, and a review of more than 300 citizen science project websites. This data set is rich, voluminous and diverse, but also surprisingly convergent.

One striking point of convergence between the qualitative and quantitative participant data set was the trend toward extrinsic motivation in co-created projects. Additionally, motivation was interpreted as having a central role in engagement in the qualitative data and strongly associated with engagement and learning in the quantitative data. Another point of convergence centered around the sources of learning, especially experiential learning, prior knowledge, and project materials. The quantification of the project activities from the interviews showed the same three activities in common with the quantitative survey (namely data collection, data submission, and communicating with others about the project). Also, data from both the qualitative and quantitative data show surprisingly few examples of participants engaged in "higher order" scientific practices such as formulating hypotheses or designing their own studies as described in Bonney et al. (2009a). Self-efficacy, confidence, or agency were often discussed in the interviews and in the quantitative survey efficacy mean scores were relatively high, although they were not strongly correlated with PEM scores.

There were also some notable divergences in the datasets. For instance, Research Question 1 highlighted the disconnect between intended outcomes related to skills and the dearth of projects that actually measure skill acquisition. During the participant interviews, the importance of the social aspects of the projects was called out repeatedly; in the quantitative survey however, social interactions were not considered an important learning source. Moreover, most participants reported little, if any, in-person or online interactions with others in the quantitative data. This latter discrepancy may point to issues with the online instrument or the relative strength of interviews as a better methodology for this type of descriptive information.

SIGNIFICANCE OF THE STUDY

To date, few if any studies have conducted cross-programmatic analysis of learning outcomes in environmentally-based projects using similar measures. With the exponential growth of citizen science in the last decade, funders, stakeholders, and program developers are looking for evidence-based findings. To that end, this work shows the complexity and multi-dimensionality of engagement and suggests doing away with simplistic characterizations of citizen science engagement as "just data collection," which ignores other important facets such as affective, cognitive, social, and motivational dimensions. While the research lends support to the hypothesis that participants in co-created projects tend to engage in more aspects of the scientific process, the majority of citizen scientists engage in just three main project activities: engaging in data collection, data submission, and sharing information with others. This is not necessarily a negative finding, but it does require the elimination of "broad brush" statements about the potential for citizen science to democratize science for example. Such statements are meaningless without attention to content and context that describe under what conditions these outcomes might be achieved.

This research also revealed that the more engaged in project activities an individual is, the more likely they will have enhanced perceptions of science inquiry skills. Essentially, the more practice one gets, the better they feel they are able to conduct the task. While this seems obvious, to date, social and scientific practices in citizen science had not been empirically measured. This work also rejects an often-touted hypothesis that participants in co-created projects tend to achieve deeper learning outcomes with findings that show learning outcomes were possible across all project types. Lastly, the research illustrated the strong influence that intrinsic motivation may have on both engagement and learning.

These findings would not have been possible without the ability to use existing generic, yet customizable, scales that are considered valid and reliable for measuring common learning outcomes in citizen science contexts (see DEVISE: http://www.birds.cornell.edu/citscitoolkit/evaluation/instruments). Such measures allow for cross-programmatic analysis to answer basic yet foundational questions about the nature of learning and engagement in citizen science.

LIMITATIONS

One of the most important factors when designing studies or developing instruments is to determine validity, or the degree to which interventions and measured variables actually represent what they claim to measure (Shadish et al. 2002). Because this work did not use experimental design using random assignment and control groups, there are potentially many threats to internal validity. However, given the nature of the research questions, the complex and interrelated aspects of the phenomenon in question and the multiple variables included, a mixed method, case study was the most appropriate choice. Nevertheless, threats to internal validity undermine our confidence in making claims about the nature of a relationship. Below, are some of the threats to internal validity that are possible in the current study.

In the case of this research, it is difficult to completely know which variable is the independent and which is the dependent. This is called “Ambiguous temporal precedence” and is a serious threat to internal validity because it is unclear what variable affects another. As such, this research cannot make claims about cause and effect. Instead, the research relies on correlations to determine associations between variables (e.g., PEM and learning outcomes). Another threat to internal validity for this study is selection bias, which refers to groups not being equivalent at the start of the study or not having an equal probability of being selected. As in most informal science education settings, selection bias is a concern. While each of the participants within the six projects had the same opportunity to take the survey, quota sampling allowed for self-selection, which can be problematic for selection bias. These individuals may not be accurately representative of the actual population, because for example, they could overly represent “super participants.” In the qualitative study, selection bias was minimized by using maximum variation sampling to include a wide range of engagement levels (low, medium, high).

Case study designs are also at risk of history and maturation effects. History threats occur when an unanticipated even occurs during treatment or participation. The fact that GCM stopped operating during the study caused the sample size for this project to be very small. Maturation effects are naturally occurring changes that may confound dependent variables. For example, efficacy and skills may increase over time, without necessarily being effected by other variables. However, the association with time was examined and only found to be moderately correlated with PEM. Mortality or attrition, is also a threat to internal validity and occurs when cases or groups are lost over time, as was the case with GCM.

Other limitations that threaten internal validity related to specific methodologies within the chapters also exist. For example, in Chapter 2, online survey respondents disproportionately represented contributory projects and no additional effort was made to include more collaborative and co-created projects in the survey, thus response bias may be an issue. Also, the practitioner survey was based on self-reports, which could increase social desirability bias, whereby respondents answer in the ways that appear favorable and threaten internal validity. In Chapter 3, the main limitations center around its qualitative focus, which is highly subjective and can threaten internal validity, mainly because of researcher bias, this was discussed in detail in the limitations section within the chapter. Lastly, in Chapter 4, a major limitation was the very small sample size for GCM making it difficult to generalize the findings about co-created projects more broadly, and threatening both internal and external validity. Measurement error through data collection procedures and/or instruments with low validity or reliability, or floor or ceiling effects, also can pose serious threats to internal validity. Finally, each of these threats could influence the statistical validity of the work, which relies on the use of appropriate sampling, reliable measurements, and suitable statistical tests.

There are other threats to validity to also consider including: conclusion, construct, and external validity. Conclusion validity has to do with the validity of relationships between treatments and outcomes, particular in terms of the strength of a relationship (Shadish, et al., 2002). Lack of statistical conclusion validity can lead to Type I errors where covariation is inferred when it does not actually exist or Type II errors when a true covariation relationship exists that is not detected. Common threats include low statistical power to detect relationships, small sample sizes, and measurement error. The lack of statistical conclusion validity presents a serious concern because it is not possible to rule out other reasons for observed covariation in relationships. However, in the present study, the large sample size and emphasis on describing the nature of the relationships between variables, as opposed to describing causal inferences of treatment to outcomes, should minimize threats to statistical conclusion validity.

Construct validity is perhaps the most challenging type of validity because it relies on the translation of abstract concepts into variables that accurately measure the construct in question. According to Shadish et al. (2002) to achieve construct validity, it is critical to establish a theoretical framework that clearly defines the construct; to select examples that might predict behavior of those constructs; and to assess the observed versus expected outcomes. The study design for achieving construct validity included a review of the literature to define numerous constructs, experts review and feedback to establish face and content validity of instruments; and several statistical analyses to test for convergence, discriminant, and concurrent validity. Each of these

External validity is a measure of generalizability so that findings from the case study can be generalized to other settings, people, and times. Since this was not using a random assignment, external validity threats may be heightened. Trochim (2006) suggests that the best way to increase external validity is to replicate the study across a variety of settings and audiences. In this study, the use of six different projects operating in various conditions and contexts, helps to improve external validity.

IMPLICATIONS AND FUTURE WORK

Practical Implications

This work has both practical and theoretical implications. On the practical side, this work includes the development of a conceptual model for articulating and evaluating citizen science learning outcomes. The conceptual model described in Chapter 2 should afford practitioners with a theoretical and empirical starting point for measuring individual learning outcomes and for considering how their program theory aligns to intended outcomes. In Chapter 2, the Dimensions of Engagement (DoE) framework was developed as a way to operationalize engagement across multiple domains including cognitive, social, behavioral, affective, and motivational. Beyond providing much needed definitional support to the term engagement, the DoE framework helps to move away from simple characterizations of engagement as just "data collection" and be more reflective of the many complex and dynamic aspects of engaging in citizen science.

The Participant Engagement Metric (PEM) informed by qualitative data and tested quantitatively, can be used across the field of citizen science to quantify scientific and social practices within citizen science. The PEM serves to more accurately measure behavioral engagement using a simple index that provides a numeric summation of 12 different scientific and social practices. This work also relied heavily on the use of common measures to conduct cross-programmatic research. Practically speaking, common measures that are valid, reliable, and readily available should be leveraged and used by the field to the extent possible to continue to provide evidence of impact.

Taken together the practical aspects of this dissertation also have several design implications for the field of citizen science. First, project developers should consider the role of evaluation and measurement of outcomes as projects are being designed, not as an afterthought. Goal setting in advance will go a long way towards developing a project that is geared toward achieving and measuring intended learning outcomes. Additionally, designing for specific forms of learning is imperative. To date, most projects operate under the assumption that learning is a natural by-product of engagement. While this is often true for learning related to content knowledge, it is not the case for higher order learning skills such as using statistics to interpret information or critically evaluating evidence. To achieve these types of outcomes requires sophisticated instructional supports that are sometimes at odds with informal settings and may even minimize the "fun factor" for participants. K-12 environments may actually serve as a better setting for this form of deeper learning because of the routine and structured exposure to these concepts (Bonney et al. 2016). Therefore, before taking on the time and resource intensive task of designing for higher order skills, a solid understanding of audiences' pre-existing knowledge and their motivations to participate in such endeavors is necessary.

Second, project developers should consider all of the dimensions of engagement and develop activities that provide various levels of support for them. For example, the social aspect of citizen science, even individual-based projects cannot be overstated.

Providing tools that allow participants to easily communicate with each other or share their experiences with others, including the media and decision makers, is critical. Also, being aware of how feelings and emotions influence engagement is in its infancy, but project leaders can begin by understanding how participants positive and negative emotions influence decisions to stay or leave a project. This in turn, could help inform design of projects activities. Additionally, providing diverse ways to engage so that participants can take on expanding roles, if desired, is another design element that helps to build community internally and maintain retention in projects. Project leaders should also be aware however, that many participants aren't looking to become an expert or a scientist or to expand their role in anyway, so providing a base level of engagement that is valued in its own right, is essential.

Another implication for design coming from this work involves leveraging strengths of different project structures. For instance, this work supported the hypothesis that participants in co-created projects tended to engage in more aspects of the science process than contributory or collaborative projects largely through the provisioning of in-person training and supports. If contributory projects are interested in engaging participants more deeply, they might consider what additional forms of training are needed, for example, to use data to make scientific claims. Conversely, this work also revealed that engaging in more aspects of the science process does not necessarily relate to deeper learning outcomes. One explanation is that participants arrive at contributory projects with mostly intrinsic motivations, which studies have shown lead to greater persistence in behavior. Participants in co-created projects on the other hand, have much more extrinsic motivations than contributory projects, and research shows extrinsic motivations are typically not sustainable for long periods of time. Therefore, co-created projects could be designed such that intrinsic motivations are continually nurtured by making project experiences as interesting and rewarding as possible, for example, by creating spaces for casual social gatherings.

Future efforts should build professional development opportunities for citizen science practitioners to spearhead evaluations of projects, which can also be shared as a resource with others. Over time, a steady source of knowledge about impacts will lead to improved project design, implementation, and sustainability for the field as a whole.

Theoretical Implications

This dissertation has several theoretical implications for the field of citizen science. First, this is one of a few studies that attempts to use learning theory to research learning in citizen science. One obvious finding is that socio-cultural theories of learning such as Situated Learning Theory (SLT), (Lave and Wenger 1991) and Experiential Learning (Kolb 1984) provide a relevant lens for this type of research. SLT for example, highlights the process of co-participation in knowledge production, tool use, practice, and the embedded nature of learning to make meaning. Through repeated practice, social relationships, and shared resources, participants acquire skills to engage fully in the process, which over time, can move an individual from being a peripheral member to one that is more centrally involved. This work revealed that practice, defined via the PEM, is positively associated with learning, but that these relationships vary according to context, content, and community. Although this study did not look at how practice changes over time to affect engagement, using the lens of SLT for such a study would be wholly appropriate because of the ease with which content, context, community, and participation can be studied.

The hands-on nature of citizen science provides many opportunities to study experiential learning or how people 'learn by doing' in everyday contexts.

Triangulation of data in this work demonstrated that experiential learning is the most common way that people learn about the topic and how to successfully participate in the project. Is this learning transferable to other contexts? A deeper theoretical examination of experiential learning could be designed according to Kolb's (1984) initial ideas and focus on the role of concrete experiences, reflective observation, abstract conceptualizations, and active experimentation or application of learning to new experiences.

Other theoretical implications of this work include empirically based evidence about the nature of engagement in citizen science. To date, there are few well-developed theories of engagement for informal settings; the few that exist are found in K-12 and organizational labor studies. The Dimensions of Engagement framework provides a first step toward a theory of engagement for citizen science that should continue to be tested. Such testing will advance scholarly work in the area of engagement and provide fertile ground for future research agendas in informal learning environments.

The use of Self-Determination Theory, while not novel for citizen science, proved a very useful perspective for distinguishing between motivations of different types of projects and the potential influence on learning. Continued use of SDT to examine motivations as it relates to learning would be a fruitful pursuit for the field. This work also brings into question the usefulness of the Contributory-Collaborative-Co-created typology first described by Bonney et al. (2009a). While this typology was able to differentiate common practices and motivations between contributory and co-created projects, it was less accurate at predicting how these project types relate to learning. One reason for this may be due to the "hybrid" nature of collaborative projects, which sometimes operate more like contributory projects and sometimes more like co-created projects, making them difficult to accurately categorize. Another reason may be that as projects evolve, they become more diverse and offer a wide range of experiences that don't fit neatly into a single category. Further, this study revealed that deep learning is possible in any project regardless of the overall structure and that individual motivations and practice may be the most important aspects of engagement as they relate to learning. Future work could continue to test this hypothesis using a pre-post experimental design that accounts for participants pre-existing knowledge.

Although this study did not consider deeply the cognitive aspects of engagement, future work should consider how we can better study the more complex facets of science inquiry (i.e., critical thinking, reflection, and reasoning) that likely happens but are difficult to design for, capture, and measure. Learning theories that are based in the cognitive sciences may be helpful here. Also, initiation of more in-depth longitudinal studies that can measure persistence or change over time would add much needed understanding of the impacts of such experiences. The development of robust and contextually appropriate tools that can be used across studies, but that don't necessarily rely on self-reports are also needed.

Finally, this research hopes to engender new research questions, agendas, and methodologies for continued study of this vibrant and growing field. As citizen science continues to grow, however, it will be important for the field to critically evaluate itself and avoid making claims that are not born out by evidence. This study failed to provide evidence that citizen scientists are engaged in all aspects of the science process, even in co-created projects. A few participants do a lot, but the vast majority are engaging at a very peripheral level of data collection, submission, and sharing information. These findings are positive in their own right! To make broad, sweeping claims however about the revolutionary potential of citizen science to democratize science should be qualified, if not avoided. Certainly, from this study's rich interview data, there are several examples showing how citizen science can aid in the democratization of science. For instance, the woman who changed majors from environmental science to science communication so that she could communicate the effects of fracking directly to her community. Or the community that has been repeatedly ignored by local and state agencies about the air pollution until they had a voice at the table through the data they collected. Or the woman that has no children but has decided to train others in the project in order to leave her legacy to science. Such examples are powerful outcomes of the potential to democratize science that didn't fit neatly into learning frameworks and were difficult to capture quantitatively. Also, these examples likely represent the exception, not the rule and occur because of certain conditions and contexts, which need explanation and qualification. Additional research to gather field-wide evidence for claims of democratization of science is warranted. Until then, to maintain legitimacy and not create unrealistic expectations, let's avoid portraying citizen science as the answer to the shortcomings of the scientific enterprise, and instead, appreciate it for all its other notable benefits to science and society.

REFERENCES

Bonney, R., Phillips, T. B., Ballard, H. L., and Enck, J. W. (2016). Can citizen science enhance public understanding of science? *Public Understanding of Science*, *25*(1), 2–16. https://doi.org/10.1177/0963662515607406.

Bonney, R., Ballard, H., Jordan, R., McCallie, E., Phillips, T., Shirk, J., and Wilderman, C. C. (2009a). Public participation in scientific research: defining the field and assessing its potential for informal science education. *A CAISE Inquiry Group Report*. Washington, DC: Center for Advancement of Informal Science Education (CAISE). Retrieved from http://eric.ed.gov/?id=ED519688.

Friedman, A. J., Allen, S., Campbell, P. B., Dierking, L. D., Flagg, B. N., Garibay, C., … Ucko, D. A. (2008). *Framework for Evaluating Impacts of Informal Science Education Projects, InformalScience.org*. National Science Foundation Workshop. Retrieved from http://www.informalscience.org/framework-evaluating-impacts-informal-science-education-projects.

Goldstone, R. L., Landy, D. and Son, J. Y. (2008). A well grounded education: the role of perception in science and mathematics. In M. de Vega, A. Glenberg, & A. Graesser (Eds.), *Symbols, embodiment and meaning* (pp. 327-355). New York: Oxford University Press.

National Research Council. (2009). *Learning Science in Informal Environments: People, Places, and Pursuits*. Washington DC: The National Academies Press.

Shadish, W. R., Cook, T. D., and Campbell, D. T. (2002). *Experimental and Quasi-Experimental Designs for Generalized Causal Inference*. Boston: Houghton Mifflin Company.

Trochim, W. K. (2006). Research Methods Knowledge Base. [Online]: http://www.socialresearchmethods.net/kb/intreval.php. Accessed September 4, 2010.

APPENDICES

APPENDIX A

DATABASES AND SEARCH TERMS USED TO LOCATE CITIZEN SCIENCE WEBSITES.

NAME OF DATABASE / SEARCH ENGINE	URL and search terms
CITIZEN-SCIENCE.ORG	http://citizen-science.org
CITSCI.ORG	http://www.citsci.org/
INFORMALSCIENCE	http://informalscience.org/project/search/all
CITIZEN SCIENCE CENTRAL	http://www.birds.cornell.edu/citscitoolkit/projects
SCISTARTER- SCIENCE WE CAN DO TOGETHER.	http://scistarter.com/finder?activity=andtopic=andphrase=andaddress=
CITIZEN SCIENCE ALLIANCE	http://www.citizensciencealliance.org/projects.html
ASTRONOMY/SPACE SCIENCES CITIZEN SCIENCE PROJECTS	http://buhlplanetarium2.tripod.com/FAQ/citizenscience.html#astro
MEERA- MY ENVIRONMENTAL EDUCATION EVALUATION RESOURCE ASSISTANT	http://meera.snre.umich.edu/
CITIZEN-BASED MONITORING NETWORK OF WISCONSIN	http://wiatri.net/cbm/partnership/abstracts08.cfm
NATIONAL DIRECTORY OF VOLUNTEER MONITORING PROGRAMS	http://yosemite.epa.gov/water/volmon.nsf/VPT!OpenViewandExpandView. 871 projects listed. Every 5th project was checked for a website with information.
SCIENTIFIC AMERICAN CS DATABASE	http://www.scientificamerican.com/citizen-science/
NSF	http://www.nsf.gov/awardsearch/. Used the following search terms: citizen science, public participation science, collaborative science, informal science.
GOOGLE	www.google.com. Searched database using following search terms: "citizen science project", "citizen science database", "citizen science program", "citizen science", citizen science projects", "informal science project", "informal science programs", "informal science database", "public participation science", "public participation science program", "public participation science project." *Usually just the first 10-20 hits were followed on each of these searches.*

APPENDIX B: PRACTITIONER SURVEY

Welcome!

Thank you for volunteering a few minutes of your time to offer feedback about evaluation of Citizen Science projects. The Cornell Lab of Ornithology is administering this survey to gather information that will improve the design and implementation of Citizen Science evaluations.

The survey has two major goals: 1) to determine the types of assistance/support needed by practitioners for conducting quality evaluations and 2) to document the strategies and instruments or measures that have been used in Citizen Science project evaluations.

(Please note: Projects that involve the public in research go by many different names. In this survey we use the term "Citizen Science" to refer to any project that involves the public as collaborators in scientific research.)

The survey should take about 10-15 minutes to complete. All responses are confidential, and you are welcome to exit the survey at any time. A few required questions (mostly to enable survey logic) are marked with an asterisk.

If you need to leave the survey before completing it, no problem — when you return you'll be taken to the place where you left off.

Evaluation of Citizen Science/PPSR Projects

Project background

*How would you describe the structure of the Citizen Science project that you work on? (If you work on more than one project, please answer all questions for the project that you are most closely associated with.)

- ○ Contributory (Participants are asked by scientists to collect and contribute data and/or samples)
- ○ Collaborative (Participants assist scientists in developing a study and collecting and analyzing data for shared research goals)
- ○ Co-Created (Participants develop a study and work with input from scientists to address a question of interest or an issue of concern)
- ○ Other (Please specify below)

Other:

About how many years has your project been operating?

- ○ It's just getting started
- ○ From 1 – 5
- ○ From 6 - 10
- ○ 11 or more
- ○ I don't know

On average, approximately how many people participate in your project each year?

- ○ Fewer than 100
- ○ 101 - 500
- ○ 501 - 1000
- ○ 1001 - 5000
- ○ More than 5000

How would you describe the kind of training received by the MAJORITY of your participants?

- ◯ Participants receive instructions online or in print and no other training is required
- ◯ Voluntary training through “in-person” workshops/seminars
- ◯ Mandatory online tutorials prior to participation
- ◯ Mandatory training thorough “in-person” workshops/seminars
- ◯ Mandatory multi-day training or certification course
- ◯ Other (please specify below)

Other:

(Optional but helpful!) Please provide the name and a brief description of the project that you are most closely associated with.

*To the best of your knowledge, has ANY type of evaluation been conducted on your citizen science project within the last 10 years? (This could include any effort to gather data about your project participants and their needs, information about whether the project is working well, or evidence about project impacts, either educational or scientific.)

- ◯ Yes, definitely
- ◯ Yes, I think so
- ◯ No, I don’t think so
- ◯ No, definitely not
- ◯ I don’t know

Evaluation of Citizen Science / PPSR Projects

Projects with evaluations

For the most recent evaluation of the project that you are most closely associated with, did you…

- ◯ Hire an external evaluator
- ◯ Conduct the evaluation using internal personnel
- ◯ Use a mix of external and internal personnel
- ◯ I don't know

To the best of your knowledge, what type of evaluation was conducted during your most recent project evaluation? (Please check all that apply.)

- ☐ Front-end (to conduct needs assessment or obtain baseline information about audience)
- ☐ Formative or Process (during project development to inform project implementation)
- ☐ Summative (to describe project outcomes or impacts)
- ☐ I don't know

Comments about this question?

[ ]

Briefly describe the main reason for conducting the evaluation and what you were hoping to measure.

Main Reason for evaluation: [ ]

What did you measure? [ ]

Projects with evaluations - continued

For the most recent evaluation of the project, which broad categories of learning outcomes, if any, were evaluated? (Please check all that apply.)

- ☐ Knowledge of science content, process, careers, and/or environment
- ☐ Engagement and/or interest in science content, process, careers, and/or environment
- ☐ Science inquiry skills (asking questions, designing studies, data collection and analysis, using technology)
- ☐ Attitudes toward science content, process, careers, and/or environment
- ☐ Behavior changes resulting from participation
- ☐ Did not measure learning outcomes

Other (please specify below)

What other aspects of your project, if any, were evaluated? (Please check all that apply.)

- ☐ Effectiveness of workshops and training sessions
- ☐ Motivation to participate
- ☐ Overall participant satisfaction/enjoyment with project
- ☐ Scientific/conservation outcomes, adaptive management
- ☐ Community capacity building
- ☐ Summation of project outputs (numbers of participants, web hits, journal articles, data submitted, etc)
- ☐ Evaluation of data quality
- ☐ Social policy change

Other (please specify below)

To the best of your knowledge, what types of data were collected during the most recent evaluation? (Please check all that apply.)

- ☐ Survey data
- ☐ Scores from tests or quizzes
- ☐ Interview data
- ☐ Data from focus groups
- ☐ Observational data
- ☐ Data from diaries/journals
- ☐ Data from existing database(s)
- ☐ Portfolio data

Other (please specify below)

For the most recent evaluation, what design features were used? (Please check all that apply.)

- ☐ Pre-test only
- ☐ Post-test only
- ☐ Pre- and post-test
- ☐ Control or comparison groups
- ☐ Random assignment groups
- ☐ I don’t know

Other (please specify below)

Please do your best to provide the name or description of any instruments (e.g., Views on Science and Technology to collect evaluation data (even if you developed the instrument). If possible, provide the source for all evaluation instruments used. This information is very important - if you need to look this up you can leave the survey by clicking "exit survey” in the upper right corner, and when you return, you'll come back to this question.

Evaluation of Citizen Science/PPSR Projects

Evaluation effectiveness

How much do you agree or disagree with the following statements regarding the most recent evaluation of your project?

	Strongly Agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree	N/A
The evaluation was of high quality	○	○	○	○	○	○
Findings from the evaluation were informative to the project managers/developers	○	○	○	○	○	○
Recommendations from the evaluation were implemented into the project	○	○	○	○	○	○
The project has improved as a result of the evaluation	○	○	○	○	○	○
I have learned a lot about evaluation through this process	○	○	○	○	○	○
I feel confident that I could personally conduct a quality evaluation in the future	○	○	○	○	○	○

Other comments about the evaluation?

[ ]

To the best of your knowledge did any kind of report or publication result from the most recent evaluation of your project? (Please check all that apply.)

- ☐ Yes, publication in a peer-reviewed journal
- ☐ Yes, report for external funders
- ☐ Yes, report for in-house or public audience
- ☐ No, nothing was ever published

Other (please specify below)

[ ]

May we contact you or someone in your organization to learn more about your evaluation? (If yes, please include an email address in the box below.)

- ○ Yes
- ○ No

Enter email address below (for survey purposes only)

[ ]

Evaluatio

Projects without evaluations

Which of the following reasons best describes why your project has not been evaluated?

- ◯ Not enough staff expertise
- ◯ Lack of financial support
- ◯ Not enough internal support
- ◯ Too time consuming
- ◯ I am not sure where to begin
- ◯ Other (please specify below)

Other:

Evaluation of Citizen Science / PPSR Projects

Help with evaluation

If you were to conduct your own evaluation of your project, what THREE aspects of the evaluation process would you most like assistance with?

	First Priority	Second Priority	Third Priority
Developing logic models	◯	◯	◯
Developing goals, objectives, and indicators	◯	◯	◯
Determining sample size	◯	◯	◯
Creating or finding appropriate survey instruments	◯	◯	◯
Collecting data (through surveys, focus groups, interviews, observations, etc.)	◯	◯	◯
Analyzing and interpreting data	◯	◯	◯
Disseminating results to others	◯	◯	◯
Implementing findings from the evaluation	◯	◯	◯

Other areas you would like help with?

If you were to conduct your own evaluation of your project, what three resources would be most valuable to you?

	First Priority	Second Priority	Third Priority
An entry level User's Guide for conducting evaluations	◯	◯	◯
Online webinars focused on specific evaluation topics	◯	◯	◯
A list of must-read evaluation resources	◯	◯	◯
Sample evaluation reports from citizen science projects	◯	◯	◯
A database of potential surveys and data collection instruments	◯	◯	◯
Examples of possible evaluation designs	◯	◯	◯
Tutorials on data analysis	◯	◯	◯
Regional workshops focused on specific evaluation topics	◯	◯	◯
Community driven online forum for asking questions	◯	◯	◯

Other comments about the evaluation?

How often do you access evaluation resources from the following web sites?

	Frequently	Sometimes	Rarely	I have never heard of this resource
MEERA (My Environmental Education Evaluation Resource Assistant – meera.snre.umich.edu	○	○	○	○
InformalScience (informalscience.org)	○	○	○	○
CAISE (enter for the Advancement of Informal Science Education – caise.insci.org)	○	○	○	○
ATIS (Assessment Tools for Informal Science – pearweb.org/atis)	○	○	○	○
OERL (Online Evaluation Resource Library – oerl.sri.com)	○	○	○	○
AEA (American Evaluation Association – eval.org)	○	○	○	○
VSA (Visitor Studies Association – visitorstudies.org)	○	○	○	○
Citizen Science Central (citizenscience.org)	○	○	○	○

Other websites you use for evaluation?

Evaluation of Citizen Science/PPSR Projects

Last page & final thoughts

What other sources, if any, do you use to obtain information about evaluation?

In your opinion, what types of information/resources/opportunities are MOST needed for the field of citizen science in order to conduct more effective evaluations?

Any other thoughts about evaluation in general that you'd like to share?

Evaluation of Citizen Science/PPSR Projects

Thank You!

Thank you for taking the time to share your thoughts about evaluation of Citizen Science - your feedback is extremely helpful and appreciated!

When you click on the "Submit" button below, your responses will be submitted and you will be taken to the Citizen Science Central home page.

APPENDIX C

INTERVIEW GUIDE

Interviewee: ____
Level/Project______________________ Date: ______________
Interviewer: ____
Start time:_____________ End time: ______________

Introduction:
Hi my name is ___________. Thank you for taking time out of your day to chat with me. As you know, the reason we are calling is to talk to you about the _______________ project. As we described in the email, I am going to record the conversation, you can skip any questions that you want to, and you can stop the interview at any time. To protect your privacy, your name will be confidential, and none one of your answers will be shared with your name to the project leaders or anyone else.

We are going to be asking you questions about your experiences with the __________ project. So that I understand the context of our conversation, can you confirm that you are answering all these questions with respect to _________ project? If not, what project would you like to answer these questions about? Do you have any questions before we start?

Ok great! First, we are going to ask some questions about your experiences with the project, how you got involved, and some important memories for you about the project.

Category	*Questions*	*Notes*
Motivation & Engagement	1. When did you start participating in __________________ project? 2. What was it that led you to start participating in ___________ project? Probe: Have you always been interested in _____________?	

	3. What did you expect the experience of participating in this program to be like? Probe: what were you hoping to get out of it? **(Describe in notes)** *4.* Please describe for me what a typical day for you participating in this project looks like? 5. Please describe all the activities that you do or have done as part of this project. Probe: (Wait for answer, then prompt with: a) Any activities to learn about the protocol? b) Any activities to collect or explore data (online or on the ground)? c) Any activities about sharing info or results of the project with others (media, friends, policy people)? d) How often do you do each of these?	

	6. So you just described for me a typical day, can you describe for me the *most memorable* day you had while participating in ____________________ project? 7. How has your involvement in the project changed over time since you began participating? <u>Probe</u>: For example, are you doing things you didn't used to do, or spending more or less time with the project than you used to? 8. What is it about your experience with _________________ project that keeps you involved? <u>Probe</u>: What might cause you to participate more?	

	9. *[Refer to questions # 3]* Earlier you mentioned that you expected your experience with the project to be… Did it meet your expectations? Probe: Please explain? 10. Have you experienced any barriers or challenges to participating in _________________________ project? Probe: For example, is there anything that might cause you to drop out of the project? Please explain. 11. Do you see yourself as part of the ______________ project? – For example, do you feel connected to the people and organization that run this project? Mandatory Probe: What makes you say that? (Prompt - Ask for BOTH the larger organization (ALLARM or Bucket Brigades) AND for the local org.	

Now we are going to ask some questions about how you think about science in general and with respect to _______________ project.		
Interest in Science & Science Activities	12. Do you think what you are doing in __________ project is science? What makes you say that? Probe: what activities do you think makes it science?) *13.* a. Do you consider yourself as someone who understands science? Probe: What makes you say that? b. Do you consider yourself as someone who uses science? Probe: What makes you say that?	

	14. Do you think your friends and family would describe you this way, too? Probe: How so? Or why not?	
	15. Do you talk about your participation in the project with your friends and family? (Follow-up prompt: What kinds of things do you talk about? What is their reaction when you talk about your participation in the project?)	
	16. Do you think participating in______________ project has changed the way you see yourself as someone who understands or uses science?	

	17. Does participating in ___________________ project make you feel part of the larger scientific community, as you see it? Probe: How so or why not? *18.* Has your engagement in __________________ project led you to take part in other science or environmental activities? Please describe if so, or why not? (Probe for whether they do it for social reasons, for connection to place, for values around environment, etc., use previous 3 questions for prompts). *19.* So just one last question, so that I can fully understand your experiences with ________ project, could you tell me what this project	

	has meant to you since you started?	

Thank you so much for your time. We really appreciate it and will be sending you a $25 card. We will be contacting you again in about 6 to 9 months with some follow-up questions. Will this be a good number to reach you?

APPENDIX D

DRAFT OF LOW-MEDIUM-HIGH ENGAGEMENT DEFINITIONS

Based on the definitions you provided to us about low, medium, and high engagement for your project, we synthesized these definitions into the table below to provide you with a reference for recruiting people to be interviewed. The synthesis revealed several themes common to many projects and included: *frequency, quantity, diversity of activities, communication, and leadership.* Part of the goal of the interviews is to help define engagement in these kinds of projects, so this is just a draft to make sure we have a good range of interviewees. Keep in mind that no one project mentioned all of these themes in their definitions, and so some may not apply to you. Also, within any one level of engagement, an individual will not necessarily represent all of the stated definitions. (For example, a low level of participation may only meet one of the bullets within the "frequency" dimension). You should feel free to add anything else to your existing definitions of engagement (and send us your new ideas!).

	Low engagement	Medium	High
Frequency	• Submits data occasionally or inconsistently • May not use official data forms • Submits during key or interesting events	• Submits complete or partial data on a regular basis • Participates in events in an ongoing way but sporadically	• Submits complete data for all sites on a regular basis and on time • Participates regularly in events in an ongoing way
Quantity	• Monitor a small number of sites (less than 5)	• Monitors a moderate number of sites	• Monitors a large number of sites
Diversity of activities	• Rarely visits project website or data archives • Collects one kind of data but does few additional activities • May come to one meeting, but then never again	• Visits project website and explores data • May own additional equipment • May conduct optional data collection procedures • May submit more than one type of data • May participate in one or two types of events or meetings	• Consistently participates in optional data collection • Owns ancillary equipment • Frequent visitor to project website • May contribute to study design • Participates in many types of events or meetings

Communication	• Little to no communication with project staff and other participants and external to the project	• Likely to engage in social media, contact project leaders • Attends regular meetings	• Active in social media • May host own web page or blog • Encourages others to participate • Frequent communication with project staff, other participants or media
Leadership	• No leadership activities noted	• May make public comments or help coordinate data or events • May attend meetings but doesn't organize them	• Organizes meetings, data, events • Serves as a volunteer coordinator - trains or supports others

APPENDIX E

DIMENSIONS OF ENGAGEMENT CODEBOOK

Node	Description
Barriers	
access or liability	Participant describes not having access to land or concern over liability issues when trying to access land.
amotivation	Participant is unmotivated to participate more than they currently do
commitment requirements	Participant describes the project as taking up too much time, effort, or commitment
concern for flora, fauna	Participant describes fee\ling bad or anxious about potentially harming flora or fauna in the project
cost	Participant mentions cost as a barrier
data transparency	Participant expresses concern about whether data are being used or the lack of transparency about how the data are being used
disease - ticks	Participant describes concern over disease such as ticks as a barrier
feeling isolated	Participant describes feeling alone or not having a support system within the project
going on vacation	Participant mentions going away on vacation as a barrier to engagement
harassment from other people	Participant describes being harassed by others.
health or safety risks	Participant describes feeling concerned about their own health or safety during participation
lack of confidence, inadequate	Participant describes feeling inadequacy or lack of confidence in successfully participating in the project

Node	Description
lack of immediate threat	Participant describes that lack of immediate environmental threat is a de-motivator or barrier to participation.
lack of in-person contact	Participant describes desire for social contact with other participants
lack of representation	Participant describes not having an effective way to voice concerns
loss of trusted leader	Participant describes loss of project leader or scientist from the project as a reason to quit or decrease participation.
no data to report	Interviewee reports diminished interest or motivation to participate because of lack of data to report (e.g., because of effects of drought on abundance or presence of focal species)
old age - health	Participant mentions the effects of old age or health as a barrier or inhibition to participation.
other wildlife interfering with the project	Interviewee mentions other wildlife competing or interfering with the citizen science project in some way.
recruiting or retaining volunteers	Participant describes challenges in trying to drum up interest from potential or existing volunteers.
technical	Participant describes technical barriers to participating or to participating more than they currently do
time	Participant describes time constraints or other commitments as a barrier
transportation - logistics	Participant mentions that they are not contractually allowed to drive students, so students who have their license and can drive sometimes are in limited quantity.
travel distance	Participant describes travel distance to site as a barrier to participation
weather	Participant describes weather as a barrier to participation
Degree of participation - effort	

Node	Description
change over time	Participant talks about attitudinal, behavioral, or knowledge changes over time since participating in the citizen science project.
consistency	Refers to the reliability of a certain task, such as maintaining participation levels even under adverse conditions or persisting with tasks despite challenges.
duration	Participant describes how long they have been participating or interested in a particular topic or project.
frequency	Participant discusses how often a behavior, affective state, or interaction occurs.
Feelings, affective, attitude	Participant talks about any kinds of feelings or attitudes, they had/have about specific activities, or spending time with other participants doing these activities, or toward others people (friends, family members), or towards other living and non-things (plants, animals, places), or about an interest or motivation (eg. I'm interested and excited about learning more), or about science –
commitment	From the organizational labor arena (Bakker, Schaufeli, Leiter, & Taris, 2008). Participant expresses passion about being committed or dedicated to the idea, the project, the environment, or the science. In a work environment the "positive, fulfilling, task-related state of mind (Meyer & Allen, 1984, 1997; Mowday, Steers, & Porter, 1979) might be characterized by: vigor, dedication, absorption, identification and effort. In the absence of these fine-grained descriptions, simply code as "pos/neg Commitment".
efficacy or confidence	Participant describes having confidence, agency or self-efficacy in their participation in the project
excitement	Participant describes having feelings of excitement about their participation in the project
interest	Participant describes cognitive or affective components of interest resulting from interaction between them and some specific content, tool, or experience
negative	Participant talks about discomfort, uncertainty, nervousness,

Node	Description
	dislike, frustration, sadness,
positive	Participant talks about enjoyment, comfort, positive, fun, appreciation
recognition or credibility	Participant describes positive or negative feelings related to being recognized or valued for their participation by others
surprise or new ideas or experiences	Participant talks about encountering something they hadn't expected, or discovering something new
uncertainty	Participant expresses doubt or uncertainty about some aspect of their participation or the project
QA-QC concerns	Participant refers to a stated desire to act responsibly, particularly regarding accuracy in data collection or concern about the responsibility of others.
Learning	Participant talks about learning as part of their engagement; about something they have learned about a topic or from particular activities in the citizen science project.
experiential learning	Participant talks about something they learned because of their direct experience with the citizen science project.
increased awareness	Participant mentions increased awareness as a learning outcome from participation
new behaviors	Participant describes undertaking new behaviors and activities as a result of participation
new knowledge	Participant describes new acquisition of content understanding or subject matter, e.g., plant or animal ID, animal behavior, geology, etc.
new skills	Participant describes new habits or skills acquired as a function of the practice.
other learning	Participant describes learning something not described above.
pre-existing knowledge	Participant describes knowledge that they brought with them to the project
science process or	Participant describes new understanding of or appreciation for

Node	Description
citizen science	how science works as a function of engaging in science practices, or understanding of citizen science and their role in science through citizen science
Memorable quotes	Verbatim quotes from interviewees that highlight key themes
Motivations	The underlying psychological need for why someone does something (Ryan and Deci 2000a). Use this code when participant talks about things that initially caused their participation or help them stay engaged in the citizen science project. In the absence of these fine-grained descriptions, simply code as "pos/neg Motivation"
career	Participant talks about being motivated to do citizen science because it would benefit their job or career in some way
community concern	Participant talks about any issues specific to the community or the need to bring people together and/or the need to empower community members
environmental concern	Participant talks about any environmental issues/concerns that are important to them and that they want to address, such as environmental health, air and water quality, climate change, conservation of habitat or species, and weather
air quality	Participant talks about air quality as an important issue
climate change	Participant talks about climate change as an important issue
conservation of habitat	Participant talks about conservation of habitat as an important issue
conservation of particular species	Participant talks about conservation of particular species as being important to him/her
environmental health	Participant talks about environmental health as an important issue
water quality	Participant talks about water quality as an important issue
weather	Participant talks about weather as an important issue
contribution	Participant talks about wanting to make a contribution (whether to science, the environment, education, or community) as a

Node	Description
	motivation for participating in the citizen science project.
education	Participant talks about any issues/problems in education that are important to them (e.g., the need to get students interested in science or the environment, the need to increase students' connection with nature).
enjoyment	Participant talks about personal enjoyment, fun, excitement, or satisfaction as a motivation for participation.
interest	Participant talks about his/her interest in a topic or issue as a motivation for participation.
learning	Participant talks about learning as a motivation for staying engaged.
management of information	Participant describes joining a project because of the desire to manage their data or information better.
place	Participant talks about attachment or connection to specific places or types of places, including the built environment as well as the natural environment, includes connections to places because of people or community reasons, as well as or separate from ecological systems or natural places.
nature	Participant describes being outdoors or in nature as a motivation to participate
political distrust	Participant describes concern or mistrust of political forces as a key motivation for participation
scientific credibility	Participant talks about the need to obtain data or evidence that can be used to defend a claim; or desire to engage in scientific work
social	Participant talks about the desire to be with like-minded people or being introduced to the project by someone
Non-project activities	Participant talks about other non-project tasks and activities.
other activities- not citizen science	Participant talks about engaging in other activities, hobbies, or work that is not citizen science

Node	Description
other citizen science project	Participant talks about engaging in other citizen science projects
work related activities	Participant describes activities or affiliations related to their work
Project activities and practices	Participant talks about any project tasks and/or activities. Use this code to capture the degree of participation – both the number and kinds of different steps of the scientific process that participants engage in
data collection	Participant talks about collecting data, whether counting larvae eggs, counting bird eggs, counting eels, recording amount of rainfall
classification	Sorting events, organisms, or phenomena into distinct categories or classifications as part of data collection.
counts	Counts of numbers of organisms or events.
equipment	Assembling or modifying equipment as part of data collection.
identification	Participant describes activates related to careful identification of events, organisms, or phenomena as part of data collection.
measures	Measures of size, amounts, or quantities of organisms or events as part of data collection.
observation	Participant describes activities related to careful observation or watching of events, organisms, or phenomena as part of data collection.
other	Participant describes conducting additional data collection nor reflected in the other sub-nodes listed).
samples	Collection of samples for analysis (e.g., water samples, insects, etc.)
site selection	Participant describes the rationale for selecting a particular site to monitor
stages	Participant describes gathering data on the developmental stages of organisms or events as part of data collection.

Node	Description
timing	Timing of events as part of data collection.
extra activities	Use the following codes to describe activities done on behalf of the project that are not related to data collection specifically.
adapt or modify protocols	Participant describes things done to adapt or change the protocol to suit their need
analyzing or interpreting data	Participant talks about analyzing or interpreting data that he/she has collected
asking questions	Participant asks and attempts to answer questions or choosing/defining questions, or helping to choose /define questions.
attend meetings	Participant talks about attending meetings related to project
communicating finding to ...	Participant talks about communicating findings to others
friends, family, co-workers, general public	Participant talks about communicating findings to friends or family members
media, policy, decision makers	Participant talks about communicating findings to the media policy people or decision makers
other project participants	Participant discusses communicating findings to others participating in the project -- not project leaders or scientists.
scientists, project leaders	Participant talks about communicating findings to scientists or project leaders
communicating with others ...	Participant talks about communicating general information about the project to others (exclusive of findings)
friends, family, co-workers, general public	Participant talks about communicating about the project to friends or family members
media, policy decision makers	participant talks about communicating findings to the media policy people or decision makers
other project	Participant describes communicating with other project

Node	Description
participants	participants either virtually or in person
scientists or project leaders	Participant talks about the project in general to project leaders and scientists
coordinating participant activities	Participant describes coordinating trainings, events, or data from others related to the project
exploring data	Participant talks about exploring publicly available data from the project, either online or on paper
forming hypothesis	Participant discusses a hypothesis they have formulated relative to the project
getting updates and feedback	Participant describes reading updates or feedback about the project
habitat improvement	Participant describes activities to improve or restore habitat or local landscape
learning protocols	Participant describes what they did to learn about the protocol or how to participate.
managing-compiling data	Participant describes compiling, managing, or organizing their own data or other people's data
miscellaneous	Use when participants talk about doing extra tasks and activities that are related to the project (e.g., driving to sites, taking pictures)
recruiting participants	Participant talks about recruiting people into the project
Study design-investigations	Participant describes what they did to design their own study such as planning and implementing an investigation, designing data collection methodologies, collecting samples, or data.
submitting data or reports	Participant talks about submitting data or sending off reports
tool building	Participant talks about building tools on behalf of the project
training	Participant talks about training new individuals to take part in

Node	Description
participants	the project
use data	Participant provides examples of using the data as a source of evidence to defend or critique claims.
using standardized methods	Participant describes using standardized tools, methods, or documentation as part of their participation
Science and Environmental Identity	Broad category to describe what participants have to say about how they think or feel about science or the environment in general, not necessarily related to the project, per se.
Social connections/ community of practice	Participant talks about other participants in the project or getting together with other participants, learning from others. Participants talk about sense of belonging to the project or the extent to which they feel allegiance to a group. Participants talk about connection to the larger scientific community as a result of their participation
relations	Participant discusses collaboration or social interactions with others as a key aspect of doing some kind of activity
role expansion	Participant describes behavior that reveals attention to a wider range of tasks than is typical or usual, or the choice to perform extra-role tasks can be regarded as role expansion and has been found to be related to self-efficacy (Parker, 1998). An example of this is when an individual describes becoming a leader and training others or taking part in civic engagement opportunities such as going to town board meetings. The main idea to look for is moving from the periphery to the core
using mutual resources	Participant describes using systems to coordinate or communicate a shared practice. For example, participants may describe use of the list serve or in-person trainings to take part in a shared activity
using shared knowledge	participant describes sharing one's own competence or accessing that of others to reflect on what they do and know (as well as to make meaning of what they don't know and don't do).

APPENDIX F

PARTICIPANT ENGAGEMENT METRIC

How often have you done the following activities on behalf of __________________ project in the last year?

	Never	Rarely	Sometimes	Often	Very Often
Gathered data and/or samples as often as suggested by the project protocol	O	O	O	O	O
Shared information about the project to the general public	O	O	O	O	O
Communicated project data or findings to politicians, decision makers, or media outlets	O	O	O	O	O
Used social media to communicate with project staff or other participants (email, listserv, Facebook, Twitter, blog posts, etc.)	O	O	O	O	O
Submitted data or reports as often as suggested by the project protocol	O	O	O	O	O
Recruited other participants	O	O	O	O	O
Trained new participants	O	O	O	O	O
Sought answers to questions about a project or protocol	O	O	O	O	O
Explored publicly available project data	O	O	O	O	O
Created graphs and maps of project data	O	O	O	O	O
Used statistics and probability to interpret project data	O	O	O	O	O
Used project data to make or defend a scientific claim	O	O	O	O	O

APPENDIX G

PARTICIPANT ONLINE SURVEY

Q0 Thank you for agreeing to be part of an NSF-funded study about learning and engagement in citizen science, led by the Cornell Lab of Ornithology and in collaboration with UC Davis. We are partnering in this work to better understand and compare the experiences of citizen scientists across six different projects. The research team is now in their last phase of the study and they need your help to better understand the aspects of citizen science engagement that lead to the greatest outcomes for participants.

This survey should take about 15-20 minutes to complete. You must be 18 years or older to participate. All responses are confidential, and you are welcome to exit the survey at any time. If you must leave the survey before completing it, no problem – just return to the survey on the same device you used when you started it, and you'll be taken to the place where you left off. Once you complete the survey, you will have the chance to enter to win one of six $50 Amazon gift cards. Winners will be drawn after the survey is closed.

By clicking the arrow below, you confirm that you are at least 18 years old, and agree to voluntarily participate in this survey. Thank you in advance for your help with this important research!

Q1 Do you now or have you in the past year, participated in a citizen science or volunteer monitoring project?

❍ Yes
❍ No

Q2 Please tell us if you have had any involvement with the following projects in the past year:

	Yes	No
NestWatch	❍	❍
Monarch Larva Monitoring Project	❍	❍
Community Collaborative Rain, Hail, and Snow (CoCoRaHS)	❍	❍
Hudson River Estuary Program	❍	❍
Alliance for Aquatic Resource Monitoring (ALLARM)	❍	❍
Global Community Monitor (GCM)	❍	❍
Other citizen science project not listed (please specify)_____	❍	❍

Q3 Which one of the following projects have you been involved with the most?

❍ NestWatch
❍ the Monarch Larva Monitoring Project (MLMP)
❍ Community Collaborative Rain, Hail and Snow (CoCoRaHS)
❍ the Hudson River Estuary Program (EELS)

❍ water quality monitoring/ ALLARM
❍ air quality monitoring/ Global Community Monitor (GCM)

Q4 How many years have you been involved with [PROJECT]?
❍ Less than 1 year
❍ 1-2 years
❍ 3-5 years
❍ 6-10 years
❍ 11-20 years
❍ 21+ years

Q5 On average, approximately how many hours per year do you spend participating in [PROJECT] (include all activities including data collection, submission, visiting project website, etc.)? (Common average times: 5min/day at 6 days per week = about 2hr/month = 24hr/year. 1hr/ week = 4hr/month = 48hr/yr.1hr/day at 5 times a week = about 20hr/month = 240hr/year.) ________

Q6 How often have you done the following activities on behalf of [PROJECT] in the last year?

	Never	Rarely	Sometimes	Often	Very Often
Gathered data and/or samples as often as suggested by the project protocol	❍	❍	❍	❍	❍
Shared information about the project to the general public	❍	❍	❍	❍	❍
Communicated project data or findings to politicians, decision makers, or media outlets	❍	❍	❍	❍	❍
Used social media to communicate with project staff or other participants (email, listserv, Facebook, Twitter, blog posts, etc.)	❍	❍	❍	❍	❍
Submitted data or reports as often as suggested by the project protocol	❍	❍	❍	❍	❍
Recruited other participants	❍	❍	❍	❍	❍
Trained new participants	❍	❍	❍	❍	❍
Sought answers to questions about a project or protocol	❍	❍	❍	❍	❍
Explored publicly available project data	❍	❍	❍	❍	❍
Created graphs and maps of project data	❍	❍	❍	❍	❍
Used statistics and probability to interpret project data	❍	❍	❍	❍	❍
Used project data to make or defend a scientific claim	❍	❍	❍	❍	❍

Q7 What is your current level of interest with respect to [PROJECT]?
- ❍ Not at all interested
- ❍ Not very interested
- ❍ Somewhat interested
- ❍ Interested
- ❍ Extremely interested

Q8 How does your participation in [PROJECT] compare to your interests in other leisure activities you do in your spare time?
- ❍ It is the activity I am least interested in
- ❍ I'm not very interested in it compared to other activities
- ❍ About the same as other activities
- ❍ I'm more interested in it compared to most other activities
- ❍ It is the activity I am most interested in

Q9 On a scale of 1 to 5, with 1 being not at all connected, and 5 being extremely connected, how connected do you feel to...

	1	2	3	4	5
...the NestWatch site(s) that you monitor?	❍	❍	❍	❍	❍
...NestWatch and its organizers?	❍	❍	❍	❍	❍
...other NestWatch participants?	❍	❍	❍	❍	❍
...your local community as it relates to your NestWatch activities?	❍	❍	❍	❍	❍
...your local environment?	❍	❍	❍	❍	❍

Q10 How often do you do the following activities related to [PROJECT]?

	Never	Rarely	Sometimes	Often	Very Often	Not Applicable
Read project newsletters	❍	❍	❍	❍	❍	❍
Visit project website	❍	❍	❍	❍	❍	❍
Email project leaders	❍	❍	❍	❍	❍	❍
Take part in project webinars	❍	❍	❍	❍	❍	❍
Communicate with other participants (virtually or in person)	❍	❍	❍	❍	❍	❍
Post to Facebook, Twitter, or other social media	❍	❍	❍	❍	❍	❍
Participate in meetings or conference calls	❍	❍	❍	❍	❍	❍

Q11 Please rate what you think your level of participation in [PROJECT] is compared to other participants in this project.

❍ Very low level of participation
❍ Low level of participation
❍ Average level of participation
❍ High level of participation
❍ Very high level of participation
❍ I am unable to rate my participation in this project compared to others

Q12 How likely are you to participate in [PROJECT] in the future?
❍ Not at all likely
❍ Not very likely
❍ Unsure
❍ Somewhat likely
❍ Very Likely

Q13 Please rate your agreement with each statement below. Start each statement with: "Most of what I learned about bird ecology while participating in this project came from..."

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
...materials and training provided by the project organizers.	❍	❍	❍	❍	❍
...what I observed and experienced while doing the project.	❍	❍	❍	❍	❍
...in-person interactions with other participants.	❍	❍	❍	❍	❍
...online interactions with other participants.	❍	❍	❍	❍	❍
...external sources of information that I looked for on my own.	❍	❍	❍	❍	❍
... knowledge that I had before starting the project.	❍	❍	❍	❍	❍

Q14 What has been the most beneficial or useful aspect of your participation with [PROJECT]? ________

Q15 We'd like to know what, if any, barriers you faced that caused you to stop participating or prevented you from ever participating in citizen science. Please indicate your level of agreement with each of the following statements:

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I didn't know any other participants	❍	❍	❍	❍	❍
I didn't feel I had enough experience	❍	❍	❍	❍	❍
It was too costly	❍	❍	❍	❍	❍
My ability to access sites to monitor was limited	❍	❍	❍	❍	❍
My friends and/or family didn't support my involvement	❍	❍	❍	❍	❍
I didn't know much about the topic	❍	❍	❍	❍	❍
I don't know if my contribution was achieving anything	❍	❍	❍	❍	❍
My ability to access transportation was limited	❍	❍	❍	❍	❍
My ability to access the Internet was limited	❍	❍	❍	❍	❍
I didn't feel I could participate because of my own limitations	❍	❍	❍	❍	❍
I had other competing commitments	❍	❍	❍	❍	❍
I lost interest	❍	❍	❍	❍	❍
I had concerns about my safety	❍	❍	❍	❍	❍
I didn't understand how the data were being used	❍	❍	❍	❍	❍
Other (please describe)________	❍	❍	❍	❍	❍

Q16 The second half of the survey deals more generally with issues around science and the environment. Please indicate how much you DISAGREE or AGREE with each of the following statements by selecting the appropriate bubble. Please respond regardless of whether you've previously participated in citizen science. These statements are about how you feel about learning and understanding science content (e.g., breeding bird ecology).

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I think I'm pretty good at understanding science-related topics.	❍	❍	❍	❍	❍
Compared to other people my age, I think I can quickly understand new science topics.	❍	❍	❍	❍	❍
It takes me a long time to understand new topics.	❍	❍	❍	❍	❍
I feel confident in my ability to explain science topics to others.	❍	❍	❍	❍	❍
I feel confident in my ability to explain science topics to others.	❍	❍	❍	❍	❍

Q17 These statements are about how you feel about doing citizen science activities (e.g., breeding bird monitoring).

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I think I'm pretty good at following instructions for NestWatch activities	❍	❍	❍	❍	❍
Compared to other people my age, I think I can do NestWatch activities pretty well.	❍	❍	❍	❍	❍
It takes me a long time to understand how to do NestWatch activities.	❍	❍	❍	❍	❍
I feel confident about my ability to explain how to do NestWatch activities to others	❍	❍	❍	❍	❍

Q18 For each of the following statements listed below, please indicate your level of agreement with the following statements about your current skill level. Please respond regardless of whether you've previously participated in citizen science. Begin each statement below with "I CURRENTLY have the skills necessary to..."

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Closely observe/record bird nests.	❍	❍	❍	❍	❍
Accurately identify different species' bird nests in my region.	❍	❍	❍	❍	❍
Understand the NestWatch data collection protocol	❍	❍	❍	❍	❍
Successfully submit my observations to NestWatch	❍	❍	❍	❍	❍
Collect NestWatch data in a standardized manner	❍	❍	❍	❍	❍
Use the NestWatch database to answer a bird-related question	❍	❍	❍	❍	❍
Interpret the meaning of NestWatch data presented in maps, charts, graphs, etc.	❍	❍	❍	❍	❍
Conduct statistical analyses using NestWatch data	❍	❍	❍	❍	❍
Use NestWatch data as a source of evidence	❍	❍	❍	❍	❍
Design a study to understand nesting success in my region	❍	❍	❍	❍	❍
Communicate NestWatch findings to others	❍	❍	❍	❍	❍
Train others to participate in NestWatch	❍	❍	❍	❍	❍

Q19 Why do you choose to participate in citizen science projects like [PROJECT]? Please indicate how much you AGREE or DISAGREE with each of the following statements about why you choose to participate in citizen science. We understand some of these statements may sound redundant, but we need to be completely thorough in our research.

	Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
Because I think it's a good idea	❍	❍	❍	❍	❍
Because I enjoy doing it	❍	❍	❍	❍	❍
Because it is important to me	❍	❍	❍	❍	❍
Because other people will be disappointed in me if I don't participate	❍	❍	❍	❍	❍
Because I enjoy getting involved in scientific activities	❍	❍	❍	❍	❍
Because people I look up to think it's a really good thing	❍	❍	❍	❍	❍
Because I'm concerned about what could happen to me	❍	❍	❍	❍	❍
Because it's fun to do	❍	❍	❍	❍	❍
Because the project topic is really important to me	❍	❍	❍	❍	❍
For the recognition I get from others	❍	❍	❍	❍	❍
For the pleasure I experience	❍	❍	❍	❍	❍
Because I would feel guilty if I didn't get involved	❍	❍	❍	❍	❍
Because I'm concerned about what could happen to people I care about	❍	❍	❍	❍	❍
Because I want people to see me as a good person	❍	❍	❍	❍	❍

Q20 For the following statements, please rate the extent to which you do or don't take part in these activities by marking the appropriate response. Please respond regardless of whether you've previously participated in citizen science or volunteer monitoring.

	I don't do this	I am thinking about doing this	I used to do this	I intend to do this	I am currently doing this	I will continue to do this	I can't imagine NOT doing this
Routinely recycle paper, glass and plastics	❍	❍	❍	❍	❍	❍	❍
Donate to an environmental or conservation organization	❍	❍	❍	❍	❍	❍	❍
Sign petitions for environmental protections	❍	❍	❍	❍	❍	❍	❍
Pay more for products made from recycled materials	❍	❍	❍	❍	❍	❍	❍
Vote for candidates who advocate for environmental protections	❍	❍	❍	❍	❍	❍	❍
Recruit others to participate in environmental causes	❍	❍	❍	❍	❍	❍	❍
Speak out against harmful environmental practices	❍	❍	❍	❍	❍	❍	❍
Regularly purchase goods from environmentally responsible companies	❍	❍	❍	❍	❍	❍	❍
Purchase energy efficient appliances	❍	❍	❍	❍	❍	❍	❍
Grow your own or buy locally grown food that is in-season.	❍	❍	❍	❍	❍	❍	❍
Regularly maintain energy efficient heating and cooling zones	❍	❍	❍	❍	❍	❍	❍
Be a vegetarian or pledge to eat less meat	❍	❍	❍	❍	❍	❍	❍

Q21 For the following statements, please rate the extent to which you do or don't take part in these activities by marking the appropriate response. Please respond regardless of whether you've previously participated in citizen science.

	I don't do this	I am thinking about doing this	I used to do this	I intend to do this	I am currently doing this	I will continue to do this	I can't imagine NOT doing this
Compost or participate in composting	❍	❍	❍	❍	❍	❍	❍
Practice strategies to reduce electricity consumption	❍	❍	❍	❍	❍	❍	❍
Invest in a hybrid vehicle or choose not to own a car	❍	❍	❍	❍	❍	❍	❍
Use alternative transportation whenever possible (bicycle, mass transit, carpool)	❍	❍	❍	❍	❍	❍	❍
Regularly pick up litter in my neighborhood	❍	❍	❍	❍	❍	❍	❍
Choose not to use fertilizers	❍	❍	❍	❍	❍	❍	❍
Choose not to use pesticides	❍	❍	❍	❍	❍	❍	❍
Use less water in and around the home	❍	❍	❍	❍	❍	❍	❍
Reduce use of toxic household products	❍	❍	❍	❍	❍	❍	❍
Participate in environmental efforts organized by others	❍	❍	❍	❍	❍	❍	❍
Participate in habitat restoration projects	❍	❍	❍	❍	❍	❍	❍
Volunteer for an environmental or conservation organization	❍	❍	❍	❍	❍	❍	❍

Q22 LAST PAGE!!! Demographic Information- In an effort to minimize bias in our survey and be as inclusive as possible, we ask that you answer the following questions. Your answers will be anonymized and used solely for research purposes. If you do not wish to answer these questions you may select "Decline to Respond" and click forward to the final question.

Q23 Are you...
- ❍ Male
- ❍ Female
- ❍ Other
- ❍ Decline to Respond

Q24 In what year were you born? _____

Q25 What is your highest level of formal education?
- ❍ Did not complete High School
- ❍ Completed High School
- ❍ Some College/University
- ❍ Associate's degree
- ❍ Bachelor's degree
- ❍ Some Post-graduate studies
- ❍ Master's or professional degree
- ❍ Doctorate (PhD, EdD, PsyD, MD, etc.)
- ❍ Decline to Respond

Q26 Which of the following groups do you most identify with?
- ❍ African American, Black
- ❍ American Indian, Native American, or Alaskan Native
- ❍ Asian, Asian-American
- ❍ Caribbean Islander
- ❍ White/Caucasian (non-Hispanic)
- ❍ Latino or Hispanic
- ❍ Middle Eastern or Arab
- ❍ Native Hawaiian or Other Pacific Islander
- ❍ Other/Multi-Racial (please specify) ____________________
- ❍ Decline to Respond

Q27 Which of the following best describes the area where you live?
- ❍ Urban, Inner City, Metropolitan
- ❍ Small City
- ❍ Suburban
- ❍ Rural or Farming community

❍ Decline to Respond

Q28 What field do you currently work in? Please select all that apply. If you are retired or unemployed, please select your previous field in addition to selecting "retired" and/or "unemployed".

❑ Architecture and Engineering
❑ Arts/Design
❑ Building and Grounds Maintenance
❑ Business and Financial
❑ Community and Social Service
❑ Computer and Information Technology
❑ Construction
❑ Education (K12)
❑ Education (College/University)
❑ Education (Informal)
❑ Emergency Management
❑ Entertainment, Sports
❑ Farming/Fishing/Forestry/Ranching
❑ Food Preparation/Restaurant
❑ Hydrology/Water Management
❑ Medical/Healthcare
❑ Maintenance and Repair
❑ Law and Legal
❑ Life, Physical Sciences
❑ Management
❑ Manufacturing/production
❑ Media/Journalism
❑ Meteorology/Climatology
❑ Military
❑ Office and Administrative Support
❑ Personal Care and Service
❑ Recreation/Tourism
❑ Research
❑ Social Sciences
❑ Student (College/University)
❑ Transportation
❑ Unemployed
❑ Retired
❑ Other (please specify) ____________________
❑ Decline to Respond

Q29 And finally, are there any additional comments about your participation, or about the survey in general that you would like to share with us? ________

QZ (Optional) If you would like to be entered into a drawing for one of six $50 Amazon gift cards, please provide your email address below: ________

APPENDIX H

INTER-ITEM CORRELATIONS FOR VALIDATED SCALES

1. MOTIVATION - Inter-Item Correlation Matrix

	Because I think it's a good idea to be a citizen scientist.	Because I enjoy doing it.	Because I'm concerned about the environment.	Because other people will be disappointed in me if I don't participate in citizen science.	Because I enjoy getting involved in scientific activities.	Because people I look up to think it's a really good thing to be involved in citizen science.	Because I'm concerned about what could happen to me if I don't participate.	Because it's fun to do.	Because the project topic is really important to me.	For the recognition I get from others.	For the pleasure I experience as a citizen scientist.	Because I would feel guilty if I didn't get involved in citizen science.	Because I'm concerned about what could happen to people I care about.	Because I want people to see me as a good person.
Because I think it's a good idea to be a citizen scientist.	1	0.54	0.44	-0.08	0.343	0.064	0.086	0.355	0.437	-0.069	0.293	0.032	0.096	0.005
Because I enjoy doing it.	0.54	1	0.35	-0.119	0.37	-0.018	0.047	0.691	0.411	-0.091	0.581	-0.049	0.007	-0.025
Because I'm concerned about the environment.	0.44	0.35	1	0.002	0.342	0.08	0.178	0.294	0.52	0.036	0.28	0.121	0.203	0.111
Because other people will be disappointed in me if I don't participate in citizen science.	-0.08	-0119	0.002	1	0	0.5	0.386	-0.132	-0.057	0.532	-0.149	0.504	0.348	0.486
Because I enjoy getting involved in scientific activities.	0.343	0.37	0.342	0	1	0.104	0.068	0.41	0.398	0.069	0.352	0.075	0.055	0.097
Because people I look up to think it's a really good thing to be involved in citizen science.	0.064	-0.018	0.08	0.5	0.104	1	0.432	-0.006	0.085	0.505	0.013	0.433	0.357	0.483
Because I'm concerned about what could happen to me if I don't participate.	0.086	0.047	0.178	0.386	0.068	0.432	1	0.035	0.11	0.417	0.052	0.441	0.67	0.436
Because it's fun to do.	0.355	0.691	0.264	-0.132	0.41	-0.006	0.035	1	0.411	-0.052	0.673	-0.038	0.002	-0.008
Because the project topic is really important to me.	0.437	0.411	0.52	-0.057	0.398	0.085	0.11	0.411	1	0.024	0.365	0.093	0.158	0.061
For the recognition I get from others.	-0.069	-0.091	0.036	0.532	0.069	0.505	0.417	-0.052	0.024	1	-0.002	0.46	0.348	0.62
For the pleasure I experience as a citizen scientist.	0.293	0.581	0.28	-0.149	0.352	0.013	0.052	0.673	0.365	-0.002	1	-0.009	0.042	0.031
Because I would feel guilty if I didn't get involved in citizen science.	0.032	-0.049	0.121	0.504	0.075	0.433	0.441	-0.038	0.093	0.46	-0.009	1	0.435	0.519
Because I'm concerned about what could happen to people I care about.	0.096	0.007	0.203	0.348	0.055	0.357	0.67	0.002	0.158	0.348	0.042	0.435	1	0.481
Because I want people to see me as a good person.	0.005	-0.025	0.111	0.486	0.097	0.483	0.436	-0.008	0.061	0.62	0.031	0.519	0.481	1

2. PEM Inter-Item Correlation Matrix

	Gathered data and/or samples as often as suggested by the project protocol	Shared information about the project to the general public	Communicated project data or findings to politicians, decision makers, or media outlets	Used social media to communicate with project staff or other participants (email, list serve, Facebook, Twitter, blog posts, etc.)	Submitted data or reports as often as suggested by the project protocol	Recruited other participants	Trained new participants	Sought answers to questions about a project or protocol	Explored publicly available project data	Created graphs and maps of project data	Used statistics and probability to interpret project data	Used project data to make or defend a scientific claim
Gathered data and/or samples as often as suggested by the project protocol	1	0.273	0.153	0.107	0.739	0.185	0.125	0.146	0.278	0.181	0.156	0.111
Shared information about the project to the general public	0.273	1	0.431	0.35	0.279	0.452	0.325	0.305	0.355	0.311	0.306	0.336
Communicated project data or findings to politicians, decision makers, or media outlets	0.153	0.431	1	0.446	0.141	0.439	0.423	0.389	0.281	0.422	0.463	0.485
Used social media to communicate with project staff or other participants (email, list serve, Facebook, Twitter, blog posts, etc.)	0.107	0.35	0.446	1	0.118	0.402	0.409	0.406	0.24	0.293	0.303	0.331
Submitted data or reports as often as suggested by the project protocol	0.739	0.279	0.141	0.118	1	0.17	0.071	0.139	0.294	0.16	0.127	0.101
Recruited other participant	0.185	0.452	0.439	0.402	0.17	1	0.666	0.418	0.303	0.354	0.34	0.384
Trained new participant	0.125	0.325	0.423	0.409	0.071	0.666	1	0.457	0.189	0.346	0.34	0.391
Sought answers to questions about a project or protocol	0.146	0.305	0.389	0.406	0.139	0.418	0.457	1	0.341	0.304	0.332	0.347
Explored publicly available project data	0.278	0.355	0.281	0.24	0.294	0.303	0.189	0.341	1	0.362	0.359	0.318
Created graphs and maps of project data	0.181	0.311	0.422	0.293	0.16	0.354	0.346	0.304	0.362	1	0.643	0.491
Used statistics and probability to interpret project data	0.156	0.306	0.463	0.303	0.127	0.34	0.34	0.332	0.359	0.643	1	0.613
Used project data to make or defend a scientific claim	0.111	0.336	0.485	0.331	0.101	0.384	0.391	0.347	0.318	0.491	0.613	1

3. EFFICACY Inter-Item Correlation Matrix

	I think I'm pretty good at understanding science-related topics.	Compared to other people my age, I think I can quickly understand new science topics.	It takes me a long time to understand new topics.	I feel confident in my ability to explain science topics to others.	I think I'm pretty good at following instructions for (NestWatch, monarch, precipitation, eel, water quality, air quality) monitoring activities	Compared to other people my age, I think I can do (NestWatch, monarch, precipitation, eel, water quality, air quality) monitoring activities pretty well.	It takes me a long time to understand how to do (NestWatch, monarch, precipitation, eel, water quality, air quality) monitoring activities.	I feel confident about my ability to explain how to do (NestWatch, monarch, precipitation, eel, water quality, air quality) monitoring activities
I think I'm pretty good at understanding science-related topics.	1	0.737	0.394	0.633	0.391	0.377	0.295	0.42
Compared to other people my age, I think I can quickly understand new science topics.	0.737	1	0.403	0.563	0.353	0.428	0.275	0.36
It takes me a long time to understand new topics.	0.394	0.403	1	0.333	0.2	0.201	0.59	0.231
I feel confident in my ability to explain science topics to others.	0.633	0.563	0.333	1	0.317	0.325	0.28	0.524
I think I'm pretty good at following instructions for (NestWatch, monarch, precipitation, eel, water quality, air quality) monitoring activities	0.391	0.353	0.2	0.317	1	0.596	0.343	0.534
Compared to other people my age, I think I can do (NestWatch, monarch, precipitation, eel, water quality, air quality) monitoring activities pretty well.	0.377	0.428	0.201	0.325	0.596	1	0.286	0.463
It takes me a long time to understand how to do (NestWatch, monarch, precipitation, eel, water quality, air quality) monitoring activities.	0.295	0.275	0.59	0.28	0.343	0.286	1	0.326
I feel confident about my ability to explain how to do (NestWatch, monarch, precipitation, eel, water quality, air quality) monitoring activities	0.42	0.36	0.231	0.524	0.534	0.463	0.326	1

4. SKILLS Inter-Item Correlation Matrix

	Closely observe/ record	Accurately identify	Understand the data collection protocol	Successfully submit my observations	Collect data in a standardized manner	Use the database to answer project related question	Interpret the meaning of data presented in maps, charts, graphs, etc	Conduct statistical analyses using data	Use data as a source of evidence	Design a study	Communicate findings to others	Train others to participate	
Closely observe/record	1	0.585	0.588	0.528	0.562	0.416	0.415	0.287	0.374	0.32	0.368	0.365	**1**
Accurately identify	0.585	1	0.498	0.418	0.433	0.451	0.458	0.38	0.414	#####	0.401	0.382	**2**
Understand the data collection protocol	0.588	0.498	1	0.709	0.722	0.498	0.503	0.365	0.397	#####	0.439	0.454	**3**
Successfully submit my observations to	0.528	0.418	0.709	1	0.742	0.477	0.458	0.343	0.376	#####	0.419	0.43	**4**
Collect data in a standardized manner	0.562	0.433	0.722	0.742	1	0.52	0.512	0.381	0.409	0.32	0.45	0.438	**5**
Use the (database to answer a (elated question	0.416	0.451	0.498	0.477	0.52	1	0.674	0.574	0.587	#####	0.524	0.42	**6**
Interpret the meaning of data presented in maps, charts, graphs, etc.	0.415	0.458	0.503	0.458	0.512	0.674	1	0.615	0.595	#####	0.564	0.459	**7**
Conduct statistical analyses using data	0.287	0.38	0.365	0.343	0.381	0.574	0.615	1	0.598	#####	0.491	0.397	**8**
Use data as a source of evidence	0.374	0.414	0.397	0.376	0.409	0.587	0.595	0.598	1	#####	0.609	0.48	**9**
Design a study	0.32	0.401	0.343	0.274	0.32	0.476	0.526	0.646	0.617	1	0.549	0.506	**10**
Communicate findings to others	0.368	0.401	0.439	0.419	0.45	0.524	0.564	0.491	0.609	#####	1	0.672	**11**
Train others to participate	0.365	0.382	0.454	0.43	0.438	0.42	0.459	0.397	0.48	#####	0.672	1	**12**

1.* Recycle …	2. Donate to an envir. or cons. org…	3. Sign petitions …	4. Pay more for recycled products. ..	5. Vote for env. cand…	6. Recruit others …	7. Speak out…	8. Reg. purchase goods…	9. Energy efficient appl.	10. Buy locally grown food…	11. Reg. maintain energy ...	12. Be a vegetarian …	13. Compost…	14. Reduce electricity cons..	15. Invest in a hybrid vehi…	16. Use alt. transp …	17. Pick up litter …	18. Fertil …	19. Pesti…	20. Use less water …	21. Reduce use of toxic…	22. Parti. in envir …	23. Parti. in habitat rest…	24. Vol. for an envir …
1	0.395	0.357	0.435	0.442	0.287	0.322	0.375	0.322	0.229	0.262	0.257	0.288	0.355	0.223	0.252	0.208	0.269	0.298	0.342	0.347	0.301	0.19	0.246
0.395	1	0.562	0.523	0.552	0.452	0.459	0.496	0.277	0.26	0.28	0.309	0.269	0.282	0.264	0.29	0.24	0.304	0.325	0.286	0.361	0.504	0.41	0.497
0.357	0.562	1	0.591	0.654	0.539	0.575	0.559	0.307	0.32	0.287	0.366	0.282	0.324	0.296	0.353	0.229	0.353	0.411	0.304	0.415	0.534	0.35	0.401
0.435	0.523	0.591	1	0.603	0.476	0.499	0.707	0.363	0.37	0.326	0.402	0.301	0.353	0.319	0.355	0.238	0.428	0.425	0.391	0.482	0.505	0.36	0.352
0.442	0.552	0.654	0.603	1	0.51	0.555	0.636	0.338	0.313	0.283	0.388	0.264	0.372	0.351	0.361	0.178	0.388	0.42	0.35	0.45	0.53	0.34	0.387
0.287	0.452	0.539	0.476	0.51	1	0.661	0.536	0.259	0.283	0.268	0.314	0.281	0.282	0.28	0.346	0.268	0.359	0.366	0.322	0.365	0.628	0.51	0.53
0.322	0.459	0.575	0.499	0.555	0.661	1	0.604	0.342	0.308	0.291	0.34	0.308	0.345	0.275	0.338	0.264	0.356	0.371	0.349	0.428	0.587	0.43	0.451
0.375	0.496	0.559	0.707	0.636	0.536	0.604	1	0.415	0.413	0.388	0.41	0.345	0.405	0.315	0.358	0.268	0.424	0.422	0.424	0.521	0.544	0.37	0.381
0.322	0.277	0.307	0.363	0.338	0.259	0.342	0.415	1	0.354	0.52	0.202	0.273	0.452	0.224	0.206	0.254	0.215	0.206	0.343	0.383	0.3	0.22	0.203
0.229	0.26	0.32	0.37	0.313	0.283	0.308	0.413	0.354	1	0.412	0.236	0.473	0.329	0.17	0.209	0.226	0.278	0.298	0.253	0.353	0.307	0.27	0.248
0.262	0.28	0.287	0.326	0.283	0.268	0.291	0.388	0.52	0.412	1	0.21	0.308	0.52	0.226	0.219	0.263	0.269	0.225	0.377	0.361	0.306	0.27	0.25
0.257	0.309	0.366	0.402	0.388	0.314	0.34	0.41	0.202	0.236	0.21	1	0.282	0.244	0.302	0.292	0.127	0.367	0.411	0.257	0.363	0.356	0.22	0.252

*Chart labels have been abbreviated here. Full titles are listed below.

	1. * Recycle …	2. Donate to an envir. or cons. org…	3. Sign petitions …	4. Pay more for recycled products...	5. Vote for env. cand…	6. Recruit others …	7. Speak out…	8. Reg. purchase goods…	9. Energy efficient appl.	10. Buy locally grown food…	11. Reg. maintain energy ...	12. Be a vegetarian…	13. Compost …	14. Reduce electric cons..	15. Invest in a hybrid vehi…	16. Use alt. transp…	17. Pick up litter …	18. Fertil …	19. Pesti …	20. Use less water …	21. Reduce use of toxic…	22. Parti. in envir …	23. Parti. in habitat rest…	24. Vol. for an envir …
13	0.288	0.269	0.282	0.301	0.264	0.281	0.308	0.345	0.273	0.473	0.308	0.282	1	0.378	0.225	0.283	0.254	0.316	0.322	0.272	0.305	0.315	0.297	0.271
14	0.355	0.282	0.324	0.353	0.372	0.282	0.345	0.405	0.452	0.329	0.52	0.244	0.378	1	0.242	0.273	0.292	0.315	0.293	0.525	0.446	0.358	0.28	0.258
15	0.223	0.264	0.296	0.319	0.351	0.28	0.275	0.315	0.224	0.17	0.226	0.302	0.225	0.242	1	0.415	0.138	0.279	0.251	0.192	0.236	0.321	0.21	0.223
16	0.252	0.29	0.353	0.355	0.361	0.346	0.338	0.358	0.206	0.209	0.219	0.292	0.283	0.273	0.415	1	0.217	0.318	0.33	0.299	0.328	0.393	0.307	0.315
17	0.208	0.24	0.229	0.238	0.178	0.268	0.264	0.268	0.254	0.226	0.263	0.127	0.254	0.292	0.138	0.217	1	0.179	0.155	0.279	0.238	0.301	0.283	0.247
18	0.269	0.304	0.353	0.428	0.388	0.359	0.356	0.424	0.215	0.278	0.269	0.367	0.316	0.315	0.279	0.318	0.179	1	0.742	0.391	0.477	0.433	0.357	0.369
19	0.298	0.325	0.411	0.425	0.42	0.366	0.371	0.422	0.206	0.298	0.225	0.411	0.322	0.293	0.251	0.33	0.155	0.742	1	0.402	0.501	0.427	0.319	0.333
20	0.342	0.286	0.304	0.391	0.35	0.322	0.349	0.424	0.343	0.253	0.377	0.257	0.272	0.525	0.192	0.299	0.279	0.391	0.402	1	0.501	0.402	0.313	0.315
21	0.347	0.361	0.415	0.482	0.45	0.365	0.428	0.521	0.383	0.353	0.361	0.363	0.305	0.446	0.236	0.328	0.238	0.477	0.501	0.501	1	0.468	0.327	0.326
22	0.301	0.504	0.534	0.505	0.53	0.628	0.587	0.544	0.3	0.307	0.306	0.356	0.315	0.358	0.321	0.393	0.301	0.433	0.427	0.402	0.468	1	0.597	0.629
23	0.194	0.413	0.354	0.356	0.336	0.506	0.429	0.372	0.215	0.265	0.274	0.223	0.297	0.28	0.21	0.307	0.283	0.357	0.319	0.313	0.327	0.597	1	0.682
24	0.246	0.497	0.401	0.352	0.387	0.53	0.451	0.381	0.203	0.248	0.25	0.252	0.271	0.258	0.223	0.315	0.247	0.369	0.333	0.315	0.326	0.629	0.682	1

*Chart labels have been abbreviated here. Full titles are listed below.

Environmental Stewardship Inter-Item Correlation Matrix key:

1. Routinely recycle paper, glass and plastics
2. Donate to an environmental or conservation organization
3. Sign petitions for environmental protections
4. Pay more for products made from recycled materials
5. Vote for candidates who advocate for environmental protections
6. Recruit others to participate in environmental causes
7. Speak out against harmful environmental practices
8. Regularly purchase goods from environmentally responsible companies
9. Purchase energy efficient appliances
10. Grow your own or buy locally grown food that is in-season.
11. Regularly maintain energy efficient heating and cooling zones
12. Be a vegetarian or pledge to eat less meat
13. Compost or participate in composting
14. Practice strategies to reduce electricity consumption
15. Invest in a hybrid vehicle or choose not to own a car
16. Use alternative transportation whenever possible (bicycle, mass transit, carpool)
17. Regularly pick up litter in my neighborhood
18. Choose not to use fertilizers
19. Choose not to use pesticides
20. Use less water in and around the home
21. Reduce use of toxic household products
22. Participate in environmental efforts organized by others
23. Participate in habitat restoration projects
24. Volunteer for an environmental or conservation organization

APPENDIX I

FACTOR LOADING TABLES FOR VALIDATED SCALES

1. MOTIVATION Rotated Component Matrix[a]			
	Component		
	1 - Extrinsic	2 - Intrinsic	3 -Identified Regulation
Because I think it's a good idea to be a citizen scientist.	-0.038	0.343	0.666
Because I enjoy doing it.	-0.077	0.772	0.330
Because I'm concerned about the environment.	0.084	0.167	0.794
Because other people will be disappointed in me if I don't participate in citizen science.	0.745	-0.088	-0.121
Because I enjoy getting involved in scientific activities.	0.088	0.517	0.349
Because people I look up to think it's a really good thing to be involved in citizen science.	0.725	0.070	0.000
Because I'm concerned about what could happen to me if I don't participate.	0.693	-0.052	0.288
Because it's fun to do.	-0.043	0.877	0.151
Because the project topic is really important to me.	0.044	0.361	0.682
For the recognition I get from others.	0.784	0.065	-0.149
For the pleasure I experience as a citizen scientist.	-0.001	0.833	0.116
Because I would feel guilty if I didn't get involved in citizen science.	0.729	-0.036	0.102
Because I'm concerned about what could happen to people I care about.	0.654	-0.122	0.373
Because I want people to see me as a good person.	0.796	0.063	-0.007
Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. a. Rotation converged in 5 iterations.			

2. PEM Rotated Component Matrix[a]			
	Component		
	Social	Data Use	Basic/Beginner
Gathered data and/or samples as often as suggested by the project protocol	0.082	0.063	0.897
Shared information about the project to the general public	0.520	0.245	0.350
Communicated project data or findings to politicians, decision makers, or media outlets	0.550	0.474	0.073
Used social media to communicate with project staff or other participants (email, list serve, Facebook, Twitter, blog posts, etc.)	0.669	0.186	0.046
Submitted data or reports as often as suggested by the project protocol	0.062	0.048	0.911
Recruited other participants	0.793	0.174	0.127
Trained new participants	0.805	0.162	-0.016
Sought answers to questions about a project or protocol	0.640	0.228	0.099
Explored publicly available project data	0.202	0.464	0.405
Created graphs and maps of project data	0.201	0.792	0.112
Used statistics and probability to interpret project data	0.199	0.858	0.058
Used project data to make or defend a scientific claim	0.325	0.733	0.004

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 4 iterations.

3. EFFICACY - Rotated Component Matrix[a]			
	Component		
	Learning	Doing	Negative Items
I think I'm pretty good at understanding science-related topics.	0.854	0.231	0.174
Compared to other people my age, I think I can quickly understand new science topics.	0.830	0.214	0.177
It takes me a long time to understand new topics.	0.321	0.008	0.849
I feel confident in my ability to explain science topics to others.	0.785	0.249	0.130
I think I'm pretty good at following instructions for (NestWatch, monarch, precipitation, eel, water quality, air quality) monitoring activities	0.146	0.854	0.146
Compared to other people my age, I think I can do (NestWatch, monarch, precipitation, eel, water quality, air quality) monitoring activities pretty well.	0.217	0.798	0.089
It takes me a long time to understand how to do (NestWatch, monarch, precipitation, eel, water quality, air quality) monitoring activities.	0.066	0.287	0.866
I feel confident about my ability to explain how to do (NestWatch, monarch, precipitation, eel, water quality, air quality) monitoring activities	0.346	0.692	0.124
Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. a. Rotation converged in 5 iterations.			

4. SKILLS - Rotated Factor Matrix		
	Factor	
	1	2
Collect data in a standardized manner	0.267	0.64
Use the (database to answer a (elated question	0.396	0.485
Interpret the meaning of data presented in maps, charts, graphs, etc.	0.27	0.809
Conduct statistical analyses using data	0.223	0.793
Use data as a source of evidence	0.272	0.802
Design a study	0.614	0.424
Communicate findings to others	0.669	0.4
Train others to participate	0.735	0.199
Collect data in a standardized manner	0.753	0.254
Use the (database to answer a (elated question	0.766	0.148
Interpret the meaning of data presented in maps, charts, graphs, etc.	0.672	0.334
Conduct statistical analyses using data	0.543	0.368
Extraction Method: Principal Axis Factoring. Rotation Method: Varimax with Kaiser Normalization. a Rotation converged in 3 iterations.		

5. ENVIRONMENTAL STEWARDSHIP - Rotated Component Matrix[a]					
	Component				
	Civic?	2 - home-based?	3 - participation	4 - toxicity	5 - transformative
Routinely recycle paper, glass and plastics	0.501	0.336	-0.030	0.155	0.093
Donate to an environmental or conservation organization	0.629	0.144	0.363	0.064	0.097
Sign petitions for environmental protections	0.730	0.136	0.251	0.145	0.160
Pay more for products made from recycled materials	0.705	0.247	0.130	0.260	0.150
Vote for candidates who advocate for environmental protections	0.770	0.158	0.155	0.198	0.181
Recruit others to participate in environmental causes	0.515	0.112	0.576	0.121	0.137
Speak out against harmful environmental practices	0.604	0.196	0.423	0.130	0.108
Regularly purchase goods from environmentally responsible companies	0.678	0.329	0.191	0.242	0.134
Purchase energy efficient appliances	0.320	0.690	0.007	-0.008	0.041
Grow your own or buy locally grown food that is in-season.	0.178	0.548	0.133	0.158	0.152
Regularly maintain energy efficient heating and cooling zones	0.161	0.744	0.110	0.060	0.073
Be a vegetarian or pledge to eat less meat	0.364	0.077	0.022	0.411	0.377
Compost or participate in composting	0.043	0.485	0.204	0.218	0.351
Practice strategies to reduce electricity consumption	0.196	0.708	0.096	0.213	0.073
Invest in a hybrid vehicle or choose not to own a car	0.224	0.126	0.060	0.056	0.794
Use alternative transportation whenever possible (bicycle, mass transit, carpool)	0.186	0.155	0.234	0.178	0.667
Regularly pick up litter in my neighborhood	0.033	0.464	0.376	-0.046	0.106
Choose not to use fertilizers	0.173	0.139	0.220	0.803	0.161
Choose not to use pesticides	0.239	0.104	0.165	0.823	0.153
Use less water in and around the home	0.201	0.506	0.184	0.442	-0.048
Reduce use of toxic household products	0.364	0.400	0.135	0.528	0.023
Participate in environmental efforts organized by others	0.432	0.183	0.636	0.240	0.164
Participate in habitat restoration projects	0.141	0.180	0.806	0.169	0.089
Volunteer for an environmental or conservation organization	0.234	0.112	0.794	0.171	0.087

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization. Rotation converged in 6 iterations