ABSTRACT

GEORGE, SHANNAN WHEAT. Investigation of the Scientific and Participant Outcomes of a Multi-Country Citizen Science Project in Water, Sanitation, and Hygiene. (Under the direction of Dr. Sarah J. Carrier and Dr. K.C. Busch).

Over the past twenty years, citizen science projects have grown to place more emphasis on public education and advancing science learning. People in all stages of life, cultures, and socio-economic backgrounds can benefit from learning science knowledge and skills based on real-world experiences afforded by citizen science. Citizen science projects allow participants the opportunity to not only learn scientific principles, but to also apply those principles to their everyday lives. Citizen science projects are one such example of informal learning experiences that offer opportunities for people to not only learn science but to experience it as well.

The purpose of this dissertation study was to better understand the science and participant learning outcomes resulting from a multi-country citizen science project. This study uses data from a water, sanitation, and hygiene project to answer research questions related to the use of citizen scientists as data collectors in a multi-country context. Ultimately, the goal of this research is to inform the field of informal science education by better understanding how training impacts the quality of data collected by citizen scientists and the educational, science learning, and social outcomes experienced by citizen scientists participating in a water, sanitation, and hygiene project.

The first chapter is a systematic literature review that characterizes the state of the evidence on how citizen science projects influence individuals through participant learning outcomes and science outcomes in various disciplines. Specifically, this study investigated how citizen science projects influence participants and science. The results suggest there is a need for

more rigorous studies that provide evidence on the outcomes achieved from citizen science projects.

A second chapter is a study that used quantitative research methods to develop a data quality index to assess the quality of public health data collected by citizen scientists in 14 low and middle income (LMIC) countries. The data quality index presented in this study can be used by citizen science projects in different disciplines. This data quality index score was also able to evaluate the quality of data from citizen scientists participating in expert-led training compared to those using the train-the-trainer approach. The results suggest there is no correlation between data quality and training groups.

The third chapter is a study that used qualitative research methods to gain an understanding of the scientific, social, and educational impacts of the project on citizen scientists. Specifically, this study explored the experiences of citizen scientists in terms of the educational, scientific, and social outcomes realized during this project. Implementation questionnaires and transcripts from Skype interviews from project participants were collected and analyzed for evidence of statements from previously published outcomes from citizen science projects. Of the representation statements, 57% were related to education, followed by 26% being social outcomes; surprisingly, only 17% related to science learning. Based on these findings it is recommended that designers of citizen science projects better align communication and project activities with desired outcomes.

Investigation of the Scientific and Participant Outcomes of a Multi-Country Citizen Science Project in Water, Sanitation, and Hygiene

by
Shannan Wheat George

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APPROVED BY:

Dr. Sarah J. Carrier Committee Co-Chair	Dr. K.C. Busch Committee Co-Chair
Dr. Gail Jones	Dr. Kathryn Stevenson

DEDICATION

This dissertation is dedicated to Zoë and Ari whose constant support and beautiful spirits have sustained me through this process.

BIOGRAPHY

Shannan Wheat George was born in Southern Virginia. Her parents, Herbert and Arnette Wheat, supported her curious nature and encouraged her to pursue a career in science. Shannan Wheat George is currently a Training Specialist at Water Institute at the University of North Carolina at Chapel Hill. Her work focuses on instructional design and the development of e-learning resources for international public health practitioners. She holds a B.S. in Marine and Environmental Science from Hampton University and a M.S. in Environmental Science and Public Policy from George Mason University. She lives with her husband and two daughters (Zoë and Ari) in Knightdale, NC.

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CHAPTER 1: INTRODUCTION

Since Americans spend up to 95% of their time outside of a classroom there is an opportunity for informal science education (ISE) to play a significant role in increasing science learning (Falk & Dierking, 2010). Formal science education takes place in classrooms from elementary school through colleges and universities by trained teachers. Teachers in formal K-12 classrooms must meet educational science standards and follow a specified curriculum. ISE takes place in non-classroom settings including science museums, community-based organizations, and after-school programs. The internet, television, films and books are also sources of ISE. While formal science education follows a pre-determined curriculum, ISE can be described as learning that results from voluntary participation and allows participants to choose topics of interest (Crane, Nicholson, & Chen 1994; Falk, 2001; Habig, Gupta & Levine, 2018; Hofstein & Rosenfeld, 1996).

Another distinction between formal and informal science education is the amount of time spent teaching science principles and theory versus practice. As more K-12 instructional time and funding is spent preparing for high stakes mathematics and literacy testing, there is a greater opportunity for informal settings to supplement the science education that occurs in K-12 classrooms (NRC, 2009; Sacco, Falk, & Bell, 2014). ISE also reaches a portion of the population that may not be served by formal K-12 education. People in all stages of life, cultures, and socio-economic backgrounds can benefit from learning science that includes knowledge and skills based on real-world experiences. Informal science learning experiences allow participants the opportunity to not only learn scientific principles, but to apply those principles to their everyday lives (NRC, 2009). Citizen science projects are one such example of informal learning experiences that offer opportunities for people to not only learn science but to experience it as well.

Citizen Science

Citizen science projects vary widely in who participates and at what levels of scientific research they are involved. Because of the amount of variation in citizen science projects and related activities, an umbrella definition that would cover each type of citizen science project is difficult to establish (Eitzel et al., 2017). The definition used in this dissertation is what Harris (2017) defines as "activities or programs in which members of the public collaborate with professional scientists on scientific research and monitoring in either scientist-led or community-led endeavors" (p. 65).

With roots dating back thousands of years to agricultural settings in ancient China, citizen science is not a new phenomenon, but given its complexity, the boundaries of the field are not clearly defined (Ceccaroni, Bowser, & Brenton, 2017; Hinkson et al., 2017; National Academies of Sciences, Engineering, and Medicine (NASEM), 2018; Tian et al., 2011). Part of the complexity lies in how citizen science projects are structured. Citizen science projects are designed to be opportunities for experiential education by individuals who are not professionally trained in a scientific discipline directly related to the project (Brossard, Lewenstein, & Bonney, 2005; NAMS, 2018; Wiggins & Crowston, 2011). NASEM (2018) highlights that "citizen science and research on science learning are mutually beneficial" (p.S-1). Citizen science is a way to explore how science learning occurs in a number of ways. Part of the diversity of citizen science exists in the way that it engages individuals of all ages and backgrounds in science, conservation and research (NASEM, 2018).

Types of Citizen Science projects

Citizen science projects are categorized by the level of involvement of their participants, project design, and goals (Ballard, 2017; Bonney et al., 2014; Shirk et al., 2012). Bonney, Ballard, McCallie, & Phillips (2009b) categorize citizen science projects into three groups based on level of participation: contributory, collaborative, and co-created. Wiggins and Crowston (2011) further classify citizen science projects by research goals and include action, conservation, investigation, virtual, and education focused projects. For the purposes of this dissertation, the Bonney et al. (2009b) classifications are used because they are the most inclusive and comprise projects of all disciplines and levels of involvement.

Contributory projects offer the least amount of input by participants. In contributory projects, professional scientists design the project and conduct analysis on data collected by citizen scientists (Bonney et al., 2009b; Shirk et al., 2012). These projects limit participant involvement to action-oriented tasks, mainly observation, identification, and monitoring of a species or phenomenon of interest (Beckler, 2016). In collaborative projects, citizen scientists expand their engagement by not only completing action-oriented tasks but also by often helping to devise research questions, design data collection methods, analyze data, draw conclusions, and communicate findings (Bonney et al., 2009b; Beckler, 2016). Co-created projects offer the most engagement for citizen scientists by allowing them to be actively involved in all stages of the project starting with project design (Bonney et al., 2009b; Shirk et al., 2012). These projects provide an opportunity for citizen scientists to define research questions, interpret data, and suggest next steps for future study (Beckler, 2016). Potential project outcomes are also determined by the project design. The type of project and the level of engagement experienced by the citizen scientists influences the extent of project outcomes that can be achieved.

Potential Outcomes from Citizen Science Projects

Citizen science projects have outcomes for 1) scientists and the field of science and 2) participants who engage in citizen science. One commonly cited science-related outcome of citizen science is that citizen scientists can collect scientific data and make observations on a scale that would be impossible for individuals or teams of researchers (Bonney et al., 2009a; Brossard et al., 2005). Bonter and Cooper (2009) argue that citizen science projects provide data for scientific advancement, and they "have been remarkably successful in advancing scientific knowledge" (p. 977). By engaging the public in science, citizen science projects also have the capacity to build connections between members of the community, scientists, and their environments.

Through engagement and communication, citizen science allows scientists to connect with the public. This communication can demystify scientific practices and build relationships in the communities where research is being conducted. These relationships are necessary to obtain the buy-in and access needed from the community for effective research. By strengthening these connections, attitudes towards science are often positively influenced, leading to greater conservation efforts, more informed environmental decision making, and project sustainability (Bonney et al., 2014 Brossard et al., 2005).

Citizen science has evolved over time, with projects focusing not only on science outcomes such increased conservation efforts, but also on participant outcomes including science learning and behavior change (Wiggins & Crowston, 2011). These outcomes are identified as individual learning outcomes (ILOs) (Kelemen-Finan, Scheuch, & Winter, 2018). For the purposes of this dissertation, ILOs are referred to as participant learning outcomes (PLOs) to emphasize the role of the individual as a participant in the citizen science project. Phillips (2005) takes a liberal definition of PLOs to include not only learning, but also changes in feelings, attitudes, and behaviors. PLOs are the result of a combination of scientific participation, engagement with scientists, and the use of educational materials (Brossard et al., 2005). While citizen science has made great strides to include positive outcomes for both scientists and participants, the field still faces challenges.

Challenges and Solutions

One particular challenge is that citizen science is not currently considered a mainstream data collection approach to science research (Cohn, 2008; Hunter, Abdulmonem, & Van Ingen, 2013; Kosmala, Wiggins, Swanson, & Simmons, 2016). Critics argue that there have been few published citizen science studies that measure the validity of data collected by citizen scientists (Bonney et al., 2014; Catlin-Groves, 2012). Bonney et al. (2014) acknowledge that papers related to citizen science have difficulty getting published and assert that the lack of publications is not because studies are not submitted, but rather because they are not valued and are often published in outreach sections of journals (Bonney et al., 2014).

While the lack of research on the quality of data citizen science projects is criticized, the reliability of these data sets is also questioned. Professional scientists question whether citizen scientists have the skills to collect data of the quality needed to inform important decisions regarding science and policy (Kosmala et al., 2016). Bonter and Cooper (2012) suggest that to become more widely accepted in the scientific community, citizen science projects must find ways to ensure that the data collected are of consistently high quality.

Although data collected by citizen scientists face criticism, there is potential to raise confidence in the quality of these data. Protocols, training, and oversight can help to increase the quality of data collected by citizen scientists (Bonney et al., 2014; Catlin-Groves, 2012). The use of data validation measures including quality assurance and compliance measures can help to ensure data sets collected by citizen scientists are fit for purpose (Bonney et al., 2014; Boudreau & Yan, 2004; Caitlin-Groves, 2012; Delaney, Sperling, Adams, & Leung, 2008). Although criticized, citizen science has the potential to positively impact the field of science and the individuals that participate in these projects (NASEM, 2008; NASEM, 2018; Shirk et al., 2012). However, because many of those who undertake citizen science projects fail to conduct evaluations, opportunities to identify the positive outcomes for science and participants often go unrealized (Bonney et al., 2014; Toomey & Domroese, 2008).

Evaluations in Citizen Science

While all citizen science projects are designed to achieve science-related outcomes, not all projects are designed to achieve PLOs. Citizen science projects can either be designed or repurposed for learning (Jordan, 2011). In projects that are repurposed for learning, learning outcomes were not a stated goal in the original project but were later promoted (NASEM, 2018). Proponents of citizen science refer to these unanticipated outcomes as "unintended byproduct(s)" (NASEM, 2018, p.15). Phillips et al. (2015) argues when projects lack stated goals, including those related to science learning there is no way to determine if these goals are being met. Therefore, the field of citizen science is left with a critical gap in understanding the effectiveness of its efforts.

Science in Society

The importance of having a society that has an informed, basic understanding of science is widely accepted (Brossard et al., 2005; Holbrook, 2007). This informed understanding is referred to as science literacy. In 1958, the term science literacy was introduced by both Paul Hurd and Richard McCurdy (Hurd, 1958; McCurdy, 1958). Science literacy is multifaceted and complicated, and over the years, many definitions have been offered. In an effort to define the concept, Shen (1975) proposed three categories of science literacy: practical, cultural, and civic. Practical scientific literacy refers to the application of basic scientific principles to make decisions about everyday life and improve living standards. Cultural scientific literacy addresses science as a means of understanding the world and is, therefore, a requirement of being an informed citizen. Cultural scientific literacy promotes the idea that citizens should know about science and its technological and societal implications. Civic scientific literacy applies the idea that a knowledge of scientific principles is needed for civic decision making that benefits communities as well as participants (NASEM, 2016; Shen, 1975). The three categories of science literacy addressed by Shen (1975) are applicable to all audiences, however an individuals' prior knowledge, interests and, cultural practices, greatly influence science learning. (NRC, 2009).

Research suggests that when an individuals' past experiences are leveraged and welcomed into educational environments science learning increases. However, when these experiences are undervalued science learning and interest is reduced (Knowles, 1984; NASEM, 2018). While embracing the prior knowledge that individuals bring to informal science environments is important, equally as important is understanding the sociocultural systems that impact how they develop science literacy (NASEM, 2016; NRC, 2009).

Sociocultural structures include but are not limited to economic systems, justice systems, healthcare systems, and educational systems. How individuals and communities access and interact with these systems have direct implications for science learning (NASEM, 2016). For example, foundational literacy is necessary for understanding scientific principles that result in science literacy. If educational opportunities do not exist, the skills necessary to develop science literacy may not be available (NASEM, 2016). The same concept applies to science literacy distributed in communities.

Communities rely on science literacy to make informed decisions about societal issues like renewable energy, climate change, and public health (Brossard et al., 2005; Conrad, 2011; Den Broeder, Devilee, Van Oers, Schuit, & Wagemakers, 2016). The result of science literacy at the community level are benefits to both scientists and the communities themselves. While seeking solutions to these issues communities often make meaningful contributions by creating scientific knowledge, which is a demonstration of science literacy (NASEM, 2016). It is also known that a community with more science literacy can make better science-related decisions (NASEM 2016).

When defining science literacy, Shen (1975) described billions of people in developing countries living in poverty and the human suffering caused by the lack of scientific knowledge related to health, nutrition, and agriculture in what he termed an “information gap” (p. 265). Shen acknowledged science literacy as an essential ingredient in improving conditions in the poorest parts of the world. Citizen science is one avenue for individuals of various cultures, ages and educational backgrounds to gain “socially robust knowledge” (Den Broeder, Devilee, Van Oers, Schuit, & Wagemakers, 2016, p. 4)

Importance of Water, Sanitation and Hygiene

Water, sanitation, and hygiene (WaSH) is a major tenet of public health and a global concern. Although access to clean drinking water and adequate sanitation facilities are recognized as a human right, 844 million people lack access to a basic drinking water source and 2.3 billion lack access to basic sanitation services (UN, 2010; WHO, 2017). Most people with inadequate services are in low- and middle-income countries (LMIC) (Bartram & Cairncross, 2010; Sobsey, Stauber, Casanova, Brown & Elliott, 2008; WHO, 2017). The lack of hygiene supplies in many parts of the world is staggering. Globally 80% of the world's population have inadequate access to materials for hand washing (Pruss-Usten et al., 2014). WHO (2017) estimates that in LMICs, 73% of the population lack soap and water or have no hand washing facilities. The health consequences of inadequate water and sanitation facilities are severe. These consequences include waterborne disease, malnutrition, and premature death (Pruss-Usten et al., 2014).

Burden of disease. The lack of clean and safe water, sanitation and hygiene facilities, and services in LMICs are linked to a number of diseases including diarrhea, cholera, dysentery, and malaria (Bartram & Cairncross, 2010; Pruss-Usten et al., 2014; Sobsey et al., 2008). Diarrhoeal disease is the second leading cause of death of children under five years old. Approximately 1.7 billion cases of childhood diarrheal disease are reported each year. Most of these cases could be prevented through improved drinking water and sanitation facilities (Arvai & Post, 2012; Sobsey et al., 2008; WHO, 2017).

Drinking contaminated water is not the only way people can become sick. Deficient domestic hygiene (e.g., access to soap and water), poor agricultural hygiene (e.g., sharing bathing facilities with animals), vector breeding grounds (e.g., mosquitos that carry malaria) and contaminated water systems (e.g., leaking pipes) can introduce contaminants and pathogens which cause disease (Pruss-Usten et al., 2014; Sobsey et al., 2008). Incidences of water-borne disease disproportionately occur in rural areas of LMICs as compared with urban areas (Bain, Wright, Christenson & Bartram, 2014; Sobsey et al., 2008).

Impacts on health and the economy. Solving the challenges presented by inadequate WaSH can have positive economic and health benefits. In areas where income is low and poverty rates are high, insufficient water and sanitation facilities have adverse economic impacts. Money that is used to provide healthcare for water and sanitation-related health conditions could instead be used for education, food, or business. Public health interventions can be used to effectively prevent death from diarrhea and increase access to safe and adequate WaSH facilities (Bartram & Cairncross, 2010). The international community has recognized how a lack of WaSH services impacts health, well-being, and the global economy and is working to solve these challenges by adopting international goals for sustainable development.

Sustainable development goals. Global water and sanitation targets are important because the United Nations estimates that by 2050, one in four people will live in a country impacted by shortages of clean water. Adopted in 2015, global water and sanitation targets were established in Goal 6 of the United Nations' Sustainable Development Goals (SDGs). The SDGs include targets for global access of safe water and adequate sanitation and hygiene. For example, target 6.1 calls for access to safe and affordable drinking water for all persons by 2030 (UN, 2010). Monitoring and evaluation data are used to track progress towards SDG targets and data are often collected through surveys (Bartram et al., 2014). Although surveys are extensively used in WaSH research, the World Health Organization (WHO, 2014) recognizes an international shortage of data collectors available to conduct WaSH surveys.

Data collectors are needed to conduct surveys to better understand WaSH conditions in regions and communities where there may be few trained professionals. The lack of trained professionals stem from many factors, including a reluctance of WaSH trained professionals to remain in rural communities and limited funding (Bonney et al., 2009a; WHO, 2014). Sending international professionals to rural communities to collect public health data is expensive and involves extensive time commitments which often make data collection impossible. Language barriers also present an issue when dialects and cultural norms can differ even within communities (Bonney et al., 2009a). In these cases, citizen scientists can be used to collect scientific data. Through the context of a multi-country citizen science project on WaSH this dissertation seeks to better understand how training impacts the quality of data collected by citizen scientists and the impact citizen science projects has on participants. This dissertation explores citizen science as it relates to public health, specifically, water, sanitation, and hygiene.

Context: Project Description

Established in 2010, The Water Institute at the University of North Carolina at Chapel Hill (Water Institute) is an interdisciplinary academic research center housed in the Gillings School of Public Health. The mission of the Water Institute is to "provide global academic leadership for economically, environmentally, socially, and technically sustainable management of WaSH for equitable health and human development" (Water Institute, 2017, p. 14). The activities of the Water Institute are focused in four primary areas: research, networking, teaching and learning, and knowledge management (Water Institute, 2017).

In 2017, the Water Institute was approached by an international aid organization to design and implement a program evaluation of their WaSH programs in 14 countries: Ethiopia, Ghana, Kenya, Malawi, Mali, Mozambique, Niger, Rwanda, Uganda, Zambia, Honduras, India, Tanzania, and Zimbabwe. The goal of the larger evaluation was to determine if WaSH conditions were better in areas where the aid organization had active programs (program areas) versus areas where the aid organization does not work (comparison areas) (Guo, 2018).

Although this dissertation only uses WaSH data from households and community water points, the larger program evaluation also examined WaSH conditions in schools and healthcare facilities. Survey data from households and community water points were chosen for this dissertation because these surveys had the largest number of respondents, which yielded a larger sample size and more opportunities to assess data quality.

The survey instrument for the larger program evaluation included questions on water (source type, distance to source, availability, water storage and treatment), water quality testing, and sanitation (type, functionality, condition, and use). The surveys were translated into local languages for each country program and questions were asked to the respondent or were observed and recorded by the citizen scientists. Survey responses were recorded using a mobile survey application (mWater) on a smartphone (Guo, 2018). At the time, the Water Institute did not have enough research staff to travel to the 14 countries and to collect the data from schools, healthcare facilities, community water points and households needed in the timeframe identified by the aid organization. The solution to this issue was to train citizen scientists to collect the survey data.

Staff from the aid organization's country program offices were responsible for recruiting citizen scientists. Due to differences in geography, language, culture, and climate, the selection process for citizen scientists was slightly different in each country. However, the Water Institute suggested that each country program recruit citizen scientists with the equivalent of a high-school education, experience using mobile phones, and proficiency in local languages. Researchers from the Water Institute traveled to five host country program sites (India, Honduras, Rwanda, Ghana, and Malawi) to facilitate training. These host country program sites were chosen because of their geographic locations and ability to provide the facilities and technology needed to conduct training activities. The host country sites also served as training centers for other country programs. Country programs involved in the project, but not identified as host country programs, were referred to as satellite country programs. Due to their geographic locations, satellite country programs did not participate in the training conducted in Honduras and India.

All citizen scientists from host country programs were trained directly by Water Institute researchers. Satellite country programs sent citizen scientists as representatives to the host countries to then become trainers for their country programs. These select citizen scientists then returned home to train citizen scientists using a train-the-trainer approach (Figure 1.1).

Figure 1.1. Example of train-the-trainer logistics in satellite and host countries.

Data collection training for the citizen scientists was developed by Water Institute researchers in the form of Power Point presentations, a website, and written guidance manuals. All educational materials were designed to be easily translated and adapted for a country's specific context (e.g. types of sanitation facilities and water sources). The goal of the training was to establish common protocols for data collection and to prepare citizen scientists to collect quality survey data (surveys are described in detail below). Trainers provided citizen scientists with the opportunity to practice data collection and reporting, use smartphones, develop interview skills, identify water and sanitation facilities, and conduct water quality testing.

As the training specialist for the Water Institute, I was responsible for working with researchers to ensure that training goals were identified and that training activities were appropriate to meet these goals. I also developed the project website and ensured that written materials were appropriate for participants with lower levels of English proficiency. After the training, I was responsible for administering post-training satisfaction surveys. The data collected during the 14-country NGO program evaluation were not originally collected for citizen science research. However, based on my role in the project, I became interested in learning more about how training impacted data quality and how project participation impacted the citizen scientists. This dissertation used data from the 14-country evaluation to answer research questions related to the use of citizen scientists as data collectors in a multi-country WaSH project.

Research Questions

Limited research has been conducted on citizen science in WaSH. A goal of this study is to inform the field of science education by providing a better understanding of the science and participant learning outcomes of a multi-country WaSH-related citizen science project. To address existing gaps in the literature, this study employed a mixed methods design to answer the following research questions:

1. How do citizen science projects influence participants and the field of science?
2. How can a data quality index be used to assess data quality in a citizen science project?
3. How does the data quality of citizen scientists trained by experts compare to those using a train-the-trainer approach?

4. What, if any, social, educational and scientific outcomes do citizen scientists report as a result of participation in a citizen science project?

Structure of this Dissertation

In this chapter, the topic of science literacy was introduced, along with how citizen science projects are informal science education experiences that can increase science literacy. The study context of a WaSH-based citizen science project was described followed by four research questions. Chapters 2, 3, and 4 are compiled as draft manuscripts, each including an abstract, introduction, research questions, methods, results, discussion, and implications.

Chapter 2 is entitled "Science and Participant Learning Outcomes from Citizen Science Projects: A Scoping Literature Review." This review characterizes the state of the evidence on how citizen science projects influence individuals through participant learning outcomes and various disciplines through science outcomes. This manuscript seeks to better understand the effectiveness of citizen science projects and the outcomes they produce.

Chapter 3, "Assessing Data Quality in a Multi Country Citizen Science Project," uses qualitative research methods to present a data quality index to assess the quality of data collected by citizen scientists in 14 low- and middle-income (LMIC) countries. The data quality index presented in this study takes steps towards building tools that can be standardized and used by citizen science projects in different disciplines.

Chapter 4 is entitled "Educational, Science Learning, and Social Outcomes from a Citizen Science Project in Water, Sanitation, and Hygiene." This chapter uses qualitative research methods to gain an understanding of the scientific, social, and educational impacts of the project on citizen scientists. Specifically, this study explores the experiences of citizen scientists in terms of the educational, scientific, and social outcomes realized during a WaSH project.

Finally, Chapter 5 synthesizes the conclusions and implications from the three chapters to highlight the impact of the overall dissertation. This chapter also presents recommendations, limitations, and implications for future research.

CHAPTER 2: Science and Participant Learning Outcomes from Citizen Science Projects: A Scoping Review

Abstract

The goal of this scoping literature review is to examine the landscape of participant learning outcomes (PLOs) and science outcomes from citizen science projects in various disciplines. Specifically, this study investigated how citizen science projects influenced participants and science. Findings suggest that although there is an abundance of grey literature, or literature not published in commercial form, published material on citizen science projects is lacking. The results of this research indicate there is a need for more rigorous studies that provide evidence on the outcomes achieved from citizen science projects. This work serves as a framework by which researchers can identify potential desired outcomes from future citizen science projects.

Introduction

Citizen science is not a new phenomenon but has its origins in agricultural settings dating back thousands of years (National Academies of Sciences, Engineering, and Medicine (NASEM), 2018; Tian et al., 2011). One of the earliest recorded instances of citizen science began when farmers in ancient China documented the seasonal appearance of locusts on crops (Tian et al., 2011). Citizen science projects have evolved over time and now operate in every discipline and around the world (Cooper, 2016; Jordan, Crall, Gray, Phillips, & Mellor, 2014; Wiggins & Crowston, 2011). Although thousands of citizen science projects exist, the term citizen science is not clearly defined (Ceccaroni, Bowser, & Brenton, 2017; Hinckson et al., 2017).

Citizen science projects vary widely in who participates and at what levels of scientific research are involved. Because of the amount of variation in citizen science projects, an umbrella definition that would cover each type of project is difficult to establish (Eitzel et al., 2017). Ballard, Dixon & Harris (2017) define citizen science as "activities or programs in which members of the public collaborate with professional scientists on scientific research and monitoring in either scientist-led or community-led endeavors" (p. 65). Within this literature review, NASEM (2018) definitions are used. The term 'project' refers to "citizen science experiences that are planned and constructed in service of specific citizen science goals" (pp. 1-4). The term 'activities' refers to the "kinds of things one might do or engage with while participating in citizen science" (NASEM, 2018, p. 5). For example, the Great Koala Count project engaged citizen scientists by asking them to do activities which included documenting koala sightings using a telephone application (app) or website. The data collected by the citizen scientists were used to assess the koala population and to help develop policies to improve koala management in the community (Hollow, Roetman, Walter, & Daniels, 2014).

Science Related Capital

Over time, citizen science has moved from a focus on data collection to one that places more emphasis on educating participants, which, through capacity building can positively impact communities (Jordan, Ballard & Phillips, 2019; Wiggins & Crowston, 2011). One way of building the capacity of communities is through science capital, essentially social and cultural capital related to science (Archer, DeWitt & Willis, 2014). More specifically, Archer, DeWitt, and Willis (2014) define science capital as "science-related qualifications, knowledge/ understanding, interest, literacy and social contacts" (p. 19). Science-related cultural capacity includes science literacy, science dispositions and preferences, and applying scientific knowledge to the job market (Archer, Dawson, DeWitt, Seakins, & Wong, 2015). Learning from science-related media and participation in science outside of the classroom, such as citizen science projects, are a form of capital associated with behaviors and practices related to science. Several categories such as contact with someone in a STEM field, being involved in science discourse, and future science aspirations comprise science-related cultural capital and can be gained through participation in citizen science (Archer et al., 2014; Archer et al., 2015).

Participant and Science Outcomes

Through contact with scientists and the environment, citizen science projects attempt to produce positive outcomes. These outcomes can vary greatly but include an increase participants' knowledge about science and the scientific process, strengthened connections to the environment, and positive attitude changes towards science (Brossard et al., 2005). Although not all outcomes related to participants address learning, those that do are identified as participant learning outcomes (PLOs) (Kelemen-Finan et al., 2018). The field of science benefits in that citizen science projects gather large data sets and make observations that would be impossible to capture by scientists alone (Bonney et al., 2009; Brossard et al., 2005). Citizen science projects also aid the field of science by building capacity in communities by increasing scientific literacy (Jordan et al., 2015). These outcomes are identified as science outcomes.

Evaluating Outcomes

As interest in citizen science project outcomes grows, so too does the need to understand and evaluate project goals and outcomes (Becker-Klein et al., 2016; McCormick, Brown & Zavestoski 2003; Wiggins & Crowston, 2011). While goals can be vague and hard to assess, outcomes are more concrete and specific, making them easier to measure. For example, a project goal may be for citizen scientists to develop a connection to their environment. An outcome of the same project may be for the citizen scientists to increase their knowledge of migratory birds through species identification. In this example, the goal would be difficult to assess as it would be hard to measure a person's connection to the environment. However, the outcome of an increased knowledge of migratory birds could be measured by pre- and post-project quizzes.

Citizen science projects can benefit from rigorous evaluations as there is a need to measure participant and science-related gains (Beckler-Klein et al., 2016; Broussard et al., 2005; Kelemen-Finan, et al., 2018). For example, to advance informal science education (ISE), in 2008, the National Science Foundation (NSF) issued a report detailing the impacts of ISE projects. This report recognized "the importance of front-end, formative, remedial, and summative evaluation in guiding projects, improving them, and ascertaining whether they achieve their intended outcomes" (Friedman et al., 2008, p. 8). Although evaluating outcomes is important and a priority for project designers, "it is often rated as one of their greatest challenges" (Phillips et al., 2014, p. 1). Phillips et al. (2014) report that without these project evaluations, a gap exists between understanding the effectiveness of citizen science projects and the outcomes they produce.

Evaluating Participant Learning Outcomes

Phillips et al. (2014) published a framework for evaluating PLOs from citizen science projects comprised of six outcomes: behavior and stewardship, skills of science inquiry, knowledge of the nature of science, motivation, self-efficacy, and interest in science and the environment. This framework draws from numerous works including Lederman's Nature of Science. The nature of science relates to the fundamental values and assumptions that lead to the development of scientific knowledge. The Phillips et al. (2014) framework was adapted for use in this literature review by incorporating aspects of the Framework for K-12 Science Education by the National Research Council (NRC, 2012) (Table 2.1). Adaptations include expanded definitions, substitution of the term ‘practices’ with ‘skills,’ and the elimination of the motivation outcome which was outside the scope of this literature review. These adaptations were done to make the framework more comprehensive for use in the current study.

Table 2.1.

Framework for Evaluating Participant Learning Outcomes (PLOs) from Citizen Science Projects

Outcomes	Definition
Behavior and Stewardship	Behavior change resulting from participation in a citizen science project includes commitment to the improvement of one’s community (local) or environment (global), sustained or new participation in a citizen science project, personal connections to the environment, and community or civic action
Scientific and Engineering Practices	Engagement in scientific and engineering practices including developing research questions or monitoring goals, designing the study and methods, collecting data, entering data, selecting and analyzing data, constructing explanations, making observations, obtaining, evaluating, and disseminating information
Knowledge of the Nature of Science	Demonstrated awareness, increased knowledge of, or understanding of the scientific process and how science is conducted by researchers; Includes scientific topics, disciplines, careers, concepts, and theories
Interest in Science and the Environment	Interest in pursuing science and environmental goals such as STEM careers and future citizen science project activities or to demonstrate an interest in learning more about a scientific concept, topic, or activity
Self-efficacy	Extent of confidence in his or her ability to participate in science or to successfully perform stewardship behaviors and think of themselves as making a positive contribution to science

NOTE: Adapted from (Phillips et al., 2014) and (NRC, 2012)

Evaluating Science Outcomes

Ballard et al. (2017) outline the science-related outcomes from a youth-focused citizen science project. The science outcomes resulting from Ballard et al. (2017) were combined with core ideas from science education outlined in the *Framework for K-12 Science Education* (NRC, 2012) to form the framework for science outcomes used in this literature review (Table 2.2). Science outcomes were divided among four outcomes: conservation and decision making, community, scientific recognition, and project sustainability. There is overlap between PLOs and science outcomes, particularly when it comes to building science literacy in a community. Only the science outcomes that are not included in the PLOs are presented in this review.

Table 2.2.

Framework for Evaluating Science Outcomes from Citizen Science Projects

Outcomes	Definition
Conservation and Decision Making	Improved conservation efforts, environmental protection, natural resource management, and informed policy resulting from data collected by citizen scientists
Community	Increases in capacity building, science capital, trust between scientists and the community, and strengthened networks
Scientific Recognition	Evidence that the data collected, and contributions made by citizen scientists was valued by accredited scientists
Project Sustainability	Ability to retain participants and maintain programming and associated benefits over time

NOTE: Adapted from Ballard et al., 2017; NRC, 2012

The goal of this study is to use these adapted frameworks to examine the landscape of PLOs and science outcomes from citizen science projects. Evidence was assessed across informal learning settings in various disciplines. Specifically, this study examines how citizen science projects influence participants and science.

Methods

Search Strategy

A scoping review is a research approach used to synthesize literature to identify key concepts and characteristics (Dijkers, 2015). In this study, literature was reviewed systematically to both identify and characterize outcomes from citizen science projects. The literature review was performed in January 2019. JSTOR, Scopus, and Web of Science were searched for relevant articles. The following search terms were used: "citizen science" and "outcome." Synonyms of citizen science (i.e., public participation in scientific research, participatory action research, participatory monitoring) were captured by searching broadly for the term citizen science in the body of the text.

Document Selection and Eligibility Criteria

Titles and abstracts from articles identified during the literature search were uploaded into Covidence, an online systematic review production tool for title/abstract screening, full text screening, and data abstraction. Abstracts and titles were reviewed to determine whether full text retrieval was necessary. Inclusion and exclusion criteria were determined prior to beginning the search and were amended after the first search results were obtained. Articles and theses that described specific citizen science projects were included. As suggested in Stepenuck and Green (2015), to address credibility, only studies that have been peer reviewed are included in this study. Articles that jointly addressed participant and science outcomes from citizen science projects are presented in this review.

Excluded were articles that were not published in English, did not describe a specific project, and were not published between 2000 and 2019. Literature reviews including systematic reviews were excluded. Also excluded were studies that did not evaluate an actual citizen science project but instead evaluated a type of citizen science project (i.e., contributory, collaborative, co-created). Citizen science projects associated with education in classroom settings were not included because the outcomes of these projects are usually associated with formal learning standards and may be different than those of projects outside the classroom.

The initial search identified 250 publications, and after removing two duplicates, the titles and abstracts of 248 publications were screened. After titles and abstracts were screened, 44 articles remained. The exclusion criteria were applied to the full articles, and data were extracted from 14 articles that are included in this study (Figure 2.1).

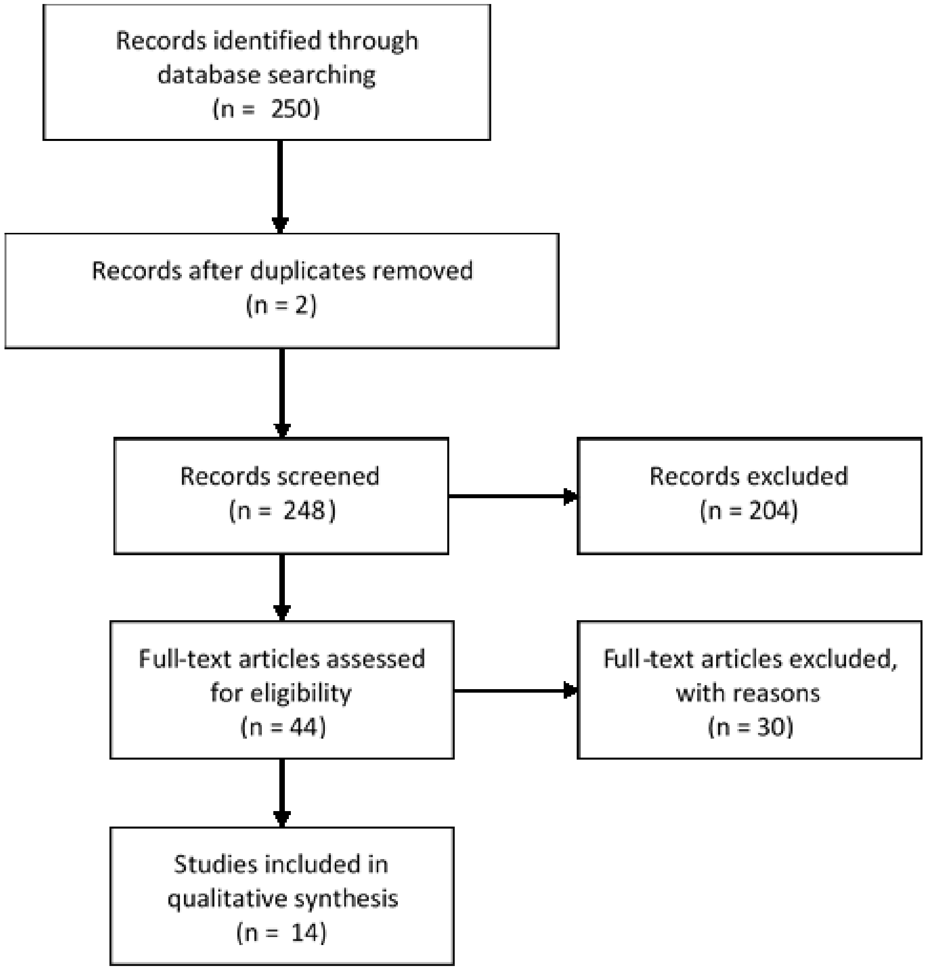

Figure 2.1. Flow diagram of screening and selection process of literature.

Data Analysis

Qualitative content analysis was conducted for all included literature, regardless of project type, using Microsoft Excel. In the first deductive round of coding, initial *a priori* codes were used to identify reported learning outcomes. Codes were guided by outcomes based on frameworks for evaluating participant learning outcomes from citizen science projects (Phillips et al., 2014; NRC, 2012) and frameworks for evaluating science outcomes from citizen science projects (Ballard et al., 2017; NRC, 2012). Once coded, tables were created to better illustrate the relationship between included studies and outcomes.

After the *a priori* coding, inductive open coding was used to identify subcodes that emerged from the data. Instead of testing theories as in deductive coding, inductive coding allows new theories to emerge from the data (Miles, Huberman, & Saldaña, 2014). Subcodes were hierarchically nested within the *a priori codes* (Table 2.3). For example, 'Conservation and Decision-making' is an *a priori code* while 'Enable and inform conservation actions' and 'Increased conservation of natural resources' are examples of subcodes within this *a priori code*. The addition of subcodes helps to further develop themes and facilitate comparative analysis (Bradley, Curry & Devers, 2007). Eight subcodes were created for the science outcomes, and 24 subcodes were created for the participant learning outcomes in this study. Reliability checks were not completed for these codes.

Table 2.3.

A priori Codes and Subcodes

A priori Codes	Subcodes
Science Codes	
Conservation Decision Making	Enable and inform conservation actions Increased conservation of natural resources Data collected were used to inform policy initiatives that address environmental issues
Project Sustainability	Ability to maintain programming and associated benefits over time Ability to retain participants Improved relationship between science and local community
Community	Increased science capital
Scientific Recognition	Contribution of citizen scientists was valued by accredited scientists
Participant Learning Outcomes	
Behavior and Stewardship	Independent work after project/continue project activities independently Greater appreciation for the environment/community/civic action Changes in behavior/decision making/opinion
Scientific and Engineering Practices	Methodologies/Tools Participation in data collection Development of science skills Making observations Disseminating information Data analysis
Knowledge of the nature of science	Increased awareness of science Increased knowledge/understanding of science and the scientific process Learning how science is conducted by scientists Scientific tools Science communication

Table 2.3. continued

Interest in science and the environment	Interest in pursuing future citizen science activities Increased interest in the environment Motivating others to have an interest in the environment Furthering formal education Interest in learning more about science and the environment Interest in learning more about the work of scientists
Self-efficacy	Confidence in communicating science with others Citizen science projects provide info for common good Citizen scientists make a meaningful impact on science Contributions to science research Increased confidence to make positive environmental action

Results

Describing the Sample

The articles in this dataset (Appendix A) reported on citizen science projects from the United States, Australia, Portugal, and the Philippines (Table 2.4). The articles were published in 10 different journals, with publication years spanning from 2001-2019. The projects focused on four areas: conservation, ecology, species management, and species mapping. With the exception of the East Bay Academy for Young Scientists (EBAYS) project (Ballard et al., 2017), all of the projects in this literature review were contributory in nature. In contributory citizen science projects, the role of citizen scientists is to collect data. Citizen scientists in contributory projects are not involved with the design of the project or the data analysis. Participants in the EBAYS project helped to disseminate research findings through presentations in the community and at professional scientific conferences. Program participants also used research findings to plan, implement, and monitor additional restoration work at the project site. This increased level of involvement by the citizen scientists made this a collaborative citizen science project (Ballard et al., 2017).

Table 2.4.

Summary of Reviewed Research Articles

Area of focus (number of publications, % of overall publications included in the review)	Conservation, Shoreline	(n=1, 7%)
	Conservation, Biology	(n=5, 36%)
	Ecology, Forestry	(n=1, 7%)
	Ecology, Biodiversity	(n=1, 7%)
	Species Management	(n=1, 7%)
	Species Mapping	(n=5, 36%)
Year of publication (number of publications, % of overall publications included in the review)	2008	(n=1, 7%)
	2011	(n=1, 7%)
	2012	(n=1, 7%)
	2013	(n=1, 7%)
	2014	(n=2, 14%)
	2016	(n=2, 14%)
	2017	(n=2, 14%)
	2018	(n=2, 14%)
	2019	(n=2, 14%)
Location (number of publications, % of overall publications included in the review)	United States	(n=9, 64%)
	Australia	(n=3, 21%)
	Philippines	(n=1, 7%)
	Portugal	(n=1, 7%)

The nature of this review is narrative and similar to Brainard and Hunter (2016) in that data extraction was limited to information that could be thematically characterized. The results for the science and PLOs are grouped and presented by outcome.

Science Outcomes

Science outcomes recognize the impact citizen science projects have on science. The framework of science outcomes adapted from Ballard et al. (2017) and NRC (2012) were grouped into four outcomes: conservation and decision making, community, scientific recognition, and project sustainability (Table 2.5). Outcomes related to conservation and decision-making were referenced in six of the studies in this review and seven studies addressed community and scientific recognition. The least recognized outcome was project sustainability (n=2). While none of the studies in this review addressed all science outcomes, Ballard et al. (2017) reported on three of the four science outcomes. Citizen scientists in the Ballard et al. (2017) study failed to report scientific recognition as a science outcome.

Table 2.5.

Science Outcomes by Article

Reference	Conservation and Decision-making	Community	Scientific Recognition	Project Sustainability
Ballard et al. (2017)	x	x		x
Cornwell et al. (2011)	x			
Dem et al. (2018)			x	
Domroese and Johnson (2017)			x	
Druschke and Seltzer (2012)		x	x	
Fernandez-Gimenez et al. (2008)*	x	x		
Ferreira et al. (2019)	x	x		
Hann et al. (2018)			x	x
Hollow et al. (2014)	x		x	
Martin et al. (2016)			x	
Roger and Klistorner (2016)		x		
Sickler et al. (2014)		x	x	
Toomey & Domroese (2013)*	x			

*article addresses more than 1 citizen science project

Conservation and decision making. Science outcomes related to conservation and decision making focused on projects that informed conservation actions, increased conservation of natural resources, and informed environmental policy. Most conservation and decision-making outcomes were related to projects that used data to enable and inform conservation actions (Table 2.6). Hollow et al. (2014) found that citizen science data were used to make policy decisions on the care and management of koalas. The authors stated that this project allowed for data to be collected in a greater geographic range than could be collected by scientists alone. Ballard et al. (2017), the lone collaborative study in this review, noted that data collected by youth participating in the EBAYS citizen science project contributed to the site management of the riparian zones they studied. The data collected by the citizen scientists informed management decisions of the local utility company which, in turn, led to water quality testing by the city and conservation of natural resources. These timely data were provided to the local environmental services department for follow up. Because these data aided the work of the department, the local water utility supported the project by providing needed materials that allowed for more testing (Ballard et al., 2017).

One study in this review found evidence that citizen science data were used to inform policy initiatives that addressed environmental issues. The forestry observation and monitoring data collected by citizen scientists at the Watershed Research and Training Center (WRTC) were used to address habitat degradation and a history of poor logging practices. These data were ultimately used to revise fire management policies in California forests. Specifically, the data were used in the design of subsequent thinning projects and to develop guidelines for timber harvesting (Fernandez-Gimenez, Ballard, & Sturtevant, 2008).

Table 2.6.

Subcodes of Conservation and Decision Making Outcomes

Subcodes	Citation
Enable and inform conservation actions	Ballard et al., 2017; Cornwell et al., 2011 Fernandez-Gimenez et al., 2008; Ferreira et al., 2019; Hollow et al., 2014
Increased conservation of natural resources	Ballard et al., 2017; Cornwell et al., 2011 Toomey & Domroese, 2013
Data collected were used to inform policy initiatives that address environmental issues	Fernandez-Gimenez et al., 2008

The relatively few articles that are represented in this outcome highlight the need for more long-term evaluation on the impact of data collected by citizen scientists on policy and decision-making. The research from this outcome also stresses the need to be intentional about the use of data and the desire to achieve policy outcomes. Citizen science can be useful in policy making because it allows the people who will adhere to the polices to be involved in the process.

Project sustainability. Only two studies made claims that related to project sustainability either through maintaining programming and benefits or retaining participants (Table 2.7). The EBAYS project conducted water quality testing that helped to identify point sources of pollution in local waterways. Since the testing conducted by the citizen scientists reduced the financial and human resources strain on the city's environmental services department, the city donated materials and labor to assist in sustaining the program (Ballard et al., 2017).

While Ballard et al., (2017) reported an inflow of materials to sustain a project, Hann, Stelle, Szabo, and Torres (2018) noted an inability to retain citizen scientists. The goal of the Whale mAPP project was to collect opportunistic marine mammal sighting data using an Android mobile app during the summer of 2014. Researchers found that after September 2014, over 72% of project participants had stopped using the app; after two years only one of the original participants continued to use the app, and after three years, none of the original citizen scientists were using the mWhale app. The authors realized that an increased effort to retain participants was needed for a "long-term successful" citizen science project (Hann et al., 2018, p. 13).

Table 2.7.

Subcodes of Project Sustainability Outcomes

Subcodes	Citation
Ability to maintain programming and associated benefits over time	Ballard et al., 2017
Ability to retain participants	Hann et al., 2018

Two major takeaways result from the literature reporting on project sustainability as a project outcome. The first is that a lack of published literature reporting on project sustainability can represent a lack of emphasis on sustainability across the broader citizen science community. Secondly, both projects in this outcome reference intentional citizen scientist recruitment. Ballard et al. (2017) refer to recruiting youth that will have an impact on conservation in the near and long term, and Hann et al. (2018) refer to recruiting participants with a background knowledge of the marine environment. Recruiting the right citizen scientists for the project has an impact on achieving outcomes related to project sustainability.

Community. Outcomes related to community refer to projects that improve relationships between citizen science projects and local communities, increase science capital, and promote healthier communities. It is interesting that although healthier communities was a potential outcome, none of the studies included in this review noted this result (Table 2.8).

Ferreira, Soares, and Andrade (2019) simply mention that general citizen science projects help to decrease the gap between science and communities. Evans, Abrams, Reitsma, Roux, Salmonsen, and Marra (2005) go further and examine the Neighborhood Nestwatch project whose goal is to foster citizen scientists' science literacy and connection to place. The project goals were accomplished through citizen scientists who collected data on birds in Washington, DC. Community related outcomes stemming from this project included the personal connections made between scientists and citizen scientists and the development of community partnerships. Transcripts of interviews with citizen scientists noted how the scientists and citizen scientists were able to make personal connections through real time communication. Through these interactions, scientists were able to answer the citizen scientists' questions and allowed the citizen scientists to observe the scientists in action.

Evidence of a citizen science project increasing science capital was presented by Sickler, Cherry, Allee, Smyth, and Losey (2014). The Ladybug Project engaged citizen scientists in research on the species distribution and conservation of ladybugs in the United States. Project researchers termed citizen scientists that demonstrated above average data collection skills and engagement "super-spotters" (p. 117). Project staff highlighted the need to develop more super-spotters. These super-spotters exhibited greater scientific engagement and had the ability to increase the science capital of their communities by recruiting additional citizen scientists.

Biological surveys, like the WPC BioBlitz events, where citizen scientists worked to catalog flora and fauna, increase science capital by making it easier for hard to reach audiences to participate in community science activities. Although the WPC BioBlitz activity did not collect demographic information researchers noted that citizen scientists from the local Sydney community, across Australia, and international visitors participated in the event (Roger & Klistorner, 2016).

Table 2.8.

Subcodes of Community Outcomes

Subcodes	Citation
Improved relationship between science and local community	Ballard et al., 2017; Druschke & Seltzer, 2012; Evans et al., 2005; Ferreira et al., 2019 Roger & Klistorner, 2016
Increased science capital	Evans, et al., 2005; Fernandez-Gimenez et al., 2008; Roger & Klistorner, 2016; Sickler et al., 2014

Overall, the literature that provides evidence of community outcomes emphasizes the need to alleviate the gap between science and society by improving relationships and building trust between scientists and the community. Citizen science provides an opportunity to clarify science, makes scientists approachable, and can translate scientific results for non-scientists. Citizen science can also help to build avenues to increase community interest and can increase interest in science learning at the community level, encouraging additional participation beyond data collection.

Scientific recognition. Scientific recognition focused on evidence that the contribution of citizen scientists was valued by scientists (Table 2.9). The value of citizen scientist collected data was explored by few publications in depth. One exception was Dem et al. (2018), who state the specific amount of data collected by citizen scientists and note that of the of the 695 pictures submitted by citizen scientists, 289 were “considered good for scientific research” (p. 3).

However, not all studies address scientific recognition in detail. The Lost Ladybug project found that only when researchers began to work with the data provided by the citizen scientists did they recognize its potential for advancing research (Sickler et al., 2014). Druschke and Seltzer (2012) simply commented that in the Chicago Area Pollinator Project, citizen scientists collected valuable data that contributed to a useful list of Chicago area bees.

The findings of some studies did not consider the data collected by citizen scientists to be of value. Martin, Christidis, Lloyd and Pecl (2016) found the citizen scientist-collected data to be insufficient for making marine management decisions. Hollow et al. (2014) recognize the potential of the data collected by citizen scientists. They describe mWhale app data to be potentially useful but only if it citizen scientists continued to use it to collect data.

In a citizen science project focused on the conservation of bee species in New York City, Domroese and Johnson (2017) acknowledge the responsibility of project researchers to inform citizen scientists of the value of the data they collect and how it will be used to advance science. Also highlighted is the difficulty in getting timely feedback to citizen scientists on how their data are contributing to scientific knowledge. The authors suggest that intermediate reporting, though incomplete, may help to keep citizen scientists engaged.

Table 2.9.

Subcodes of Scientific Recognition Outcomes

Subcodes	Citation
Contribution of citizen scientists was valued by accredited scientists	Dem et al., 2018; Domroese & Johnson, 2017 Druschke & Seltzer, 2012; Hann et al., 2018 Hollow et al., 2014; Martin et al., 2016 Sickler et al., 2014

Literature that includes examples of scientific recognition outcomes suggests that part of the role of scientists as ambassadors of science is that they communicate with citizen scientists and the community members where the research is being conducted (Druschke & Seltzer, 2012). This two-way communication channel is a valuable and necessary tool that can help to draw new participants, retain current participants, and to get buy-in from members of the community. This communication includes recognition of the contribution of current project participants as well as increased outreach on what is required of program participants, the educational opportunities involved with project participation, and reasons for participation. These additional messages can help to encourage improvements in current citizen scientists and to sustain the project over time.

Participant Learning Outcomes (PLOs)

PLOs highlight the impact of citizen science on project participants. In this review five outcomes resulting from Phillips et al. (2014) and (NRC, 2012) were identified as PLOs (Table 2.10). Evidence of behavior and stewardship was reported in 11 of the 14 articles presented in this literature review. Of the 14 articles described in this review, eight explicitly reference engagement with scientific and engineering practices, an increased interest in science and the environment, and self-efficacy.

Table 2.10.

Participant Learning Outcomes (PLOs) by Article

Reference	Behavior and Stewardship	Scientific and Engineering Practices	Knowledge of the nature of science	Interest in science and the environment	Self-efficacy
Ballard et al. (2017)	x	x	x		x
Cornwell et al. (2011)	x		x		x
Dem et al. (2018)		x	x		x
Domroese et al. (2017)	x	x	x	x	x
Druschke & Seltzer (2012)	x		x	x	x
Evans et al. (2005)	x	x	x		
Fernandez-Gimenez (2008)*	x	x	x	x	
Ferreira et al. (2019)	x	x	x		
Hann et al. (2018)			x	x	
Hollow et al. (2014)	x	x	x	x	
Martin et al. (2016)	x		x		x
Roger and Klistorner (2016)	x	x	x	x	
Sickler et al. (2014)		x	x	x	x
Toomey & Domroese (2013)*	x		x	x	x

*article describes more than 1 citizen science project

Behavior and stewardship. The behavior and stewardship outcome is focused on changing individual citizen scientists' past behavior, developing personal connections to the environment, and making a commitment to future civic action. Behavior change resulting from participation in a citizen science project is often evidenced by participants taking steps to improve their community (local) or environment (global). Positive changes in behavior and stewardship are goals of many citizen science projects and often reported in final evaluations.

Behavior and stewardship related actions were identified as outcomes for citizen scientists in the studies included in this review in a variety of ways. Citizen scientists revealed an appreciation for animals, commitments to make better environmental choices, an interest in continuing citizen science activities, and connecting to nature and community (Table 2.11). Behavior changes were evident not only in participants but in onlookers as well. For example, in one study, Hollow et al. (2014) reported that both project participants and onlookers reported positive changes in views towards koala management in Southern Australia. These positive changes in stewardship were linked with interest in future project participation.

The World Park Congress (WPC) BioBlitz project provided an opportunity for interested community members to engage with scientists in Sydney, Australia. Post-event surveys indicated that the citizen scientists had positively changed their "perception of science and the natural world" (p. 9). One participant responded that they "always had an interest but [this] project made me want to be more proactive" (Roger & Klistorner, 2016, p. 9).

Table 2.11.

Subcodes of Behavior and Stewardship Outcomes

Subcodes	Citation
Independent work after project/continue project activities independently	Ballard et al., 2017; Ferreira et al., 2019
Greater appreciation for the environment/community/civic action	Cornwall et al., 2011; Domroese et al., 2017 Evans et al., 2005; Ferreira et al., 2019 Martin et al., 2016; Roger & Klistorner, 2016 Toomey & Domroese, 2016
Changes in behavior/decision making/opinion	Druschke & Seltzer., 2012 Evans et al., 2005; Hollow et al., 2014 Martin et al., 2016; Roger & Klistorner, 2016 Toomey & Domroese, 2016

Studies that gave evidence of behavior and stewardship outcomes also highlighted the need for intentional recruitment, specifically in terms of sustained conservation behavior, which increases the impact of the citizen science project. The studies listed in this outcome suggest that past behavior and interest in conservation efforts increase the tendency for project-related behaviors to carry over after the project. Studies also suggest that participation in a citizen science project where citizen scientists are encouraged to communicate formally or informally within the community allows participants to become project advocates, getting buy-in and, at times, turning onlookers into active participants.

Scientific and engineering practices. To be considered a citizen science project, non-experts must participate in some level of scientific data collection, monitoring, analysis or dissemination. Since the 13 of the 14 articles were contributory in nature, it was not surprising that the most referenced PLO related to scientific and engineering practices was participation in data collection (Table 2.12). Although all the studies used citizen scientists to collect data, only 50% of the articles in this review identified data collection as a PLO.

Dem et al. (2018) and Ballard et al. (2017) highlight the importance of adapting protocols and methods to ensure data quality. During the Flying Beauties project, citizen scientists collected data on dragonflies and butterflies in rice ecosystems. Researchers associated with the project specifically described an approach that treated citizen scientists as individual learners. This individualized approach can take more time for researchers but can be an important step in ensuring data quality and, more importantly, building relationships with citizen scientists (Dem et al., 2018).

While all the articles in this literature review describe how citizen scientists engaged with scientific and engineering practices, not all articles reported this engagement as an PLO or benefit. Hann et al. (2018) describe the use of an Android mobile app (Whale mAPP) by citizen scientists to record marine mammal sightings in Southeast Alaska (USA). The authors describe the generation of a dataset by citizen scientists but do not list engaging with scientific and engineering practices as an outcome of project participation.

Few articles address citizen scientists engaging in scientific and engineering practices beyond collecting and entering data (NRC, 2012). A goal of the Neighborhood Nestwatch project was for citizen scientists to collect data to help researchers understand the ecology and population dynamics of avian species in Washington, DC. The project was contributory in nature, meaning the project was designed for citizen scientists to only collect data. However, the authors also presented evidence of citizen scientists in this project asking questions related to methodology, reporting observations, and drawing scientific conclusions which indicated a higher order of scientific thinking (Evans et al., 2005).

Table 2.12.

Subcodes of Scientific and Engineering Practices Outcomes

Subcodes	Citation
Methodologies/Tools	Dem et al., 2018; Ferreira et al., 2019; Sickler et al., 2014
Participation in data collection	Ballard et al., 2017; Cornwell et al., 2011 Domroese et al., 2017; Ferreira et al., 2019 Hollow et al., 2014; Roger and Klistorner, 2016
Development of science skills	Sickler et al., 2014
Marking observations	Domroese et al., 2017; Evans et al., 2005
Disseminating information	Ballard et al., 2017
Data analysis	Ballard, et al., 2017

Lessons learned from publications in this outcome include the need for scientists to treat citizen scientists like individuals by recognizing their diverse sociodemographic backgrounds. By understanding participants at the individual level, scientists can better determine what project related resources citizen scientists actually utilize and why. Literature also suggests that communication is key and when citizen scientists collect the data that is used as the basis for policy decisions as it promotes a sense of ownership that may sustain policy decisions over time.

Knowledge of the nature of science. This outcome was demonstrated through identification of species, wildlife management, use of tools, understanding of the scientific processes, science communication, and capacity building/training (Table 2.13). The most frequently reported example of knowledge of the nature of science was an increased knowledge/understanding of science and the scientific process (n=12). Evidence of knowledge of the nature of science was the only PLO addressed by all articles in this study (n=14).

When describing the PLOs of the WPC BioBlitz, project Roger and Klistorner (2016) note that working alongside experts benefited citizen scientists by helping them gain skills and better understand scientific processes. In this project, collaborating with experts helped to increase citizen scientists' scientific knowledge and was noted by citizen scientists as one of the highlights of the project. A single article described citizen scientists increasing their knowledge by using scientific tools. Ferreira et al. (2019) described how citizen scientists used a quantitative technique that could be applied to other settings. While Ferreira et al. described how the use of scientific tools increased knowledge, Sickler et al. (2014) recognized that adult participants in the Lost Ladybug Project wanted more tools to aid in species identification.

Science communication or sharing scientific knowledge with others was also a part of the knowledge and nature of science outcome. An example is the WPC BioBlitz project in which participants acknowledged that science communication and learning were important components of the project. Experts working with the BioBlitz project addressed the need to shift from having experts to simply educate the public to creating a dialogue where scientists and non-experts reciprocate learning (Roger & Klistorner, 2016).

Table 2.13.

Subcodes of Knowledge of the Nature of Science Outcomes

Subcodes	Citation
Increased awareness of science	Dem et al., 2018; Martin et al., 2016
Increased knowledge/understanding of science and the scientific process	Ballard et al., 2017; Cornwell et al., 2011 Domroese et al., 2017; Druschke et al., 2012 Evans et al., 2005; Ferreira et al., 2019; Hann et al., 2018; Hollow et al., 2014; Martin et al., 2016; Roger and Klistorner, 2016; Sickler et al., 2014; Toomey & Domroese, 2013
Learning how science is conducted by scientists	Roger & Klistorner, 2016
Scientific Tools	Ferreira et al., 2019
Science communication	Ballard, 2017; Roger & Klistorner, 2016

When scientists and citizen scientists interact, both groups can learn from each other. As previously noted, it is important for scientists to be project ambassadors and to be able to communicate with non-scientists in a manner that they can understand. It is only then that citizen scientists can understand the scientific process and be able to share information about the project with community members who are also potential participants. Studies in this outcome highlight the need for evaluation in order to assess knowledge gained through pre- and post-project surveys.

Interest in science and the environment. Outcomes related to interest in science and the environment were noted in 57% (n=8) of the articles reviewed in this study. Within this outcome, six subcodes emerged as evidence that citizen scientists were interested in future scientific endeavors (Table 2.14). One of the subcodes identified was an interest in citizen scientists to participate in future group projects. Hollow et al. (2019) report that over 90% of citizen scientists who responded to a survey after the Great Koala Count indicated they would participate in another count. Not only did the citizen scientists plan to participate in future projects, but 54% of onlookers planned to participate as well. Similarly, Roger and Klistorner (2016) recognize the potential of citizen scientists to have positive impacts that extend beyond those actively engaged in the projects.

Table 2.14.

Subcodes of Interest in Science and the Environment Outcomes

Subcodes	Citation
Interest in pursuing future citizen science activities	Hollow et al., 2014; Roger & Klistorner et al., 2016
Increased interest in the environment	Roger & Klistorner, 2016; Toomey & Domroese, 2013
Motivating others to have an interest in the environment	Roger & Klistorner, 2016
Furthering formal education	Roger & Klistorner, 2016
Interest in learning more about science and the environment	Domroese et al., 2017; Hann et al., 2018 Sickler et al., 2014
Interest in learning more about the work of scientists	Sickler et al., 2014

An interest in science and the environment was sometimes identified as a desire to learn more about science. This learning was evidenced in many ways including participants pursuing an educational degree related to the project, learning more about science and the environment, and learning more about the role of scientists. One citizen scientist who participated in the WPC BioBlitz revealed that the project was one of the factors that contributed to him/her enrolling in a Masters in Wildlife Management program (Roger & Klistorner, 2016). Citizen science projects were referred to as “a gateway to learning more” by a participant in the Great Pollinator project which was geared towards improving conservation efforts and raising awareness of bees in New York, NY (Domroese & Johnson, 2017, p. 44). Druschke and Seltzer (2012) recognize an interest in science and the environment as a potential outcome and acknowledge that the Chicago Area Pollinator project failed to achieve this outcome. A post-project survey revealed that citizen scientists did not want to learn more about bees, nor did they consider themselves advocates for urban wildlife. Outcomes related to interest in science and the environment rely solely on the opinions of the participants. For this outcome, researchers highlight the need for participant feedback to understand their experience but also to align science and participant goals when able.

Self-efficacy. Outcomes related to self-efficacy are characterized by an increase in the confidence of citizen scientists to perform environmental stewardship and to participate in and contribute to scientific endeavors (Table 2.15). Studies in this review identified areas where self-efficacy increased and areas where citizen scientists failed to report increased self-efficacy. In its list of missed opportunities, the Chicago Area Pollinator (CAP) project reported its failure to help citizen scientists understand the importance of their contribution to the project. Evidence of this failure was apparent when fewer respondents agreed in the pre-project survey than the post-project survey with the statement “I think that it’s important that nonscientists get involved with scientific research” (Druschke & Seltzer, 2012, p. 183).

Even within the same project, there were examples of both an increase and decrease in confidence. Responses from a survey submitted to citizen scientists at the completion of the Lost Ladybug Project revealed that adults strongly agreed that the project had a meaningful impact on science and that scientists valued their work (Sickler et al., 2014). However, at the end of the project, participants were less confident in their individual ability and contribution to science.

Interestingly, there was no link between their “perceived value of themselves and the work of the scientists” (Sickler et al., 2014, p. 114).

One interesting finding was in the North Carolina Sea Turtle Project that used citizen scientists to collect data on sea turtle nests and to monitor beaches with the goal of ensuring viable hatchlings (Cornwell & Campbell, 2011). The citizen scientists in this study engaged in debates over issues related to turtle management like nest relocation. Even though the citizen scientists in this project played an integral role, they downplayed their scientific ability. One project participant commented that “the scientists, they have the training, they have the knowledge about science … that a volunteer is not going to have” (p. 107). The citizen scientists in this project adhered to a hierarchy and even when asked their opinions about policy or sea turtle management, they would begin the conversation with “I’m not a scientist [but]…” (Cornwell & Campbell, 2011, p. 107).

Table 2.15.

Subcodes of Self Efficacy Outcomes

Subcodes	Citation
Confidence in communicating science with others	Toomey & Domroese, 2013
Citizen science projects provide info for common good	Martin et al., 2016
Citizen scientists make a meaningful impact on science	Druschke and Seltzer, 2012; Sickler et al., 2014
Contributions to science research	Cornwell et al., 2011; Dem et al., 2018 Domroese et al., 2017; Sickler et al., 2014 Toomey & Domroese, 2013
Increased confidence to make positive environmental action	Ballard et al., 2017; Toomey& Domroese, 2013

Publications in this outcome highlight the need for intentional participant recruitment, not only to understand who wants to participate, but also to determine what activities they feel comfortable participating in as comfort level may greatly impact self-efficacy. These publications also suggest the need for standardized tools to assess and provide evidence to support changes in self-efficacy that result from participation in a citizen science project.

Discussion

The goal of this scoping review was to determine how citizen science influences individual participants and science. The study adapted existing frameworks which were used as codes for identifying PLOs and science outcomes from citizen science projects in existing scientific literature. The studies in this dataset originated in four countries and were published in 10 different journals. The projects focused on four areas: conservation, ecology, species management, and species mapping.

Science outcomes relate to benefits that citizen science has on scientists and the scientific process. Science or programmatic outcomes were less reported than PLOs and divided among four outcomes. The most commonly addressed science outcome was scientific recognition of the importance of data collected by citizen scientists at 50%. The least reported was project sustainability which was only addressed by 14% of the articles identified in this literature review.

The benefits realized by individuals participating in the citizen science project were identified as PLOs. This review identified five outcomes and 24 subcodes to classify the PLOs. The most frequently referenced PLO was knowledge of the nature of science which was identified by all the studies published in this review. Although the projects presented in this review represent a wide variety of topics and designs, they have common themes included the importance of communication, intentional recruitment, and shared measures of evaluation.

Communication

Overall, the literature suggests that multiple lines of communication are necessary to help ensure a successful citizen science project. Communication between the scientists and participants, the scientists and the community, and between the community and project participants are key, not only for goals to be met, but also for project sustainability. Studies have shown the importance of scientists communicating with non-professionals to demystify the processes and to make non-scientists more comfortable with scientists (Domroese & Johnson, 2017; Roger & Klistorner, 2016). It is also important for scientists to acknowledge the important role that citizen scientists play in collecting data and what is expected of program participants. Domroese and Johnson (2017) suggest that it is the responsibility of the researchers to inform citizen scientists of the importance of the data being collected. This aligns with other studies that support the idea that providing citizen scientists with positive reinforcement that the project is advancing science helps keep them engaged (Jollymore, Haines, Satter & Johnson, 2017). This positive reinforcement can also help researchers recruit new citizen scientists and get buy-in from members of the community.

Outcomes related to societal benefits were evident in 43% of the studies. This number could be increased and demonstrates a missed opportunity for citizen science projects to improve relations between science and the community and to increase science literacy at the community level (Kelemen-Finan et al., 2018). It is important for citizen science projects to be designed to build a connection between citizen scientists and their environment. These connections can lead to healthier communities and environments which, interestingly, was not addressed by any of the studies in this review. Communication with the community can also encourage additional participation beyond data collection. However, while communication can lead to increased interest in participation in citizen science projects, it is important to first recruit the right participants.

Intentional Recruitment

Studies included in this review identified a need to recruit the 'right' citizen scientists. This includes citizen scientists of a particular demographic that best fits the needs and goals of a project. For example, to help ensure sustainability, Ballard et al. (2017) recruited youth that will have an impact on conservation in the near and long term. Hann et al. (2018) recruited participants with a background knowledge of the marine environment who would have interest in collecting data beyond the initial project period. Also highlighted in this review was that past behavior and interest in conservation efforts increase the tendency for project-related behavior to carry over after the project. When designing citizen science projects, one of the critical questions for researchers to answer is whether the project is designed to 'convince the converted' by recruiting citizen scientists who have demonstrated or shown an interest in conservation behavior in the past or recruiting participants who may be new to conservation in an attempt to increase science learning.

Shared Measures of Evaluation

"As an emerging field, citizen science has opportunities to grow, to contribute to what we know about how people learn science, and to broaden participation in science (NASEM, 2018, p. 155). However, to reach its full potential in informal science education as a way for individuals and communities to learn and participate in science, it will be necessary for citizen science to develop structured supports including tools and shared measures of evaluation (NASEM, 2018).

Grack, Goeke, Auster, Peterman & Lussenhop (2019) describe shared measures as "an instrument developed to measure a particular outcome or construct that is common across a range of programs, projects, or the [informal science education] field writ large" (p. 60). Currently informal science education and in particular citizen science lacks comprehensive shared measures to assess individual and science outcomes (NRC, 2009). Shared measures allow comparison between programs but also allows evaluators and researchers to save resources (time and money) by not having to create tools and using previously validated tools can increase confidence in the resulting data (Grack, 2019). As shared measures are used more consistently the evidence base for citizen science and informal science education also increases leading to the eventual development of theoretical frameworks designed specifically for citizen science (Grack, 2019; NRC, 2009).

In an effort to increase the citizen science evaluation base, 32 subcodes were created to allow for deeper connections between projects in this review. Not only do subcodes increase the strength of comparative analysis, providing more a more comprehensive list of possible outcomes can also increase science learning in future projects.

Limitations

There are several limitations which may affect the internal and external validity of the findings. First, articles that were not published in English were not included in this study and outcomes from some projects may have been missed. Second, because this study focused on peer- reviewed literature, grey literature was not included as a source of information. Since many citizen science projects publish information online, outcomes from these projects are not presented here. Additionally, misclassification bias may have occurred due to assuming a lack of information in the publication is akin to a lack of outcomes where, in fact, the outcome was achieved but the information was not provided.

Implications

There are several contributions of this review to the citizen science evidence base. This scoping review provides a status of the state of evidence on PLOs and science outcomes from citizen science projects. It has the benefit of being a multi-discipline review that can be used for various types of citizen scientist projects. Findings from this review also suggest that while there is an abundance of grey literature reporting on outcomes from citizen science projects, published material is lacking. The results suggest a need for more rigorous studies that provide evidence of the outcomes achieved.

Findings from this review also indicate a need for researchers and practitioners of citizen science projects to be intentional in the recruitment of citizen scientists. This recruitment should include an understanding of the sociodemographic factors that may impact interest in the topic and the ability to collect quality data.

Finally, the review revealed a need for common assessment tools and frameworks that allow outcomes from different citizen science projects to be compared. The adapted framework and subcodes included in this study can be used as a foundation for other citizen science projects to identify potential outcomes that may be achieved. Coordination and standardization of assessment tools and frameworks can increase the level of academic rigor in citizen science projects.

CHAPTER 3: Assessing Data Quality in a Multi-Country Citizen Science Project

Abstract

For years there has been a debate over the quality and reliability of data collected by citizen scientists. However, as the field of citizen science grows scientists are becoming increasingly more dependent on data collected by these non-professionals. To answer questions surrounding the quality of data collected by citizen scientists participating in a water, sanitation, and hygiene (WaSH) project in 14 low and middle income countries (LMIC), a data quality index was created. This data quality index was used to compare the quality of data from citizen scientists trained by experts to those using a train-the-trainer approach. The results show that there were no differences in the data quality of the two training groups. These results suggest that other factors may play a greater role in the quality of data collected than the training approach used to prepare citizen scientists.

Introduction

To conduct scientific research involving large data sets in multiple countries, it is often necessary to equip and train non-professionals or citizen scientists. Citizen science is broadly defined as engagement in scientific research by the general public who contribute to research activities with knowledge, tools or resources (Den Broeder, Devilee, Van Oers, Schuit, & Wagemakers, 2016; Socientize Consortium, 2013). Although citizen science projects vary in size and scope, one common feature is that these projects help to distribute workloads, collecting data that would not be feasible by individual scientists or small research groups (Den Broeder et al., 2016).

In research, the quality of data is more important than the quantity of data collected (Crall, Newman, Stohlgren, Holfelder, Graham & Waller, 2011). Wiggins and Crowston (2011) define data quality as the “fitness of data for an intended purpose” (p. 14). The fitness of data refers to measures including completeness, accuracy, validity, and consistency. These measures are multi-dimensional and vary depending on the purpose of the project (Kosmala et al., 2011). Critics of citizen science have often questioned whether data collected by non-professionals are accurate, reliable, and usable (Cohn, 2008). Supporters argue that, with proper training and data validation, citizen scientists can collect data that is of the same quality as professional scientists (Caitlin-Groves, 2012). However, data collected by professional scientists may not exist.

In order to address these conflicting views about citizen science data, it is important to understand how data quality is characterized and assessed in citizen science projects. The purpose of this study is to use a data quality index to assess the quality of public health data collected by citizen scientists in 13 low- and middle-income (LMIC) countries in Africa, Central America, and Asia. The goal of this study is to explore alternatives to assessing data quality in citizen science projects and to better understand the impacts of training on data quality.

Data Quality and Citizen Science

Citizen science is not currently considered a mainstream data collection approach to science research (Cohn, 2008; Hunter et al., 2013; Kasmala, et al., 2016). Few published citizen science studies have measured the validity of data collected by citizen scientists (Bonney et al., 2014; Caitlin-Groves, 2012). Bonney et al. (2014) suggest that the lack of papers may be because they have difficulty getting published and assert that the lack of publications is not because studies are not submitted, but rather because they are not valued by the scientific research community. Research related to citizen science is often published in outreach sections of journals or in conference proceedings instead of in professional peer-reviewed journals (Bonney et al., 2014). Although data collected by citizen scientists face criticism, there is potential to elevate the quality of these data.

Data Quality Validation

Citizen science projects used for scientific research have specific needs, one of which is for data quality to be validated. The goals of citizen science projects, the type of data collected, and the availability of resources (human and financial) determine how data are validated (Kosmala et al., 2016; Wiggins & Crowston, 2011).

Validating data can help to ensure data sets collected by citizen scientists are fit for purpose. In a review of the state of citizen science, Caitlin-Groves (2012) highlights several data validation approaches by which citizen science can gain credibility. These approaches include credentialing citizen scientists, improving training for citizen scientists, and using automated data filters. Automated data filters would instantly flag or highlight data that are outside acceptable ranges (Bonney et al., 2014; Boudreau & Yan, 2004; Caitlin-Groves, 2012; Delaney, Sperling, Adams, & Leung, 2008). Critics of data collected by citizen scientists suggest that although the data are collected by citizen scientists, the validation techniques used should be comparable to those used by professional scientists (Kosmala et al., 2016; Wiggins & Crowston, 2011).

Although the quality of data collected by citizen scientists is often assessed by comparing this data to that collected by professional scientists, comparable data collected by professionals may not exist (Danielsen et al., 2014; McKinley et al., 2016). For example, if citizen scientists collect new data that was has not been previously been collected by professionals, there is no way to use the data collected by the professionals as a quality standard for the data collected by the citizen scientists. An article by Specht and Lewandowski (2018) suggest that using data collected by professionals as a means of validating data collected by citizen scientists is problematic. Data collected by professionals is often used as a proxy for accurate data, yet the professionally collected data is also not usually evaluated for correctness or quality and variations exist in data collected by both citizen scientists and professionals (Danielsen et al. 2005; Specht and Lewandowski, 2018).

Concerns about Citizen Science

Citizen science projects frequently lack standard measures of data quality as many develop data validation tools on an ad hoc basis. The standardization of data quality validation tools could increase the acceptance of data collected by citizen scientists (Crall et al., 2011; Hunter et al., 2013). Few studies have documented the mechanisms used to validate data in citizen science projects. A review of citizen science projects by Follett and Strezov (2015) found that only 3% of articles related to citizen science included investigations of data validation techniques (McKinley et al., 2016).

There are several examples of citizen science monitoring projects where data validation methods could have improved data quality. One example is the Coral Watch citizen science project that collected approximately 18,000 data points on the health of coral reefs from over 80 countries over six years. An analysis of Coral Watch data quality revealed that most data collection errors were the result of a lack of data authentication, absence of automated metadata (i.e., time/date stamps, GPS coordinates), and an inability to attribute data to individuals. Researchers estimated that over 70% of the errors found in the data could have been prevented had appropriate data validation methods been established prior to data collection (Hunter et al., 2013) the reasons errors were committed are not addressed, but the authors had concerns about whether the citizen scientists participating in the project were properly trained.

Hunter et al. (2013) assert that data from citizen science projects are collected by non-professionals who often receive little training, have anonymity, and lack commitment. One school of thought is that since most citizen scientists are volunteers, a lack of accountability may make them more prone to provide poor or even false data. Another opinion voiced by critics is that citizen science projects lack rigor and use methods that have not been standardized and, ultimately, may not be based on standardized data collection protocols (Caitlin-Groves, 2012; Hunter et al., 2013). These issues have caused citizen science projects to have inconsistent credibility within the academic research community (Hunter et al., 2013).

Supporters of Citizen Science

While some criticize citizen science projects, others believe that with proper training, protocols, and supervision, citizen scientists can collect expert quality data (Bonney et al., 2014; Danielsen et al., 2005). Kosmala et al. (2016) suggest that "citizen science data should be judged individually according to project design and application, and not assumed to be substandard because it was collected by non-professionals" (p. 551).

While a lack of training and personal accountability are documented concerns, evidence suggests that trained citizen scientists can collect quality data. A study by Danielsen et al. (2014) compared the quality of natural resource monitoring data collected by professional scientists and citizen scientists across Madagascar, Tanzania, Nicaragua, and the Philippines. Data included in this study were collected over two years and were used to make local natural resource decisions. Citizen scientists participating in the study were chosen because of their interest in the topic and experience with forest resources. The citizen scientists were also trained on data collection protocols for 2-3 days prior to collecting data. Regression analysis indicated that trends in the data from the trained citizen scientists could accurately predict trends in the data collected by the professional scientists. The results of this study confirm that, in developing countries, trained citizen scientists can generate data that are similar to those of professional scientists (Danielsen et al., 2014).

Training Transfer

Many factors including training content, the quality of trainers, trainees' prior experience, motivation of trainees, and training methods impact how much trainees learn during the training process and, in turn, the effectiveness of training (Nikandrou, Brinia, & Bereri, 2009). Training transfer is defined as the use of skills learned in training on the job. For training transfer to occur, training objectives must be relevant to job demands and training methods must align with how participants learn (Kontoghiorghes, 2002; Nikandrou, et al., 2009). For example, the content of citizen scientist training programs must be relevant to the tasks citizen scientists are asked to perform. The planning of the training program including setting, extent, objectives, technology, and methods are also important to the overall success of the training program (Gauld & Miller, 2004; Nikandrou et al., 2009). Two of the most common types of training approaches are expert-led training and train-the-trainer.

Expert-Led Training

Expert-led training occurs when training is facilitated by an individual or group that is both knowledgeable in the training material and the delivery of content to learners. With respect to citizen science, scientists tend to favor data collected by citizen scientists that have participated in expert-led training (Parrish et al., 2018). For example, a study by Burgess et al. (2017) surveyed 423 biodiversity scientists and noted that 62.8% would use citizen science data if the citizen scientists were trained through face-to-face expert-led training. However, literature has found train-the-trainer approaches to be as effective as expert-led training. Martino et al.

(2011) reports that in a study of public health clinicians, researchers found few differences in the motivational interviewing skills of clinicians trained by expert-led and train-the-trainer approach.

Train-the-Trainer

Train-the-trainer is a widely-used method of knowledge dissemination among non-government organizations and universities. In limited resource settings, train-the-trainer happens when content experts from high resource settings give an initial training, developing participants into instructors who are then expected to train others in their respective countries (Anderson & Taira, 2018; Martino, 2011). Train-the-trainer is beneficial in that it increases access to training, reduces costs, and encourages collaboration between experts and non-experts (Anderson & Taira, 2018; Levine et al., 2007; Yarber et al., 2015). Local trainers can act as community gatekeepers as they are aware of local issues and are often seen as a trusted source of information. This familiarity may positively impact training transfer and build the social capital of that community (Levine et al., 2007; Yerber et al., 2015). Although widely used in public health disciplines like community and behavioral health, train-the-trainer methods have had few rigorous evaluations of its effectiveness (Herschell et al., 2015; Martino, 2011; Yerber et al., 2015). A better understanding of how data quality is assessed in citizen science projects and how training delivery impacts data quality seems essential to the increasing the credibility of data collected by citizen scientists.

Connection to Science Education

In 2009, the National Research Council published a report on *Learning Science in Informal Environments: People, Places, and Pursuit* which outlined six strands of learning in informal science settings. In 2018, a committee convened by the National Academies of Sciences, Engineering, and Medicine aligned the NRC strands with examples from citizen science to create a framework of possible ways that citizen science project may benefit participants.

The first strand, Sparking Interest & Excitement, captures the motivation behind learning about science and participating in a citizen science project. The second strand, Understanding Scientific Content and Knowledge, focuses on the knowledge gained through participation in a citizen science project. Strand three, Engaging in Scientific Reasoning, includes the established research methods used in citizen science projects and the methods that may result from the data collected during the project. The fourth strand, Reflecting on Science, relates to participant identity including, the social, political, and cultural contexts involved with the project. The fifth strand, Engaging in Scientific Practices, comprises the specific skills, tools, and language learned as a result of participation in a citizen science project. Finally, the sixth strand, Identifying as a Science Learner, captures a change in self-efficacy that results from participation in a citizen science project (NASEM, 2018).

Research Questions

Citizen science lacks standard tools for assessing data and is often criticized for a lack of training and personal accountability for project participants. To address these concerns and to better understand how data quality can be measured and assessed in citizen science projects, this study uses data from an evaluation of water and sanitation conditions in 14 countries to answer research questions related to citizen science. The study is guided by the following research questions (RQ):

1. How can a data quality index be used to assess data quality in a citizen science project?
2. How does the data quality of citizen scientists trained by experts compare to those using a train-the-trainer approach?

3. How do the training characteristics (number of days spent training, presence of refresher training, and days between initial training and in-country data collection) impact the data quality index score?

Study Context and Participants

Established in 2010, the Water Institute at the University of North Carolina at Chapel Hill (Water Institute) is an interdisciplinary academic research center housed in the Gillings School of Public Health. The mission of the Water Institute is to provide global academic leadership for the economically, environmentally, socially, and technically sustainable management of water, sanitation, and hygiene (WaSH) for equitable health and human development. The activities of the Water Institute are focused in four primary areas: research, networking, teaching, and knowledge management (Water Institute, 2017).

In 2017, the Water Institute worked with an international humanitarian aid organization to design and implement an evaluation of their WaSH programs which span 60 countries. The evaluation was conducted in 14 of the 60 countries: Ethiopia, Ghana, Kenya, Malawi, Mali, Mozambique, Niger, Rwanda, Uganda, Zambia, Honduras, India, Tanzania, and Zimbabwe. Due to a lack of trained WaSH professionals in each country, citizen scientists were used to collect the survey data. The data, originally collected to study WaSH conditions, was also used to better understand the quality of data collected by citizen scientists.

Participants and Participant Responsibilities

In each country, local citizen scientists were used to collect public health survey data. The number of citizen scientists varied by country program (Table 3.1). Demographic data about the citizen scientists was not collected; however, when selecting citizen scientists, preference was given to citizen scientists who were proficient in operating a smart phone, had the equivalent of a high school education, and were fluent in writing and speaking the local languages. Citizen scientists received monetary compensation for their participation in the project. Compensation was provided as an incentive for the trained citizen scientists to complete the project. For the purposes of this study, citizen scientists are defined as by individuals who are not professionally trained in a scientific discipline directly related to the project (Brossard et al., 2005; NAMS, 2018; Wiggins & Crowston, 2011).

Table 3.1.

*Number of Citizen Scientists by Country Program**

Country Program	Number of Citizen Scientists
Ethiopia	64
Ghana	24
India	28
Honduras	15
Kenya	115
Malawi	36
Mali	28
Mozambique	36
Niger	24
Rwanda	19
Tanzania	32
Uganda	10
Zambia	21
Zimbabwe	24

*NOTE: Out of 14 country programs in the evaluation, Zambia and Uganda did not submit enough data to be included in this study resulting in data being analyzed from 12 of the 14 country programs.

Training

Data collection training for the citizen scientists was developed by Water Institute researchers in the form of Power Point presentations, a website, and written guidance manuals. All educational materials were designed to be easily translated and adapted for a country's specific context (e.g., types of sanitation facilities, types of water sources). The goal of the training was to establish common protocols for data collection and to prepare citizen scientists to collect quality survey data (surveys are described in detail below). Trainers provided citizen scientists with the opportunity to practice data collection and reporting, use smartphones to record data, develop interview skills, identify water and sanitation facilities, and conduct water quality testing.

Training location. Researchers from the Water Institute at UNC traveled to five host country program sites (India, Honduras, Rwanda, Ghana, and Malawi) to facilitate training. These host country program sites were chosen because of their geographic locations and ability to provide the facilities and technology needed to conduct training activities. Some host country sites also served as training centers for other country programs. Country programs involved in the project, but not identified as host country programs, are referred to as satellite country programs. Due to their geographic locations, satellite country programs did not participate in the training conducted in Honduras and India (Table 3.2).

Table 3.2.

Training by Location and Training Approach

Host Country Program trained by UNC (Expert-led Training)	Satellite Country Program (Train-the-Trainer)
India	N/A
Honduras	N/A
Ghana	Mali
	Niger
Malawi	Mozambique
	Zambia
	Zimbabwe
Rwanda	Kenya
	Tanzania
	Ethiopia
	Uganda

Training characteristics. All citizen scientists from host country programs were trained directly by Water Institute researchers. Satellite country programs sent citizen scientists as representatives to the host countries to then become trainers for their country programs. These select citizen scientists then returned home to train citizen scientists using a train-the-trainer approach (Figure 3.1).

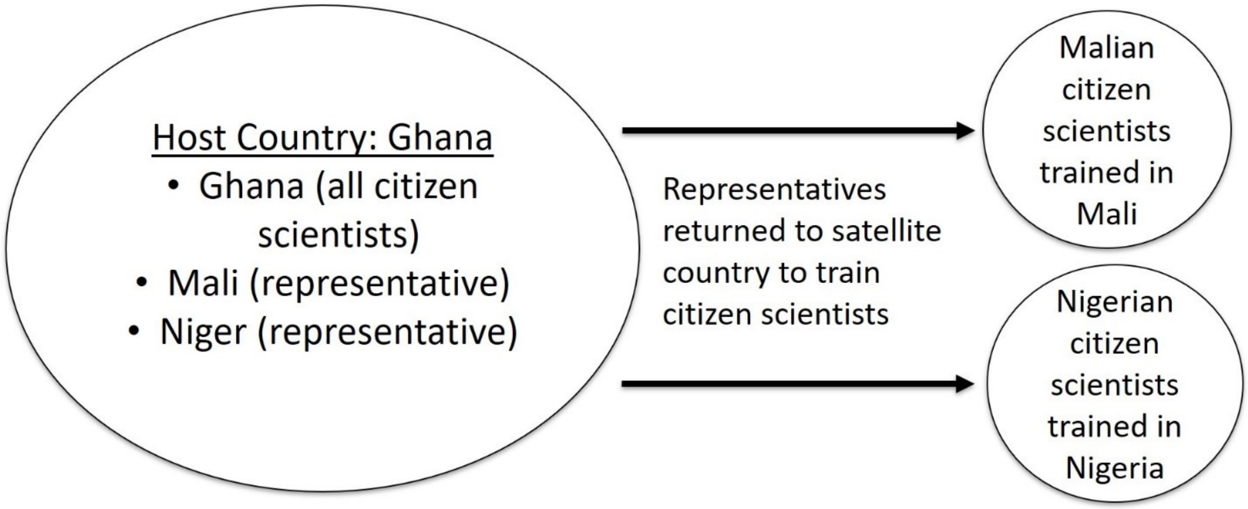

Figure 3.1. Example of train-the-trainer logistics in satellite and host countries.

The time between training and the start of data collection as well as whether a country program conducted refresher training also varied by country program (Table 3.3). For some countries, as many as 3 months elapsed between the initial training and data collection. The variations between training and data collection was attributed many factors including delays in receiving ethics approval in each country, finalizing financial agreements, finalizing sampling plans, and weather related challenges. To mitigate a loss of information, some countries chose to conduct refresher training. Refresher training allowed citizen scientists the ability to re-acquaint themselves with the training material.

During the field testing period, citizen scientists visited villages to practice conducting surveys. Field testing included practicing how to enter each community and properly greet respondents, interview techniques, water quality testing, and entering/uploading data into mWater (the application used for data collection).

Table 3.3.

Training Characteristics of each Country Program

Country Program	# of Days training	# of days field testing/piloting	Days between Initial Training and Data Collection	Refresher training? (Yes or No)
India	5	5	105	Yes
Honduras	5	5	85	Yes
Ghana	5	4	88	Yes
Mali	6	1	35	No
Niger	5	4	49	No
Malawi	5	4	81	Yes
Mozambique	7	1	8	No
Zimbabwe	10	3	7	No
Rwanda	5	5	89	No
Kenya	5	2	2	No
Tanzania	7	2	1	Yes
Ethiopia	12	2	162	No

Data completeness was high for most country programs with the exception of Zambia and Uganda. Data completeness refers to the amount of data expected and what was actually collected. For example, if weather made communities inaccessible those data points would have been missed and the overall amount of data collected would be less than expected. Out of 14 country programs in the evaluation, Zambia and Uganda did not submit enough responses to be included in this study so they were not included in the analysis, resulting in data being analyzed from 12 of the 14 country programs.

Methods

Data Collection

Survey data were collected on smartphones through the mWater app, which is an open source platform designed to map water and sanitation sites and conduct mobile surveys. In this study, no paper surveys were used to collect data. The survey was designed around core WaSH questions, compiled from WaSH evaluations across the globe. Citizen scientists were trained to conduct four surveys: household, community water points, healthcare facilities, and schools. The present study incudes data collected from the household and the community water point surveys. These surveys were selected because they had the largest number of respondents, which yielded a larger sample size and more opportunities to assess data quality.

Household survey. Approximately 2800 household (HH) surveys were conducted per country. The respondents in these households were most often the female head of household because they were responsible for collecting and storing water. To conduct household surveys, the citizen scientists visited the households, posed questions to the female head of households (or other adult if the female head of household was unavailable), and documented responses on cell phones using the mWater platform. The household survey addressed topics related to several topics: access to safe water and sanitation, the quality of water and sanitation services for the household, hygiene knowledge and practice, child wellbeing, and demographics. The full household survey instrument is propriety and cannot be included in this study but survey questions include:

- Do you do anything to your water to make it safer for drinking?
- What is the distance between your household and its water point during the rainy season?

- What is the main type of water point that your household uses to get drinking water?

Community Water Point survey. The community water point (CWP) survey focused on access to water and factors that influence water services (i.e., management and access to tools and spare parts). A water point is a designated source of water in the community. The CWP surveys were administered to local WaSH committees who were interviewed about each water point in their community. WaSH committees are made of respected men and women in the community who are responsible for the daily operations and management of water points. Between 560 and 1120 CWP surveys were administered in each country. The full community water point survey instrument is propriety and cannot be included in this study, but survey questions include:

Is this water point managed by a water/WaSH committee?

- Do you call someone to assess or fix the water point if there is (was) a technical problem that cannot be fixed on this water point?
- Is there an open sewer, gutter, or discharge pipe receiving sewage within 10 meters of the water point?

Data Quality Index

Few citizen science studies' frameworks have been developed specifically for use in data quality validation for citizen science projects (Wiggins, 2012). For this reason, a model from the manufacturing industry was used to inform the data quality validation process for this study. Total Quality Management (TQM) represents a practical approach for improving data quality (Pipino, Lee, & Wang, 2002; Wang, 1998). TQM was developed to address a need for high quality data in the product manufacturing industry, much like the need for high quality data from citizen scientists. This model was chosen for this study because of its practical nature and shared goal of improving data quality (Pipino, Lee, & Wang, 2002; Wang, 1998).

While the TQM refers to the overall process for improving data quality, the Total Data Quality Management (TDQM) cycle describes the steps for improving data quality. The TDQM cycle consists of defining, measuring, analyzing, and improving data quality (Pipino, Lee, & Wang, 2002). A benefit of the using the TDQM is that steps in the process can be tailored to fit the needs of individual projects.

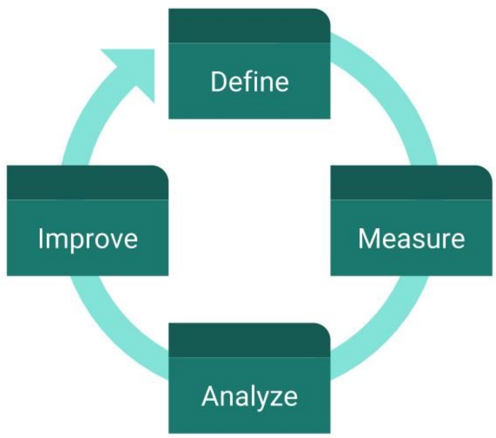

Figure 3.2. TDQM cycle. Adapted version of the TDQM cycle (Yang, Diane & Richard, 2004)

This present study focused on the first three steps (define, measure, analyze) in the cycle, and the findings from this study can be used to inform future citizen science projects (Table 3.4).

Table 3.4.

Description of Steps in the TQDM Cycle (Yang, Diane & Richard, 2004)

Step	Description
Define	Assign data quality standards that fit the needs/purpose of their use (e.g., What does data quality mean for this situation?)
Measure	Develop metrics that can be used to determine if standards are met (e.g., Percentage of errors or number of missing values)
Analyze	Check data against metrics (e.g., Process the data using validation techniques including expert review, filtering and cross checking)
Improvement	Correct errors in data directly or improve the processes that generate data

Using TDQM to Assess Data Quality

Since a methodology for determining the quality of WaSH survey data collected by citizen scientists did not exist, a data quality index was created for this study. The following steps were completed to create the data quality index. In these steps, pH data is used as an example of how the data quality was analyzed and the data quality index was created.

1. Define the data quality. In this initial step, data quality is defined in the context of the project by identifying data quality standards (Pipino et al., 2002). Data quality standards are used to determine which data are fit for their intended purpose. When developing data quality standards, it is important to review the data and to understand the types and extent of inaccuracies that may occur (Cameron, 2005). Table 3.5 provides a summary of the data quality variables, criteria for data quality, and the rationale for inclusion in the index. Variables represent data items from survey questions that were validated. A sample of variables from the HH and CWP surveys were selected for this study. These variables were chosen because they were survey questions where potential errors were identifiable and measurable by expert validation or an automatic data filter. The rationale for inclusion represents the importance of the variable to the research study.

The criteria for variables indicate acceptable ranges parameters or that questions related to the variables are answered accurately. The number of surveys sampled was dependent on whether the variable was verified manually or through an automated data filter. Data quality checks were done on all of the variables that were verified through an automatic data filter and on 10% of those verified manually.

Table 3.5.

Summary of Variables, Criteria for Data Quality, and Rationale for Inclusion

Variable	Description	Criteria	Number of surveys sampled	Rationale for Inclusion
Household water storage container	Confirm that the details of the household water storage container are accurate.	Responses to the following are accurate: 1. Does it have a lid? 2. Is it out of the reach of animals? Does it have a narrow mouth?	10%	Confirms citizen scientists can correctly take and upload photos and identify storage container characteristics
Length of survey	Compare the start and end time of the survey.	15-90 minutes	All	Surveys outside of this range may have questionable data quality (missed questions, had issues with respondents or equipment)
Trip Number	Check to see the value is within in the range	<20 trips/person/day	All	Identifies errors that may have resulted from errors in questioning respondents
Water Sample ID	Confirm that a unique water sample ID with the correct format is recorded for each sample	Responses to the following are accurate: 1. Every sample has a water sample ID 2. Every water sample ID has the correct number of digits 3. Every water sample ID is unique	All	If unique water sample ID's are not assigned to water samples data may not be fit for use

Table 3.5 continued

Fluoride	Check to see the value is within in the range	pH values should be within the range of 3-11	All	Critical water quality parameter
Arsenic	Check to see the value is within in the range	Arsenic values should be within the range of 0-100 ppb	All	Critical water quality parameter
Conductivity	Check to see the value is within in the range	Conductivity values should be within the range of 1-5000 µS/CM	All	Critical water quality parameter
pH	Check to see the value is within in the range	pH values should be within the range of 3-11	All	Critical water quality parameter

2. Measure Data Quality. In the next step, data entered by the citizen scientists were compared to acceptable ranges or validated by WI researchers (see criteria for data quality in Table 3.5). Variables that fell outside the acceptable range were highlighted by the automatic filter as errors.

3. **Data Quality Analysis.** To analyze the quality of data, a data quality index was created. While the index is not a precise measurement, it provides an indication of data quality. The index was created by assigning a score to each variable included in the index based on the likelihood of the error occurring, the impact of the error on data analysis, and the probability of detecting the error. These categories were combined to create the data quality index score. A data quality index score was calculated for each variable and a lower score indicates better data quality (Table 3.6). For data that were missing, the values were imputed, or estimated, because missing values treated as zeros may over or understate the data quality (Cameron, 2005). India was the only country program missing survey data. India did not submit GPS data. To make up for this missing data, the average of the direct training countries was imputed, or estimated to provide a score for the GPS category in India.

Table 3.6.

Structure of the Data Quality Index

% Likelihood (error)			
Percent Error	Actual number of errors/number of opportunities for error to occur		
Impact			
Type	Low Few to no consequences/accept error or negligible effect	Medium Some analysis may be affected	High Study compromised
Points	1	2	3
Probability of Detection			
Type	Low (manual detection)	Medium (Stata or Excel function then manual detection)	High (Detectable through Stata or Excel function)
Points	3	2	1

Likelihood. Likelihood is represented by the error rate. The error rate is the number of errors committed by citizen scientists divided by the number of opportunities for errors to be made. Likelihood was not assigned a number of representative points but is a percentage in the data quality index score.

Example: #of pH data errors/# of total pH samples

Impact. Errors in the data submitted by the citizen scientists have an impact on the study. Errors may have a negligible effect, only impacting some analyses, while other errors may compromise the study. An indicator with a low impact factor received 1 point—for example, survey length (the time it took the citizen scientist to conduct the survey) would have a low impact on data analysis. An indicator with a moderate impact would receive 2 points; for example, mis-identifying a water sample ID number. An indicator with a high impact received 3 points and could compromise the study; for example, an error in GPS points might indicate that data were gathered in the wrong area and thus render all data from this individual survey unfit for use. (Example: An error in pH would be considered a moderate impact on the study.)

Detection difficulty. This category represents how difficult it is for the error to be detected. Errors that are more difficult to detect may not be found, yielding inaccurate results. An indicator that yielded a high detection designation required manual detection by data analysts and received 1 point. For example, errors in survey length were easily detected using an Excel formula. A variable with a moderate detection difficulty required an Excel formula and manual detection. Manual detection required data analysts to scroll through data looking for errors. An example of indicators with a moderate detection difficulty are water sample ID numbers. These ID numbers link water samples to their sources. The sorting function in Excel identified numbers with the incorrect number of digits and, once they are identified, numbers must be matched manually. Due to the time and effort required to manually detect errors, only 10% of data entries that required manual detection were analyzed. Analyzing only 10% of this data does not give a discrete analysis of data quality but does give sufficient evidence as to whether these data are fit for their purpose.

After the likelihood, impact, and probability of detection for each variable were determined, the total scores for all variables were calculated and a data quality index score for each country program was determined. Possible data quality index scores ranged between 0 (lowest possible score) and 27 (highest possible score). The total data quality index scores for each country program were calculated and compared. In addition to comparing data quality index scores, a paired t-test examined significant differences between country programs.

Example of Development of Data Quality Index Variable

To better understand how a variable was identified and entered into the data quality index for scoring an example has been provided:

Step 1: Defining Data Quality: Citizen scientists were asked to test for pH when conducting water quality tests. Researchers compared pH values entered by citizen scientists to acceptable ranges, making this variable identifiable, measurable, and appropriate for the data quality index.

Step 2: Measuring Data Quality: pH data entered by citizen scientists was compared to the acceptable range of 3-11. If values were below 3 or above 11, they were flagged as errors.

Step 3: Data Quality Analysis: The formula for calculating the score for a particular variable is:

pH data quality index score = Likelihood x Impact x Probability of Detection

The likelihood of a citizen scientist entering an errant pH data point would be an actual number calculated by a researcher. For example, if 28 out of 100 pH values were outside the accepted range, the % likelihood would be 28%.

pH data quality index score = Likelihood (28%) x Impact x Probability of Detection

Errors in pH data would have a moderate impact on the study, meaning some, but not all, of the analysis would be affected, thereby earning 2 points in the data quality Index.

pH data quality index score = Likelihood (28%) x Impact (2) x Probability of Detection

pH values that were determined to be errors (i.e., fell outside of the acceptable range) had a high probability of detection. These errors were detected using an Excel function and earned 1 point in the data quality index.

pH data quality index score = Likelihood (28%) x Impact (2) x Probability of Detection (1)

pH data quality index score = 28% x 2 x 1 = .56

A template of the data quality index is located in Appendix B.

Results

Results are presented below in sections and organized by research question.

How can a data quality index be used to assess data quality in a citizen science project?

Results suggest that the data quality index produces a data quality index score that can be used to assess the quality of large amounts of data through a 3-step process that does not require the use of comparable data collected by professional scientists. The average data quality index score of all country programs was 5.79. The three country programs with the highest quality data (data quality score) were Honduras (2.91), Kenya (3.45) and Niger (3.48).

How does the data quality of citizen scientists trained by experts compare to those using a train-the-trainer approach?

The data quality index score was useful in comparing the data quality of citizen scientists trained by experts compared to those using a train-the-trainer approach. Host countries, which were trained directly by Water Institute researchers, represented the best data quality of the 12 countries with Honduras at 2.91; the worst quality among countries trained by experts was Malawi at 8.93. Five of the 12 country programs included in this study used expert-led training and the remaining seven were trained using a train-the-trainer approach. The data quality index score indicated a high level of variability in data quality among the country programs using expert-led training (Table 3.7).

A two-sample t-test with equal variances was conducted to compare the data quality index scores of county programs trained using the train-the-trainer approach and the data quality index scores of country programs that participated in expert-led training. There was no significant difference in the scores for the train-the-trainer group (M=5.72, SD=2.01) and the expert-led group (M=5.80, SD=2.39); t(10)=-.0598, p = 0.9535. These results suggest that the type of training approach used to train citizen scientists on data quality protocols does not impact data quality.

Table 3.7.

Country Programs Ranked by Data Quality Index Score

Rank	Country Program	Data Quality Index Score	Training Strategy
1	Honduras	2.91	Expert-led Training
2	Kenya	3.45	Train-the-Trainer
3	Niger	3.48	Train-the-Trainer
4	Ghana	4.11	Expert-led Training
5	Tanzania	4.80	Train-the-Trainer
6	Zimbabwe	5.23	Train-the-Trainer
7	Rwanda	5.90	Expert-led Training
8	Mali	6.90	Train-the-Trainer
9	India	7.12	Expert-led Training
10	Mozambique	7.63	Train-the-Trainer
11	Ethiopia	8.55	Train-the-Trainer
12	Malawi	8.94	Expert-led Training

How did the training characteristics (number of days spent training, presence of refresher training, and days between initial training and in-country data collection impact the data quality index score?

The number of initial training days, whether country programs conducted refresher trainings, and the days between initial training and in country data collection training varied between countries. Findings suggest that these training characteristics did not correlate to data quality.

Number of Training Days

Initial training for each country program took place at host country program sites and consisted of five days of classroom-style training. Training that occurred at satellite sites lasted between 5-12 days. At 12 days (not including refresher training), Ethiopia had the most training days of any country and was ranked 11th with an overall data quality index score of 8.55. The top three country programs (Honduras, Kenya, and Niger) each had 5 days of initial training for its citizen scientists. A Pearson correlation coefficient was computed to assess the relationship between the number of training days conducted by country programs and the data quality index score. There was a weak positive correlation between the two variables ($r = 0.3791$, $n = 12$, $p = .05$). These results suggest that increases in initial training days were not correlated with a better data quality index score.

Refresher Training

Of the 12 country programs included in this study, 38% (n=5) reported conducting refresher training to re-acquaint citizen scientists with the skills and methods learned during the initial training. A two-sample t-test was conducted to compare the data quality index scores of county programs that conducted refresher training and the data quality index scores of country programs that did not conduct refresher training. There was no significant difference in the data quality index scores for the country programs that conducted refresher training ($M=5.58$, $SD=2.427$) and those that did not ($M=5.88$, $SD=1.971$); $t(10)= -0.2375 p = 0.8170$. These results suggest that the type of training approach used to train citizen scientists on data quality protocols does not impact data quality.

Days between Initial Training and Start of In-country Data Collection

Variability of the data quality and lack of statistical difference is also evident in country programs when comparing the amount of time that elapsed between the last day of training (expert-led training or train-the-trainer) and the start of data collection. For host countries, the time between training and data collection ranged between 85 and 105 days. The time between the last day of training at satellite sites and the start of data collection ranged between 1and 162 days. Tanzania, which ranked 5th among country programs with a data quality index score of 4.8, was the satellite county site with the shortest amount of time between training and data collection at 1 day. Ethiopia had the longest time between training and data collection at 162 days and ranked 11th among country programs at 8.55. For host country programs, Honduras had the shortest period of time between training and data collection at 85 days and ranked 1st in data quality with a score of 2.91. Two of the three countries with the worst data quality, Malawi and Ethiopia, also had the longest periods of time between training and the start of the survey at 91 and 162 days respectively.

A Pearson correlation coefficient was computed to assess the relationship between the number of days that elapsed between the end of training and the start of data collection and the data quality index score. There was a weak positive correlation between the two variables, $r = 0.3691$, $n = 12$, $p = .05$. These results suggest that the number of days that elapsed between the end of training and the start of data collection were not strongly correlated with a better data quality index score.

Discussion

As the number of citizen science projects increase, having a means of assessing the quality of data produced by these projects becomes a greater priority (Crall et al., 2011). This study set out with the goal of better understanding how data quality is characterized and assessed in citizen science projects. On the question of how data quality index can be used to assess data quality in a citizen science project, a data quality index was created. This data quality index produced a score that was used to assess the quality of that data collected by the citizen scientists participating in the project.

The present study also sought to understand the impact of training approaches (expert-led and train-the-trainer) and characteristics (number of days spent training, presence of refresher training, and days between initial training and in-country data collection) on data quality. The results of this study did not indicate a difference between the data quality of country programs trained by experts that those trained by train-the-trainer. The correlations between the number of days spent training, presence of refresher training, and days between initial training and in-country data collection and data quality were found to be weak.

New Way of Validating Citizen Science Collected Data

Prior studies have noted concerns about using data collected by professional scientists as the sole means of validating data collected by citizen scientists (Danielsen et al., 2005; Specht & Lewandowski, 2018) because these data are not often validated and are not always available. The current study was able to create a data quality index capable of assessing the quality of data collected by citizen scientists without the use of data collected by professional scientists. The data quality index created in this study provides an alternative approach to traditional methods of validating data collected by citizen scientists. Additionally, the data quality index offers a mechanism for professionals to check their own data quality and thus improve the significance of findings by all who seek to analyze data.

Data collected by citizen scientists is increasingly being used to create policy and make management decisions (Danielsen et al., 2005). It is critical that these decisions are based on sound data. Without access tools that do not require the use of comparable data collected by professional scientists, such as the data quality index presented in this study, data may go unvalidated. Because of the ability of citizen scientists to gather large data sets from wide geographic areas, there is often is a need to rely on data collected by citizen science projects However, without assessment tools such as the index presented in this study, we may be using data of unknown quality to create policies and make decisions that impact health and safety. This data quality index can help to bring transparency to the data quality and in turn can help address critics' concerns that data collected by citizen scientists is unreliable and not fit for its purpose (Caitlin-Groves, 2012; Cohn, 2008; Hunter et al., 2013). Putitkammer et al. (2016) state that "strong data quality is a precursor for strong data use" (p.104). Data assessment tools like the data quality index presented here can provide the evidence needed for scientists to feel confident in using data collected by citizen scientists.

Impact of Individuals on Data Quality

The current study finds no difference in the quality of data resulting from citizen scientists trained by the train-the-trainer approach and those trained by experts. Our results are consistent with those found by Martino et al. (2011) who, in a study of public health clinicians, found few differences between those trained by expert-led training and train-the-trainer approaches. In the current study, training logistics were also found to have a limited impact on data quality. These findings suggest that other factors which were not initially considered, such as sociodemographic parameters of the citizen scientists collecting the data may have a greater impact on their ability to collect quality data than how the training was conducted.

Educational researchers have identified links between cognition and sociodemographic parameters (National Research Council, 2009). Socio-demographic characteristics include, for example, age, sex, education, ethnicity, employment, and income. In their work on public understanding of the nature of science and technology in Europe Durant et al. (2000) reported that sociodemographic parameters are better predictors of scientific knowledge in less industrialized countries than that of more industrialized countries (NASEM, 2016).

Contributions to Science Education

The strands of learning in formal science settings outlined by the National Research Council provide examples of how citizen scientists can benefit from project participation. This study contributes to the field of science education through strands 5 and 6 of the Strands of Science framework proposed by the National Research Council (National Research Council, 2009).

Strand 5 – Engaging in Scientific Practices

The data quality index developed in this study is a data analysis tool that can be used by practitioners and researchers, particularly in low resource settings, to analyze scientific data collected by citizen scientists. Data that may have previously gone unanalyzed can be analyzed without the use of at times complicated and expensive technologies and comparable data collected by professional scientists. Increased access to validation tools like this data quality index not only increases the scientific literacy of the individual, but it also adds to the collective scientific literacy of the community.

Strand 6 – Identifying as a Science Learner

This citizen science project provided an opportunity for participants to not only to do science in real-world, hand-on contexts, but also to have access to instructional support to experts through training. The current study provided an informal science learning experience that used a train-the-trainer approach to educating citizen scientists on data collection protocols. This training approach allowed participants to develop skills that can be used in the future. Science literacy in a community involves the use of collective skills to solve problems and accomplish goals. Citizen scientists in this project can pool and distribute their collective science literacy with others to achieve community goals and solve problems. Through the train-the -trainer approach the project creates an opportunity for sustained participation in science activities and an avenue for these skills to be shared in other settings.

Limitations

The goal of this study was to identify alternatives to assessing data quality in citizen science projects and to better understand the impacts of training on data quality. While this research did achieve this goal, some limitations of the research were discovered. First, the use of repurposed data from a single study limits the ability to generalize these data. The future robustness and utility of the data quality index as an assessment tool can only be determined after it is tested in a variety of contexts. Second, only data from variables that could be measured and verified remotely were included in the data quality index. If different variables had been used in the data quality index, the resulting data quality scores may have changed.

Implications and Suggestions for the Future

These findings lead to a number of implications for researchers who play an important role in developing tools for use informal science education settings such as citizen science projects and practitioners who are responsible for designing citizen projects that allow for meaning participation while meeting scientific goals. A deeper understanding of how data can be validated in citizen science projects and how training impacts data quality can better position researchers and practitioners to facilitate science learning.

Sociodemographic Parameters

The results presented in this study indicate a need to better understand the role of sociodemographic parameters in the collection of quality data. This study provides evidence that practitioners should collect sociodemographic data for participants in informal educational activities. In the future researchers should use this data to determine if sociodemographic factors impact the quality of citizen science data and to see if these factors correlate more the data quality index score.

Training Approach

Both practitioners and researchers should take care to make sure the parameters of interest are used to assess correlations between these parameters and data quality. The findings presented in this study reveal that there was no difference in data quality between participants trained by experts and those trained by the train-the-trainer approach. In the future, the train-the-trainer approach should be used by practitioners to engage citizen scientists in scientific practice and to encourage participants to extend their learning over time and to share learnings with others. Organizations that rely on citizen scientists to collect data can use the train-the-trainer approach to send less experts into the field for training, reducing human and financial resources.

Data Quality Index

The data quality index presented in this study should be tested by researchers in different disciplines to determine its use as a generalizable tool. The data quality index is beneficial for use in low resource settings where trained professionals specifically data analysts and statisticians may not be available. This tool allows practitioners of citizen science projects in low resource settings that may not have access to complicated statistical analysis or programs a way to validate their data.

CHAPTER 4: Educational, Science Learning, and Social Outcomes from a Citizen Science Project in Water, Sanitation, and Hygiene

Abstract

Citizen science projects are often criticized for a lack of positive and measurable outcomes for project participants. The aim of this study was to investigate the experiences of citizen scientists in terms of the educational, scientific, and social learning outcomes realized as a result of participation in a water, sanitation, and hygiene (WaSH) citizen science project spanning 14 low- and middle-income countries (LMIC). Implementation questionnaires and transcripts from Skype interviews from project participants were collected and analyzed for a representation of statements that aligned with 12 previously published outcomes from citizen science projects. The results of the study indicate that citizen science lacks common tools for evaluation of program outcomes and that a more comprehensive repository of possible outcomes is necessary to fully understand the impact of citizen science projects on participants.

Introduction

Although each year millions of people engage in citizen science projects, the projects are often criticized for a lack of benefits or outcomes for project participants (McKinley et al., 2016; Phillips, 2017; Theobald et al., 2015). To counter this criticism, practitioners of citizen science projects are trying to demonstrate that not only does citizen science advance science, but these projects also increase participant learning in informal science education settings (Friedman et al., 2008). One challenge to documenting the impact citizen science projects have on participants is a lack of knowledge among researchers as to how to evaluate participant outcomes and, more importantly, what outcomes may result from citizen science projects. Guided by the framework presented by Den Broeder, Devilee, Van Oers, Schuit, & Wagemakers (2016) this study was undertaken to investigate the experiences of citizen scientists from 13 countries who participated in a WaSH citizen science project. The goal of this study was to gain an understanding of the scientific, social, and educational impacts of the project on the participants and to add to the knowledge base for evaluation and outcomes of future citizen science projects.

Literature Review

Informal science education (ISE) can be described as learning that results from voluntary participation in science activities in non-classroom settings (Crane, Nicholson, & Chen 1994; Habig, Gupta, Levine, 2018; Hofstein & Rosenfeld, 1996). Several differences exist between science learning in K-12 and informal settings. One difference between informal and formal science learning is that informal learning activities are not solely designed to meet the goals of school curricula but also to enhance it (Hofstein & Rosenfeld, 1996). As more K-12 instructional time and funding are spent preparing for high stakes mathematics and literacy testing, there is a greater opportunity for informal settings to supplement the science education that occurs in K-12 classrooms (National Research Council, 2009; Sacco, Falk, & Bell, 2014). Another distinction that participants in informal science education settings have is the benefit of exploring personal interests through real life practice.

Informal science experiences also reach a portion of the population that may not be served by K-12 education. People in all stages of life, cultures, and socio-economic backgrounds can benefit from learning science knowledge and skills based on real-world experiences. Informal science learning experiences allow participants the opportunity to learn scientific principles and to apply those principles to their everyday lives (NRC, 2009). Citizen science projects are one such example of informal learning experiences that offer opportunities for people to not only learn science, but to experience it as well.

Citizen Science as an Informal Learning Experience

The goals of informal science learning experiences vary; however, most informal science learning experiences seek to "introduce learners to scientific skills and concepts, the culture of science, and the role science plays in decision making" (Fenichel & Schweingruber, 2010, p. xii). Citizen science projects have an advantage as an informal science learning experience because of the active role participants play in data collection and the range of outcomes produced (Fenichel & Schweingruber, 2010; National Academies of Sciences, Engineering, and Medicine (NASEM), 2018).

Outcomes from citizen science projects fall into two groups: outcomes that advance science and those that serve the individual participants. Scientific outcomes seek to collect high-quality data that can be used to create policy while participant outcomes seek to advance learning (NASEM, 2018). In 2009, the National Research Council published a report called "*Learning Science in Informal Environments: People, Places, and Pursuit*" which outlined six strands of learning in informal science settings. In 2018, a committee convened by the National Academies of Sciences, Engineering, and Medicine aligned these strands with examples from citizen science to create a framework of possible outcomes from citizen science projects.

The first strand, Sparking Interest & Excitement, captures the motivation behind learning about science and participating in a citizen science project. The second strand, Understanding Scientific Content and Knowledge, focuses on the knowledge gained through participation in a citizen science project. Strand three, Engaging in Scientific Reasoning, includes the established research methods used in citizen science projects and the methods that may result from the data collected during the project. The fourth strand, Reflecting on Science, relates to participant identity including, the social, political, and cultural contexts involved with the project. The fifth strand, Engaging in Scientific Practices, comprises the specific skills, tools, and language learned as a result of participation in a citizen science project. Finally, the sixth strand, Identifying as a Science Learner, captures a change in self-efficacy that results from participation in a citizen science project (NASEM, 2018).

Participant Outcomes

Bonney et al. (2014) argue that since the goal of a citizen science project is to collect scientific data, the project should have authentic scientific outcomes. However, as identified in the Informal Science Learning Strands, not all outcomes are scientific (Conrad, Hilchey, & Branch, 2011; Den Broeder, Devilee, Van Oers, Schuit, & Wagemakers, 2016; Kosmala et al., 016). For example, Den Broeder et al. (2016) published one of only a few studies of learning outcomes from citizen science projects in public health. Den Broeder et al. (2016) benefits the field of citizen science by building on the work of peers because they synthesize a literature review and include case studies of citizen science projects from the U.S., Latin America and Israel into a list of 12 reported participant learning outcomes (Haywood, 2016; King et al., 2016). The resulting outcomes can be characterized into educational, science learning, and social outcomes.

Some citizen science projects have been more widely recognized for their potential educational benefits, like increases in science literacy, than for scientific contributions (Kosmala et al., 2016). Conrad et al. (2011) report that citizen science projects increase the scientific literacy of the community members involved. In this context, scientific literacy encompasses knowledge of scientific processes or an increased awareness of participants' roles in the local environment. The cultural differences between participants in citizen science projects provide opportunities to expand the nature of the community-driven questions addressed (Bonney et al., 2014). For example, religion and gender equity play a role in the types of issues communities would be interested in tackling through science. There is also potential for citizen science to provide a bridge between how society and culture influence environmental issues on a community level. People are constantly making decisions about their health, environment, and finances where science, technology, engineering and math (STEM) principles play an integral role in the final decision (NRC, 2009; Socientize, 2013). To realize these participant outcomes, there must be a way to assess the evidence of these outcomes.

Assessment of Potential Learning Outcomes

NASEM (2018) suggests that citizen science practitioners need to identify potential learning outcomes and document their occurrence in a project. The common adoption of assessment tools that can be used in projects across different disciplines is important (Becker-Klein et al., 2016; Friedman et al., 2008; Phillips, 2017). Common learning outcomes and assessment tools are the foundations necessary to bridge the gap between research and practice (NRC, 2009). Due to the variability between citizen science projects, it is understandable that all learning outcomes and assessment measures will not work for all projects; however, shared tools including assessments, surveys, and frameworks allow researchers to compare findings and build on the work of peers (Hinkson et al., 2017; Friedman et al., 2008; NRC, 2009).

For example, many successful citizen science projects have utilized theoretical frameworks based on the experiential learning theory (ELT) (Brossard et al., 2005; Kolb, 1984; Messmore, 1996; Palmer, 1992). Brossard et al. (2005) developed a framework based on the Elaboration Likelihood Model and the theory of Experiential Education to understand the experience of citizen scientists participating in a bird biology project. Crall et al. (2013) used a similar framework to be able to compare findings with those of Brossard et al. (2005).

As the number of citizen science projects increases, practitioners are trying to develop new ways to better understand the ways to identify and document project outcomes (Phillips, 2017). A report from the Center for Advancement of Informal Science Education (CAISE) suggests that continued efforts to develop, validate, and disseminate assessment strategies and frameworks in informal science learning settings would benefit citizen science and the field of informal science education. The report "urge[s] the field to begin developing, testing, and employing more robust evaluation methods and to make a major effort to share project results, both positive and otherwise… to help the [citizen science] field continue to grow and mature" (Bonney et al., 2009b; Phillips, 2017, p. 51).

Research Question

Although frameworks of potential participant benefits from citizen science projects exist, few research studies documenting individual participant outcomes from citizen science projects have been published (Bonney et al., 2009; NRC, 2009). Citizen science and the field of informal science education can benefit from using shared tools and frameworks to compare findings. This study uses the participant outcomes published in Den Broeder et al. (2016) as a framework for identifying the educational, science learning, and social outcomes from a citizen science project in WaSH. This study was designed to answer the following research question:

> What, if any, social, educational, and scientific outcomes do citizens scientists report as a result of participation in a citizen science project?

Methods

Project Description

Established in 2010, The Water Institute at the University of North Carolina at Chapel Hill (Water Institute) is an interdisciplinary academic research center housed in the Gillings

School of Public Health. The mission of the Water Institute is to provide global academic leadership for economically, environmentally, socially, and technically sustainable management of WaSH for equitable health and human development. The activities of the Water Institute are focused in four primary areas: research, networking, teaching, and knowledge management (Water Institute, 2017).

In 2017, the Water Institute worked with a non-governmental organization (NGO) to design and implement an evaluation of the NGO's WaSH programs in 14 countries (Ethiopia, Ghana, Kenya, Malawi, Mali, Mozambique, Niger, Rwanda, Uganda, Zambia, Honduras, India, Tanzania and Zimbabwe). Due to the lack of trained WaSH professionals in each country, the only solution to completing the evaluation was to use citizen scientists to collect the data. The evaluation data was not originally collected with citizen science in mind. The present study used the data from the 14-country evaluation to answer research questions related to the use of citizen scientists as data collectors in this project.

Citizen Scientists

In each country, citizen scientists from local communities were used to collect data. Preference was given to citizen scientists who were proficient in operating a smart phone, had the equivalent of a high school diploma, and spoke the local languages. The citizen scientists operated as gatekeepers to the community. For example, in remote areas where maps were not available, citizen scientists worked with village elders and other community leaders to map water points and households to be surveyed. To promote the retention of citizen scientists, each received monetary compensation for project participation.

Training

Data collection training for the citizen scientists was developed by researchers and the first author in the form of Power Point presentations, a website, and guidance manuals. All educational materials were designed so they could be easily translated and adapted for a country's specific context (e.g., types of sanitation facilities, types of water sources). Each citizen scientists participated in classroom training followed by testing surveys in the field. During the field-testing period, citizen scientists visited villages to practice conducting surveys. Field testing included practicing community entry, interview techniques, water quality testing, and entering/uploading data into mWater (the application used for data collection). The goal of the training was to establish common protocols to be used by citizen scientists for data quality and to prepare them to collect quality public health survey data. Training provided participants with the opportunity to practice data collection and reporting; use smartphones; develop interview skills; identify water and sanitation facilities; and conduct water quality testing.

Project Context

Survey data from four areas (households, healthcare facilities, schools and community water sources) were collected on smartphones through the mWater application. mWater is an open source platform designed to map water and sanitation sites and conduct mobile surveys. No paper surveys were used to collect data. The surveys were designed around core public health questions as derived from similar evaluations across the globe.

Research Design

This study was a qualitative, instrumental, multi-site case study (Merriam, 2009; Stake, 2005). As this investigation sought to explore the participant learning outcomes of a citizen science project and compare them to outcomes from published literature, a case study methodology was appropriate (Stake, 2005). The study also sought to determine if additional learning outcomes that have yet to be included in published literature were identified in this citizen science project. Each country's program represents a site that is bounded by the WaSH project.

Data Sources and Collection

Sources of data included implementation questionnaires (Appendix C) and transcripts from Skype interviews (Table 4.1). A copy of the interview guide is located in Appendix D.

Table 4.1.

Data Sources Including Contribution to Research Question

Data	Contribution to research question
Implementation Questionnaire	Provides a country profile of how country teams were structured to collect data; allowed citizen scientists to describe their experience and process by which teams collected data
Skype Interview	Allowed researchers to ask follow up questions related to the implementation questionnaire; gave citizen scientists an opportunity to further explain their experiences

Implementation questionnaire. When the citizen scientists in each country completed data collection in all communities , a citizen science representative from each country program submitted an open-ended questionnaire about their experience with the project. Citizen scientists acting as representatives from each country program were chosen based on their ability to read and write English and their familiarity with all aspects of the project. The implementation questionnaire asked the citizen scientists general open-ended questions that allowed them to reflect on opportunities and challenges encountered during the project. For example, the citizen scientists were asked to describe any difficulties they had in applying what was learned in the training in the field. Implementation questionnaires were Microsoft Word documents sent over email.

Skype interviews. After the implementation questionnaire was completed, Skype interviews were conducted with the citizen scientist representing each country program who oversaw data collection in each particular country. The Skype interviews allowed the researcher to get clarification to responses from implementation questionnaire and to identify what citizen scientists considered to be 'takeaways' from project participation. The time between the end of data collection and Skype interviews varied between country programs and was dependent on the availability of the citizen scientists, UNC researchers, and the training specialist.

The interviews used a semi-structured approach with an open-ended interview guide (Appendix D). The interview questions asked about a variety of topics including aspects of the training received by citizen scientists. All interviews were conducted in the English language. As suggested in O'Malley, Perdue, and Petracca (2013), using an open-ended approach allowed subjects to emphasize the points that they deemed important based on their experience with the project. The interview questions were related to training content, training logistics, and the selection of the citizen scientists. They were intended to obtain explanations from citizen scientists about data collection and their experiences participating in the project. Consent was obtained for each interview to be audio recorded.

Skype interviews lasted between 30 minutes to 1 hour and were transcribed verbatim for analysis. The resulting transcripts and implementation questionnaires were analyzed by the author and another project researcher independently. Both data sources were used to comprehensively address the research question.

Data analysis. Many evaluation projects use both inductive and deductive methods to analyze data (Thomas, 2006). The analytic process adopted for this study was a combination of deductive and inductive coding of Skype interviews and implementation questionnaires. The unit of analysis was every instance of representation statements within each Skype interview and questionnaire for each country program. Through these representation statements the citizen scientists identified what outcomes they experienced as result of program participation. The documents were coded in two cycles, and two levels of analysis were conducted. During the first cycle the data were coded deductively at the outcome level (Level 1). Level 1 codes were 12 *a priori* outcomes from citizen science projects identified by Den Broeder et al. (2016) (Table 4.2). Two researchers coded all transcripts independently, and then agreements and disagreements in the codes were discussed and compared for interrater agreement. The independent coding resulted in agreement of 90% for the two coders.

Table 4.2.

A priori codes, Subcodes, and Descriptions

A priori codes	Subcode	Subcode Description
Educational Codes		
Enhanced science knowledge and literacy (e.g knowledge of science content, science applications, risks and benefits, and familiarity with scientific technology)	Water Quality Testing	Citizen scientists report an increased understanding of water quality testing
	Training (face-to-face)	Citizen scientists report an increase in science knowledge from the face-to-face training
	Training (manual)	Citizen scientists report an increase in science knowledge from the training manual
	Overall Experience	Citizen scientists report an enhanced knowledge from the overall experience
	Prior knowledge	Citizen scientists demonstrate an ability to apply prior knowledge to this project
Enhanced understanding of the scientific process and method	N/A	N/A
Improved access to science information (e.g. one-on-one interaction with scientists, access to real-time information about local scientific variables)	Real-time data	Citizen scientists report having access to real-time data
	Support from UNC researchers	Citizen scientists mention receiving support from UNC researchers to solve problems
	Training from UNC researchers	Citizen scientists mention receiving training from UNC researchers to solve problems
	Consultations with researchers to solve problems	Citizen scientists report having consultations with researchers to solve problems
Science Learning		
Increases in scientific thinking (e.g. ability to formulate a problem based on observation, develop hypotheses, design a study, and interpret findings)	N/A	N/A

Table 4.2 continued

Empowered participants and increased self-efficacy (e.g. belief in one's ability to tackle scientific problems	Empowered by training	Citizen scientists report feeling empowered as a result of participating in training
and questions, reach valid conclusions, and devise appropriate solutions)	Increased responsibility	Citizen scientists report giving increased responsibility to those that showed leadership qualities
Improved ability to interpret scientific information (e.g. critical thinking skills, understanding basic analytic measurements)	Lessons Learned	Citizen scientists demonstrate an ability to apply to interpret scientific information by submitting lessons learned
Science demystified (e.g. reducing the "intimidation factor" of science, correcting perceptions of science as too complex or complicated, enhancing comfort and appreciation for science)	Requesting help from researchers	Citizen scientists report becoming comfortable with requesting help from UNC researchers over the course of the project
	Comfort with water quality	Citizen scientists report becoming comfortable with water quality testing over the course of the project
Social Outcomes		
Strengthened connections between people nature and place (e.g. place attachment and concern, establishment of community monitoring networks or advocacy groups)	N/A	N/A
Increases in community building, social capital, social learning and trust (e.g. science as a tool to enhance networks, strengthen mutual learning, and increase social capital among diverse groups)	Strengthening community learning	Citizen scientists report that community learning was increased by hiring local citizen scientists
	Completing cluster maps with community leaders and village elders	Citizen scientists report learning that increased as a result of completing cluster maps with community leaders and village elders
	Community members as gatekeepers	Citizen scientists report using community members as gatekeepers to respondents
Changes in attitudes, norms, and values (e.g. about the environment, about science, about institutions)	N/A	N/A
Citizen scientists take action to influence policy and/or improve living environment	N/A	N/A
Citizen scientists gain access to broader (policy making) networks	N/A	N/A

After an initial round of coding subcodes were created *in vivo* from the data (Level 2), and are nested within Level 1 codes. The addition of subcodes helps to further develop themes and to help facilitate comparative analysis (Bradley, Curry & Devers, 2007). The subcodes included increased understanding of water quality testing, empowering participants through training, and strengthening community learning (Table 4.2). Researchers created decision rules for each of the refined codes and engaged in ongoing discussion throughout the coding process to ensure interrater reliability for all of the transcripts (85% agreement).

Results

The results are presented in sections corresponding to educational, scientific, and social outcomes, excerpts (representation statements) and a summary are included for each outcome. Of the representation statements, 57% were related to education, followed by 26% being social outcomes, and only 17% related to science learning. All outcomes were represented in the data with the exception of: changes in attitudes, norms, and values, citizen scientists take action to influence policy and/or improve living environment, citizen scientists gain access to broader (policy making) networks, and increases in scientific thinking.

Educational Outcomes

Educational outcomes were related to an increase in scientific knowledge, concepts, and access to scientists and scientific information (Table 4.3). Citizen scientists from nine country programs (Tanzania, Honduras, India, Kenya, Mali, Malawi, Niger, Ghana, and Mozambique) provided 30 examples of educational outcomes. Of these example quotes, 10 were from the Skype interviews and 19 were extracted from the implementation questionnaire.

Table 4.3.

Educational Codes, Occurrence, and Representation Statements

A priori codes	n=	Representation Statements
Enhanced science knowledge and literacy (e.g knowledge of science content, science applications, risks and benefits, and familiarity with scientific technology)	11 (5 countries)	"From the training manual, we got many new things to learn." India "It was a good exercise that helped to better understand the different [water quality] instruments" Honduras "The training [was] meant to equip and familiarize [citizen scientists] with WaSH evaluation survey which was based on science of water quality analysis where potential parameters were to be analyzed including e. coli, pH, arsenic, electroconductivity and fluoride." Tanzania
Enhanced understanding of the scientific process and method	2 (2 countries)	"We also developed STATA-DO files that were run to catch any out of range and missing values. The findings were shared with teams for purposes of improvement". Honduras
Improved access to science information (e.g. one-on-one interaction with scientists, access to real-time information about local scientific variables)	17 (8 countries)	"It was only with the help of UNC that I was able to solve this problem." Niger "Other things that worked very well were the level of communication from UNC." Honduras

Enhanced science knowledge and literacy. This outcome includes knowledge of science content, science applications, risks and benefits, and familiarity with scientific technology (n=11). Statements for this outcome were divided among four subcodes: increased understanding of water quality testing (n=6), an increased science knowledge from training (n=2) and an increased science knowledge from the training manual (n=1), enhanced knowledge from the overall experience (n=1), and the ability to apply prior knowledge to this project (n=1).

Citizen scientists from Tanzania described the value of the training and identified specific water quality tests they learned during training stating, "The training added a lot of values...in particular in the testing of arsenic and fluoride." Other comments that addressed an increased understanding of water quality testing were more general in nature. For example, Honduran citizen scientists noted that "it was a good exercise that helped to better understand the different [water quality] instruments."

Comments related to training indicated that citizen scientists benefited from the classroom activities as well as the training materials. Some statements related to training were unspecific such as the statement made by a Honduran participant who described the overall experience: "We learned a lot, also it was a lot of work, but it was a great experience." More specific was the description of the relevance and application of training topics described by a participant from Kenya:

> All topics were relevant, as including the PowerPoint slides and [citizen scientists] manuals. For instance, the general introduction on sampling approach help [citizen scientists] understand more about how the [field] survey was structured, and on overall provided guidance on the process of data collection while in the field. The presentations were customized using appropriate local (Kenyan) maps as necessary to make more relevant and suited to the local scenario. The [citizen scientists] were thus more able to relate more realistically with local maps thus improving their understanding of the evaluation. (Kenya, Implementation Questionnaire)

The experience of one citizen scientist reflected a principle of learning theory that participants bring prior knowledge and experience into new projects (NASEM, 2018). A citizen scientist described having to training others on a sampling technique that was not learned in training. It is presumed that in order to train others, this citizen scientist had some previous knowledge with which to draw on to train data collection teams in the field:

> We did work on a subject that was not mentioned during the initial training, but which is very relevant for the evaluation. This is the cluster questionnaire that has never been the subject of discussion or information in our exchanges with UNC and [the NGO]. We never exchanged on the subject. We had to go to the field and inform and train our teams and instruct them to inform the cluster questionnaire. (Mali, Implementation Questionnaire)

Enhanced understanding of the scientific process and method. Citizen scientists from Mali and Malawi recognized a better understanding of the scientific process through data validation. For example, a participant from Mali reported a more traditional means of using enhanced supervision to perform quality control on data stating:

> The various stages of data acquisition, verification, correction and validation are all followed not only by the weekly quality control system made available….by the UNC team but also by the daily verification of the data received on the mWater platform. To this must be added the different levels of supervision and control to minimize errors and maximize the quality of the data collected. This is necessary to ensure the scientific rigor of a study of this magnitude. (Mali, Implementation Questionnaire)

Improved access to science information. This outcome includes one-on-one interaction with scientists, and access to real-time information about scientific variables (n=17). Citizen scientists from eight countries indicated that they experienced improved access to researchers and scientific data. This outcome was reported in four subcodes related to access to real-time data (n=1): receiving support from UNC researchers to solve problems (n=11), training from UNC researchers (n=2), and consultations with researchers to solve problems (n=3).

Of the comments that noted this outcome, 65% percent specifically detailed receiving support from UNC directly. A citizen scientist from Honduras named an individual on the team as being the primary source of support: "Also from UNC team receive a lot of support from [WI Researcher], who was always ready to help and answer questions, even during weekends and night times. Answer needed never take more than 24 hours from [WI Researcher]" (Honduras, Implementation Questionnaire). While the previous comment mentioned a particular researcher, three citizen scientists described working with the UNC research team to solve a problem with data collection. A citizen scientist from Malawi noted, "Two [sampling] cluster were missed by UNC, [we] exchanged a number of emails with UNC to get this rectified. Eventually the [citizen scientists] and UNC agreed to use to alternate clusters."

Although mWater data could be accessed immediately, none of the countries reported having access to real-time data through this app. The lone comment related to real time information was from Tanzania and addresses the practicality and immediate water quality data results from the project. One citizen scientist mentioned that

> What I can say is that this survey has been a bit unique because it's been more practical. I've been doing some other surveys on the takeaways and this kind of stuff, but putting this on practice, collecting real data, looking at the results, looking at the water quality itself, you see the results. [Tanzania, Skype Interview]

Although all citizen scientists had the opportunity to participate in UNC sponsored webinars, only one citizen scientist from Tanzania mentioned access to real-time information through webinars led by UNC researchers, explaining, "[We] participated on the UNC-led webinars through online training to develop sampling design that was later used to train [citizen scientists]."

Science Learning Outcomes

Science learning outcomes relate to the ability to apply science concepts and to participate in science related activities (Table 4.4). Citizen scientists from four country programs (Tanzania, Honduras, Niger, and Mozambique) provided nine representation statements of science learning outcomes.

Table 4.4.

Science Learning Codes, Occurrence, and Representation Statements

A priori codes	n=	Representation Statements
Increases in scientific thinking (e.g. ability to formulate a problem based on observation, develop hypotheses, design a study, and interpret findings)	0	N/A
Empowered participants and increased self-efficacy (e.g. belief in one's ability to tackle scientific problems and questions, reach valid conclusions, and devise appropriate solutions)	4 (3 countries)	"So the water training was very very important and invaluable and it empowered me a lot on training." Honduras "It was good to have training workshop to [citizen scientists] prior to actual data survey. This empowers [citizen scientists] skills on both theory and practical through piloting to enable [citizen scientists] to gain more confidence on survey." Tanzania
Improved ability to interpret scientific information (e.g. critical thinking skills, understanding basic analytic measurements)	2 (1 country)	"More education is still needed to community members especially on hygiene and sanitation to communities, schools and health care facilities" Tanzania
Science demystified (e.g. reducing the "intimidation factor" of science, correcting perceptions of science as too complex or complicated, enhancing comfort and appreciation for science)	3 (2 countries)	"Even when we [feel] in risk as a team we take the opportunity to say the trust and ask for help or support." Honduras

Increases in scientific thinking. This outcome includes ability to formulate a problem based on observation, develop hypotheses, design a study, and interpret findings, (n=0). No citizen scientists in this study provided evidence that they increased scientific thinking through testing a hypothesis to experiment or intervention.

Empowered participants and increased self-efficacy. This outcome includes the belief in one's ability to tackle scientific problems and questions, reach valid conclusions, and devise appropriate solutions (n=4). Citizen scientists from two country programs made statements related to two subcodes: empowering participants through training (n=3) and increased responsibility as a result of showing leadership (n=1).

Statements about empowerment through training were general in nature. A Tanzanian citizen scientist said that "water training was very important and invaluable and it empowered me a lot on training." This comment could be interpreted to mean that the training empowered the citizen scientist to collect data or that training empowered the citizen scientist to train others in the future. A more straightforward quote from Tanzania mentions how training developed the citizen scientists' skills through practice in both training and theory: "It was good to have training workshop to [citizen scientists] prior to actual data survey. This empowers [citizen scientists] skills on both theory and practical through piloting to enable [citizen scientists] to gain more confidence on survey."

Citizen scientists from Mozambique described how the interactive nature of the training sessions encouraged trainees to actively participate:

> The way you put the practical exercise during the training, it makes the training more interactive. That's the main point that I saw through all this process. The exercises during the training got everybody in the room speaking and contributing with something and

> even the enumerators that were really quiet - they came and said something. The way you organized the training session, for me, it was good. This we will definitely use to make the practical exercises more interactive. (Mozambique, Skype Interview]

Citizen scientists from Honduras described how a group of participants gained more responsibility as a result of their actions at the start of data collection:

> I will say that one of the best decisions we made was in the process was not in the plan. We had four people to help only with the transportation and driving the cars. But when we got in the field, we were really lucky when the people we hired to the team were amazing. There were four men in the transportation team in the beginning and in the first two days they took a lot of the work in logistic stuff, like they were able to better understand the mapping and they were able to identify houses that were not in the mapping. They were able to more quickly identify the leaders in the community. So we changed the name of the team and we give them more power of decision in the process. And that was the best change we made, the main change in the work. [Honduras, Skype Interview]

Improved ability to interpret scientific information. This outcome includes critical thinking skills, and understanding basic analytic measurements (n=2). Citizen scientists from Tanzania offered several lessons learned as part of their evaluation report. While the lessons may not have been validated by the WI research team, it does offer a critical reflection of the project on the part of the participants. Statements revealed an understanding of the need for additional education among citizens including an understanding of the importance of sanitation facilities rather than open defecation. The participant mentions, “Still the Mange communities use open bush for defecation rather than using sanitation facilities.”

The Tanzanian report also recognized understanding of survey responses that did not make sense. For example, a review of data revealed that in some surveys, respondents indicated that they washed their hands without a rubbing motion or that hands were washed in the household but there was no water source. One observation noted that “some [said] there was water or they were washing their hands but there [was no tap].”

Science demystified. This outcome includes the reducing the "intimidation factor" of science, correcting perceptions of science as too complex or complicated, enhancing comfort and appreciation for science (n=3). This outcome was reported in two subcodes related to becoming more comfortable with requesting help from UNC researchers (n=2) and performing water quality testing (n=1). Honduran citizen scientists revealed an enhanced level of comfort with project researchers. When questions arose the citizen scientists felt comfortable with reaching out to researchers for answers and trusted that the researchers would be willing and able to answer their questions:

> Yeah, I think that when you open yourself to experience, you have to be honest, first with yourself, like this is the way I work and do and to pass that to my colleagues. If we don’t understand, if we are scared to do something in a bad way, it is better to ask before. If we make a mistake, I think it is best to say, “Hey Amy, I think that we are not doing this in the best way. Could you help us?” And I think that was one of the best parts of this experience too because we were always ready to ask and you were always ready to answer. [Honduras, Skype Interview]

Citizen scientists from Tanzania recognized that training allowed participants who had never conducted water quality testing to become more comfortable with the activities:

So getting back to a scientific point of view - working on the arsenic, working on the fluoride - they've never done this such [of thing] - or the water quality, talking about something they've never had. But, through close coordinations with them, it helped them a lot and they learned a lot and everybody would say, "Thank you very much. We've learned a lot. Thanks for taking us through slowly. And I think we've benefited a lot from these exercises. [Tanzania, Skype Interview]

Social Outcomes

Social outcomes relate to connections between the community, researchers, and the project (Table 4.5). Citizen scientists from nine country programs (Tanzania, Honduras, India, Kenya, Mali, Malawi, Niger, Ghana, and Mozambique) provided 14 representation statements of educational outcomes.

Table 4.5.

Social Codes, Occurrence, and Representation Statements

A priori codes	N	Representation Statements
Strengthened connections between people nature and place (e.g. place attachment and concern, establishment of community monitoring networks or advocacy groups)	1 (1 countries)	Beyond teamwork, each of the [citizen scientists] personally took the interest of the survey to meet the challenge because reliable data available offer many assets for the creation of knowledge in the context of research and make effective statistical inferences for the regions visited.
Increases in community building, social capital, social learning and trust (e.g. science as a tool to enhance networks, strengthen mutual learning, and increase social capital among diverse groups)	13 (7 countries)	"In some communities also was necessary identify a local leader to be with the team during the visit, to make sure the team was safe and have community support." Honduras
Changes in attitudes, norms, and values (e.g. about the environment, about science, about institutions)	0	N/A
Citizen scientists take action to influence policy and/or improve living environment	0	N/A
Citizen scientists gain access to broader (policy making) networks	0	N/A

Strengthened connections between people nature and place. This includes place attachment and concern, establishment of community monitoring networks or advocacy groups (n=1). This outcome was only reported by citizen scientists in Mali who indicated that the project built teamwork and the data collected were important for creating knowledge in the regions involved in the project. Malian participants expressed that:

Beyond teamwork, each of the [citizen scientists] personally took the interest of the survey to meet the challenge because reliable data available offer many assets for the creation of knowledge in the context of research and make effective statistical inferences for the regions visited. [Mali, Implementation Questionnaire]

Increases in community building, social capital, social learning and trust. These outcomes include using science as a tool to enhance networks, strengthen mutual learning, and increase social capital among diverse groups, (n=13). This was the most widely recognized outcome with seven countries making statements related to building capital in the community. Evidence of this outcome was reported in three subcodes: strengthening community learning by hiring local citizen scientists (n=1), completing cluster maps with community leaders and village elders (n=10), and using community members as gatekeepers to respondents (n=2).

Although every country program in this study used local citizen scientists to collect data, only participants from Kenya commented on the process of teaching community members the skills needed to collect project data. The skills learned by the citizen scientists in these remote areas can be used to build capacity for the future:

In some areas, getting quality [citizen scientists] is so difficult. Especially the very remote areas. Even the applicants were not enough. There were nomads and herders who did not have an education. Those that have a good application have already moved to town. When you advertise for such positions locally, you get people who may not have the highest skill. In those areas we had challenges because getting someone who is willing to work, but maybe they are not used to smartphones - they've been using the ordinary button phone. So you have to take them through that, but because the youth can learn very fast, it took some time, but it worked. Of course there were initial errors when they were trying to fill out the original questionnaire, their fingers were all over clicking here and there, clicking on different questions. During the piloting we saw that problem, but we advised them while doing it. So it was not possible to get the same caliber or quality of [citizen scientists] everywhere. In some areas there were challenges. [Kenya, Skype Interview]

Eleven representation statements were attributed to working with village elders and other community leaders to map water points and households to be surveyed. After citizen scientists explained the rules for sampling, local leaders were able the complete maps together. These interactions were one-sided, with the community members providing information needed to collect data. However, it appears that this joint work strengthened relationships between the citizen scientists and the communities they entered and helped to make residents feel like they were a part of the project. It should be noted that there were no statements that made the case for strengthened networks. Some comments were general; for example, one citizen scientist said "the cluster mapping was done jointly with the [citizen scientists], [NGO] staff...and in consultation with local community leaders."

Other statements were more specific about the process by which the local leaders were recruited to assist in mapping:

When the [citizen scientists] come to the village for the first time, they meet the WaSH committee if there is one in the village. We discuss with them. We explain the process of our evaluation in the village. So after that, they do kind of a mapping of all the household data in the village. [Niger, Skype Interview]

Two comments related to using community organizations and local leaders as community gatekeepers. Gatekeepers are members of the community that assist data collectors with gaining access to sites, people and information (Creswell & Miller, 2010). One statement described health center officials as gatekeepers:

> One of the difficulties was also related to access to information at the Health care facilities level. Collaboration with health center officials was not good. Our teams have very often reported cases of refusal for their interlocutors but we have been able to bring them back to collaborate by giving them detailed explanations of the objective of the study. They ended up understanding and agreeing to talk to our teams. [Mali, Implementation Questionnaire]

Another representation statement related to gatekeepers referenced using community leaders to gain access to respondents and remain safe in unfamiliar areas: "In some communities also was necessary to identify a local leader to be with the team during the visit, to make sure the team was safe and have community support."

Not all social outcomes were recognized by the citizen scientists in this study. There were no representation statements attributed to the following outcomes: changes in attitudes, norms, and values; citizen scientists take action to influence policy and/or improve living environment; and citizen scientists gain access to broader (policy making) networks.

Discussion

This study explored the experiences of citizen scientists in terms of the educational, scientific, and social outcomes realized during a WaSH citizen science project. The study also sought to determine if additional learning outcomes that have yet to be included in published literature were identified in this citizen science project. Similar outcomes to those identified in Den Broeder et al. (2016) were found in this study. Evidence of educational and science learning outcomes, including enhanced science knowledge and literacy, increased community learning, and improved access to accredited scientists were reported by citizen scientists. However, a strong connection to social outcomes was not apparent. In addition to comparing current outcomes to those previously published, subcodes that further explain the *a priori codes* presented in Den Broeder (2016) were created and more inclusive outcomes that can be used to identify possible outcomes in future projects were identified.

Educational, Science Learning and Social Outcomes

Of the 12 outcomes presented by Den Broeder et al. (2016), eight were represented by citizen scientists in this project. A total of 53 examples of these outcomes were identified, and the majority (57%) of those were related to education, followed by 14 (26%) social outcomes, and nine (17%) science learning outcomes. Given that the training focused on specific data collection protocols and emphasized using UNC researchers as a resource, the increased number of outcomes related to educational outcomes is consistent with expectations.

As defined by Den Broeder et al. (2016), the outcomes related to science learning would be more appropriate for a collaborative citizen science project where participants are involved with the project design, including formulating the research questions and analyzing data. Since our project was designed to be contributory with citizen scientists only collecting data, the lower number of outcomes related to science learning was not surprising.

One interesting finding was the number of outcomes related to social connections. Although the training did not specifically address connections between the citizen scientists, local residents, and the environment, it was anticipated that given the amount of interaction occurring during data collection, these outcomes would have been reported. The results related to social outcomes are also consistent with previous research findings that many citizen science projects are not able to demonstrate outcomes related to increased interest in science and the environment and stewardship behaviors among others (Bela et al., 2016; Bonney, Phillips, Ballard & Enck, 2016; Jordan et al., 2011; Phillips et al., 2012). Citizen science projects may support additional learning outcomes that were not reported. In this study, social outcomes may have been realized but were not emphasized by project participants in the implementation questionnaires or Skype interviews. This indicates a need for additional assessment measures to determine if, in fact, these outcomes were substantiated.

Improved Taxonomy

NRC (2009) reports that one issue that plagues informal science settings is the need for common tools to allow for settings to be compared. Outcomes are a way to characterize possible experiences that result in engaging in informal science education (NRC, 2009). Previous research suggests that the use of common outcomes and assessments can help to create consistency and synergies across citizen science projects. These synergies can provide insights and solve challenges particularly in public health (Hinckson, 2017; NRC, 2009).

The broad overarching learning and science outcomes published in Den Broeder (2016) are broad and open to interpretation. Using such generic outcomes makes comparison between projects difficult. The manner in which outcomes "compliment and build on one another" can be improved (NRC, 2009). Bradley, Curry, and Devers (2007) suggest that by improving taxonomies, outcomes, and evaluations can also be improved.

In an effort to improve taxonomy, this study includes seventeen subcodes which further classifies the a priori codes published in Den Broeder et al. (2016). Subcodes can allow for stronger comparative analysis between similar projects and eventually the development of theory. In addition to allowing for comparison across and between projects, other benefits include creating opportunities to improve science learning in informal science settings and improving the quality of evidence (NASEM, 2018). For example, the subcodes created in this study help support project designers by providing a more comprehensive list of possible outcomes for future programs.

Unanticipated Outcome

Literature suggests that in informal science settings, outcomes can sometimes be unanticipated. The unanticipated outcomes can be tied to the goals of the program or can be a result of participant priorities and guided by the learners (NRC, 2009). In this project, an unanticipated outcome was related to technology. Citizen scientists were introduced to new technology in the form of a mobile data collection platform and for some in more rural communities, a smartphone. As new data collection software is constantly being developed, in the future citizen scientists will be asked to familiarize themselves with new technology. Den Broeder et al. (2016) alludes to technology by saying ‘familiarity with scientific technology’ is an example code related to enhanced science knowledge and literacy. A number of our participants indicated that one outcome they would take from this project into future projects would be the data collection platform used in our study. This study suggests a new code be added to the codes presented by Den Broeder et al. (2016) that specifically accounts for the impact that learning new technology has on citizen scientists.

Contribution to Science Education

Citizen science can support a variety of learning outcomes such as learning new scientific skills and developing scientific reasoning. While evidence some exists that “participation in citizen science projects can enhance science learning,” there is more information needed on potential outcomes and how to assess these outcomes (NASEM, 2018, p. 146). The National Academy of Science convened committees charged with studying topics related to outcomes and science learning in informal environments. The resulting report identified recommendations for the best practices for supporting learning through citizen science project (NASEM, 2018). One recommendation suggests that citizen science practitioners and researchers develop shared tools and frameworks that that can be used to collect and assess data on learning outcomes (NASEM, 2018; NRC, 2009).

Few common tools and frameworks exist for analyzing learning within citizen science projects. A particular need exists for tools that can be applied across a range of citizen science projects (NASEM, 2018). These tools need to be "practical and evidence-centered to allow for assessing outcomes across a variety of citizen science projects" (NRC, 2009, p. 55).

Without common tools and frameworks, it is difficult to build consensus in the field of citizen science. The current study contributes to the field of science education by providing an evidence-centered assessment of educational, science learning and social outcomes resulting from participation in a citizen science project. This research helps to satisfy the recommendations of the NASEM committee and not only compares outcomes between projects, but more importantly adds to a previously published citizen science framework by adding a technology related *a priori codes* and seventeen subcodes. These comparisons show what educational, science learning, and social outcomes opportunities occur across the citizen science landscape. As suggested by NRC (2009), this work complements and builds on the Den Broeder et al. (2016) framework. The use of Skype interviews and implementation questionnaires also show additional ways that evidence of outcomes can be documented, particularly in low resource settings (NRC, 2009).

Limitations

This study sought to identify social, educational, and scientific outcomes reported by citizen scientists as a result of participation in a WaSH project. First, respondents were limited to citizen scientists who were fluent in written and spoken English and familiar with all aspects of the project. As a result, this may have led to missing or biased outcomes that may have differed if more citizen scientists with different backgrounds had been included in this sample. Secondly, since the public health survey and training data in this study was repurposed to assess educational, science learning, and social outcomes, questions directly related to participant outcomes were not asked of respondents. Instead, the available data was mined for evidence of outcomes. Because of this, this study may have missed outcomes that might have been realized had the respondents been asked directly about potential outcomes.

Implications and Suggestions for the Future

This research can help inform the development of future citizen science projects, allowing for more a more impactful experience for participants, specifically in the field of public health.

In the current study, outcomes and descriptions from Den Broeder et al. (2016) were used literally. Given the literal use of the codes, there were outcomes that may have been realized had the outcomes published in Den Broeder et al. (2016) been expanded or open to interpretation. For example, the outcome related to increases in scientific thinking specifies that this thinking is in relation to the ability to formulating a problem based on observation, developing a hypothesis, designing a study, and interpreting findings. Without this description, this outcome could be interpreted as the citizen scientists having the ability to resolve issues in the field. In the current study, one citizen scientist described solving a problem in the field without contacting the research team to help resolve the issue.

As the pool of common outcomes continues to grow, it is important to recognize that while descriptions of project outcomes are needed, careful consideration should be taken when determining the level of detail used in the descriptions. The descriptions will impact the realization of outcomes. The addition of subcodes can be used to further classify outcomes and allow for more comprehensive comparisons between projects. Researchers who work on the perimeter of the project and citizen scientists who are working more closely with the project may describe outcomes in different ways. It is also important for researchers and citizen scientists to work together to define potential and provide evidence of realized outcomes (NRC, 2009)

In addition to carefully defining potential outcomes to create more comprehensive assessments, project evaluators can consider restructuring evaluation questions to capture more focused responses related to the benefits realized by citizen scientists. For example, to better assess evidence of social outcomes, during the Skype interviews citizen scientists could have been asked a question related to the number of people encountered during data collection and whether these encounters impacted them in any way. Care should be taken to structure questions to reduce acquiescence and social desirability that occur when respondents agree or give answers they feel are favorable (Groves et al., 2009).

CHAPTER 5: Conclusion

The purpose of this dissertation was to better understand the science and participant learning outcomes resulting from a multi-country WaSH related citizen science project. This study re-purposed data to answer research questions related to the use of citizen scientists as data collectors in a multi-country WaSH project. Specifically, the goal of this research is to inform the field of informal science education by better understanding: 1) how training impacts the quality of data collected by citizen scientists, and 2) the educational, science learning, and social outcomes experienced by citizen scientists participating in a WaSH project. Key conclusions, limitations and implications are presented below.

There are three main contributions of this research to the citizen science evidence base. These conclusions include the need for intentional recruitment of citizen scientists, common assessment tools and frameworks, and shared learning through journal publications.

Intentional Recruitment of Citizen Scientists

This dissertation demonstrates the impact of the participant on the success and sustainability of a citizen science project. Findings from Chapters 2, 3 and 4 further support those of Crall et al. (2013) who suggests that "citizen science can make major contributions to informal science education by targeting participants' attitudes and knowledge about science while changing human behavior towards the environment" (p. 745). Science is a sociocultural activity, and studies show that in low- and middle-income communities such as those studied in this dissertation, community issues and participant backgrounds can have significant impacts in science interest and in turn program sustainability (NRC, 2009).

The findings of the current study are consistent with Haywood et al. (2016) who suggest that further research is needed to better understand the influence of place and sociodemographics among citizen scientists to inform the development of activities and resources that will best position them to achieve program goals. NASEM (2016) suggests that because "the research community has yet to study in sufficient detail the value of science literacy "in action" in society and within societal systems and communities" (p. 111). how communities develop and apply science literacy is still misunderstood. This research can help to discover the relationships between science literacy, communities and individuals.

Given the impact of participants on the success and sustainability of a citizen science project, project designers should take care to communicate with communities in and around projects sites to gain a deeper understanding of community needs and relations as well the availability of potential program participants. Research suggests that with regard to science, the cultural identities of low-income and communities of color like those highlighted in this dissertation study are often overlooked. Experts suggest that citizen science is a way to engage these communities in the creation of scientific knowledge that not only considers their experiences but uses that information to increase their science literacy as well (NASEM, 2016, NASEM, 2018).

Literature suggests that to achieve desired learning outcomes, it is necessary to also choose activities that support those outcomes and to choose evaluative tools that allow outcomes to be measured (NASEM, 2018). Activities and goals can be developed that align with the strengths that potential citizen scientists bring to the project. As suggested by NRC (2009), when project goals and activities are mutually determined by scientists and citizen scientists, science learning and, in turn, community capacity increase. While science learning through citizen science projects can happen intentionally or as a by- product of participation, outcomes can only be realized through evaluation.

Assessment Tools, Frameworks, and Evaluations

Critics of citizen science often complain that citizen science takes from its participants, but they do not benefit. In order for citizen science to counter this criticism, is to necessary for project designers to articulate desired outcomes and to develop, validate, and employ evaluation strategies that can measure environmental and scientific literacy to document changes attributable to project participation (Bonney et al., 2014; Phillips, 2017). As noted by NASEM (2018) and Crall et al. (2013), the absence of published evaluation results could be attributed to a lack of evaluation tools specifically designed for citizen science. These findings were confirmed by the lack of published frameworks to evaluate science outcomes, participant learning outcomes, and data quality for the current project. Another benefit of using a published framework is that it allows outcomes from different citizen science projects to be compared. Coordination and standardization would increase the level of academic rigor currently lacking in many citizen science projects, helping to make citizen science a more accepted mainstream method of data collection.

The development of common assessment tools, frameworks and evaluations can not only highlight individual projects but also help identify shared strengths and opportunities leading to a set of best practices for citizen science projects (Hinkson, 2017). Although studies show that citizen science engages participants in in scientific practice (Strand 6), there is no set list of best practices for developing projects that increase science knowledge (NRC, 2009). Best practices that could include activity choices, training methods, resources, and communication plans can only be developed through the comparison of projects using shared assessment tools. Because frameworks were not available, they had to be adapted or created in Chapters 3 (Data Quality) and 4 (Outcomes). Also missing were publications addressing the overall outcomes achieved during citizen science projects.

Shared Learning through Publication in Scientific Journals

The scoping literature review presented in Chapter 2 identified journal articles that characterized the impact of citizen science projects on individual participants and the larger field of science. Of 248 publications screened during the review process, only 14 jointly addressed participant and science outcomes from citizen science projects and met the inclusion criteria for this study. These results match those reported by Crall et al (2013) who highlighted the need for more rigorous studies detailing outcomes achieved during citizen science projects.

As citizen science emerges as a source of informal science education, it is imperative that the field disseminate evaluation results, both good and bad, to improve projects and, as a result, to also improve science learning and environmental impact. Research shows that in informal science settings, like citizen science, successful examples that show an increase in science literacy are more likely to be published than examples where science goals were not met. However, it is important to note that even in instances where goals were not met, there are lessons to be learned to improve future projects (NASEM, 2016).

NRC (2009) suggests that researchers and evaluators of citizen science projects should increase the opportunities and provide incentives for non-academic practitioners to publish their work in scientific journals. Increased publications helps to provide a more cohesive and evidence based “body of knowledge and practice” (NRC, 2009, p. 305). Another benefit of using a published framework is that it allows outcomes from different citizen science projects to be compared and lessons learned shared.

While data sets from citizen science projects are often published online or made available upon request, the rate at which citizen science data is published in peer reviewed journals is low. Because of this, citizen science is not reaching its full potential to impact the research community, especially in resource poor settings (Theobald et al., 2015). As suggested by Theobald et al. (2015), this dissertation has taken steps towards developing a framework that can be used as a foundation for research in other citizen science projects particularly in low resource settings.

Methodological Contribution

There are three methodological contributions from this research. First, as part of the scoping review (Chapter 2), the framework adapted for evaluating participant learning outcomes and science outcomes can be used by practitioners to begin to standardize evaluations of citizen science project outcomes. Using a comprehensive framework allows outcomes from different citizen science projects to be compared. This coordination and standardization would increase the ease at which practitioners could evaluate projects and the level of academic rigor currently lacking in many evaluations.

Second, the data quality index developed for this study serves as a tool to quantitatively assess the quality of data collected by citizen scientists. By adapting a model from the product manufacturing industry, this study was able to develop a data validation tool that can be used to data quality in citizen science projects. The fact remains that there is a need to rely on data collected by citizen scientists, and without assessment tools such as the index presented here, we may continue using data of unknown quality. This data quality index can help to bring transparency to performance of citizen scientists. This transparency can also help to build confidence in citizen science as a mainstream data collection approach. The data quality index can be used in low resource settings where statistical expertise may be lacking. Allowing practitioners in low resource settings to validate data will increase science literacy and, in turn, the scientific capacity of the community.

Finally, using published social, educational and scientific outcomes, this study helped to build evidence for the development of possible participant learning outcomes for future studies. This research can help inform the development of future citizen science projects, allowing for more a more impactful experience for participants specifically in the field of public health. By developing a repository of possible outcomes, future citizen science projects have the potential to have a more impactful experience for participants, including increases in science literacy, skills of science practice, and environmental stewardship.

Limitations

Several limitations apply to these findings. This study represents one project in public health which limits the generalizability of results. However, this project reflects the amount of variation in citizen science projects and related activities. Also, since the public health survey and training data in this study was repurposed to assess educational, science learning, and social outcomes, questions directly related to outcomes were not asked of respondents. Instead, the available data was mined for evidence of outcomes. Because of this, this study may have missed outcomes that might have been realized had the respondents been asked directly about potential outcomes.

Future Research

Further research is needed to better understand how citizen science impacts science learning and science. The tools and frameworks used in this study will need to be published for use by the wider citizen science community. For example, the data quality index developed in this study can be used in other studies and tested in a variety of contexts to determine its robustness and utility as a data validation tool. Additionally, future research should take care to understand the cultural and educational backgrounds of the citizen scientists. Data on the sociodemographics of the citizen scientists may have implications on data quality and should be explored. Finally, during the next round of data collection, the project should be designed so that the degree to which project participation changed the science literacy and attitudes towards science and the environment can be determined.

Of all the citizen science projects reviewed in this dissertation, none collected data on the scale (data points or geographic) of the WaSH project presented. Practitioners and researchers interested in conducting a large-scale international citizen science project can use this project as a model by using the potential outcomes presented in this study as a basis for project design. It is important that citizen science projects begin to design for the outcomes they want to produce.

Researchers can also use this project as a model for repurposing data sets for the purpose of informing other disciplines such as science education. As grant funding becomes harder to get, education and training may be one of the line items cut when budget funding is scarce. This provides evidence for the need for additional research on citizen science outcomes but maybe more widely applicable is evidence of the ability for data sets to be repurposed. By repurposing this public health data set, the resources used to collect the data were leveraged to answer additional questions related to science education.

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APPENDICES

Appendix A: Scoping Review Articles

Reference	Title	Description
Ballard et al. (2017)	Youth-focused citizen science: Examining the role of environmental science learning and agency for conservation	
Cornwell et al. (2011)	Co-producing conservation and knowledge: Citizen-based sea turtle monitoring in North Carolina, USA	Citizen scientists collected data on sea turtle nests, monitored beaches, reported on nesting activity, and educated the public about sea turtle biology and conservation.
Dem et al. (2018)	Understanding the relationship between volunteers' motivations and learning outcomes of Citizen Science in rice ecosystems in the Northern Philippines	Citizen scientists in the Philippines documented butterflies and dragonflies in rice ecosystems.
Domroese and Johnson (2017)	Why watch bees? Motivations of citizen science volunteers in the Great Pollinator Project	Citizen scientists in New York City collected data on bee visitation to selected species of native flowers
Druschke and Seltzer (2012)	Failures of Engagement: Lessons Learned from a Citizen Science Pilot Study	In Chicago, citizen scientists collected data on urban bee diversity and abundance.
Evans et al. (2005)	The Neighborhood Nestwatch Program: Participant Outcomes of a Citizen-Science Ecological Research Project	Citizen scientists in Washington, DC were asked to closely observe and report nesting behavior and nesting success of bird species on their property.
Fernandez-Gimenez et al. (2008)*	Adaptive Management and Social Learning in Collaborative and Community-Based Monitoring: a Study of Five Community-Based Forestry Organizations in the western USA	Five community-based forestry organizations in the western USA engaged citizen scientists in collaborative and community-based monitoring projects.

Ferreira et al. (2019)	Educating citizens about their coastal environments: beach profiling in the Coastwatch Project	Citizen scientists in Portugal participated in a coastal management project by monitoring beaches in terms the geology, flora, and, fauna.
Hann et al. (2018)	Obstacles and Opportunities of Using a Mobile App for Marine Mammal Research	Citizen scientists in Southeast Alaska used a mobile application to collect marine mammal sighting data.
Hollow et al. (2014)	Science Direct Citizen science for policy development : The case of koala management in South Australia	Citizen scientists collected data about koala abundance and management in Australia.
Martin et al. (2016)	Understanding drivers, barriers and information sources for public participation in marine citizen science	Citizen scientists in Australia reported sightings of marine species that were uncommon the area being studied.
Roger and Klistorner (2016)	BioBlitzes help science communicators engage local communities in environmental research	Citizen scientists in Australia cataloged flora and fauna species during an expert-led tour.
Sickler et al. (2014)	Scientific Value and Educational Goals: Balancing Priorities and Increasing Adult Engagement in a Citizen Science Project	Citizen scientists across North America submit photos of ladybug species to scientists to be entered into a master database.
Toomey & Domroese (2013)*	Can citizen science lead to positive conservation attitudes and behaviors?	Citizen scientists in New York City collect baseline data on bees, and other fauna and flora species.
Reference	Title	Description
Ballard et al. (2017)	Youth-focused citizen science: Examining the role of environmental science learning and agency for conservation	
Cornwell et al. (2011)	Co-producing conservation and knowledge: Citizen-based sea turtle monitoring in North Carolina, USA	Citizen scientists collected data on sea turtle nests, monitored beaches, reported on nesting activity, and educated the public about sea turtle biology and conservation.

Dem et al. (2018)	Understanding the relationship between volunteers' motivations and learning outcomes of Citizen Science in rice ecosystems in the Northern Philippines	Citizen scientists in the Philippines documented butterflies and dragonflies in rice ecosystems.
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Evans et al. (2005)	The Neighborhood Nestwatch Program: Participant Outcomes of a Citizen-Science Ecological Research Project	Citizen scientists in Washington, DC were asked to closely observe and report nesting behavior and nesting success of bird species on their property.
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Hann et al. (2018)	Obstacles and Opportunities of Using a Mobile App for Marine Mammal Research	Citizen scientists in Southeast Alaska used a mobile application to collect marine mammal sighting data.
Hollow et al. (2014)	Science Direct Citizen science for policy development : The case of koala management in South Australia	Citizen scientists collected data about koala abundance and management in Australia.
Martin et al. (2016)	Understanding drivers, barriers and information sources for public participation in marine citizen science	Citizen scientists in Australia reported sightings of marine species that were uncommon the area being studied.

Roger and Klistorner (2016)	BioBlitzes help science communicators engage local communities in environmental research	Citizen scientists in Australia cataloged flora and fauna species during an expert-led tour.
Sickler et al. (2014)	Scientific Value and Educational Goals: Balancing Priorities and Increasing Adult Engagement in a Citizen Science Project	Citizen scientists across North America submit photos of ladybug species to scientists to be entered into a master database.
Toomey & Domroese (2013)*	Can citizen science lead to positive conservation attitudes and behaviors?	Citizen scientists in New York City collect baseline data on bees, and other fauna and flora species.

*article addresses more than 1 citizen science project

Appendix B: Data Quality Index Template

Variable	Country Program	# of Errors/# of Entries	Likelihood	Impact	Detection Difficulty	Score
Household water storage container	Country A					
	Country B					
	Country C					
Length of survey	Country A					
	Country B					
	Country C					
Trip Number	Country A					
	Country B					
	Country C					
Water Sample ID	Country A					
	Country B					
	Country C					
Fluoride	Country A					
	Country B					
	Country C					
Arsenic	Country A					
	Country B					
	Country C					
Conductivity	Country A					
	Country B					
	Country C					
pH	Country A					
	Country B					
	Country C					

Total Score	
Country A	
Country B	
Country C	

Appendix C: Implementation Questionnaire

WV 14-Country Evaluation: Implementation Questionnaire

Last revised 8/17/2017

<u>INSTRUCTIONS:</u> The Narrative Summary is a description of the evaluation work that was completed over the past few months. The details you provide here will help explain any variations from the original study protocol, and will also help document any special challenges that your teams faced while collecting data.

This template is divided into 9 sections. Each section has a list of questions to help you write a description of how each part of the evaluation was carried out. To fill out this template, simply type your responses to the questions in each section in the blank area below the questions (where it says "[Type your response here]". There is no limit on the amount you can write – please take as much space as is necessary to describe the evaluation thoroughly!

When completed, save this file as "WV-14 Narrative Summary_CountryName_Date" and return to Amy Guo at aguo@live.unc.edu. UNC will contact you at a later date for additional follow-up information and a Skype call if we have any further questions.

Country name	[Enter country name here]

Date of summary	[Enter the date you are filling this form out]

This form is being filled out by	[Enter your name, role within evaluation, and contact information here]

Country sampling plan

Describe the sampling plan for your country here. What are the names of the different regions included in the sample frame, and why were they selected? Were there any other special considerations or requests that your country had while creating the sampling list?

Did any of the original sampling units have to be subdivided into smaller units, or secondary sampling units (SSUs)? If so, please describe the process here.

What were the sizes of the final sample frame for each survey, as well as the final sample sizes?

If you had to obtain any lists of households, water points, schools, or healthcare facilities from an outside source instead of making the list yourself, who or where did you obtain the list from? Please include a name and contact information if possible.

Were there any areas that had to be excluded for the sampling frame (ex. for safety concerns)? If so, which areas were excluded?

[Type your response here]

Survey instrument

Were there any additional questions or modifications that were made to the survey questions in your country? If so, why?

Which languages was your survey translated into? Who was responsible for translating the surveys, and for verifying the translations?

[Type your response here]

Piloting and training

If applicable, describe any difficulties which your team encountered during the initial piloting and training process.

Did your teams have any difficulties applying what was learned in the training? If so, please describe.

Were there any topics that were not covered in the initial training, but would have been helpful to know during the evaluation? Were there any topics that were covered in the training, but were not used in the field?

[Type your response here]

Survey data collection

Describe the setup of your enumerator teams. How many supervisors did you have, and how many enumerators was each supervisor responsible for? Did enumerators always work in teams, or did they conduct interviews on their own? How often were you able to communicate with your supervisors and enumerators to check in with them?

Were you able to verify 10% of interviews by re-administering the first section of the survey?

What were the dates on which major events occurred (ex. trainings; refresher trainings; beginning of data collection; end of data collection)?

Were there any other major challenges that your teams encountered in the field? If so, please describe them here.

[Type your response here]

Water quality testing

What was the process for ensuring the microbial tests were incubated for the correct period of time? Have 10% of these test results been reviewed and checked against the corresponding photos?

For water points, were duplicates or blanks collected at every cluster? If not, why?

[Type your response here]

Data entry and data checks

Did you review the data for quality control on a regular basis (for example, through the weekly QA/QC sheet)? Did you notice any common problems or misunderstandings about certain survey subjects or questions? What steps did you have to take to correct these?

Were there any major data corrections that you had to make after enumerators submitted their final responses in mWater? Are there any remaining errors or anomalies that should be noted for UNC?

[Type your response here]

Ethical approval

Were there any additional changes to the study design within your country, in order to meet the requirements of your local ethical board? If so, what were these changes?

Which languages were the verbal consent forms translated into for your country? Who was responsible for translating and verifying the translations of these consent forms?

Does your country have any special requirements (ex. storage or management requirements) for the data collected?

[Type your response here]

Other challenges and considerations

Were there any other special circumstances or challenges that arose in your country, which have not been described elsewhere in this summary? This might include any major equipment malfunctions (ex. broken fluoride meters, broken phones) or unexpected logistical issues (ex. schools out of session for the majority of data collection period, extreme weather).

[Type your response here]

Comments and suggestions for future evaluations

Are there any comments or suggestions that you have for improving future evaluations? For example, were there certain questions that were hard for respondents to understand, or for enumerators to answer? Were there any confusing situations that would be helpful to explain within the trainings?

Would you consider using mWater for future evaluations? If not, why?

[Type your response here]

Appendix D: Interview Guide

1. Because of the time between training and conducting the survey some citizen scientists forgot the information they learned in training? What did you do to address this issue?
2. How were the citizen scientists chosen? Was preference given to applicants with smartphone proficiency or that had a background in science?
3. Did you use What's App to communicate in the field?
4. Other than translations, was it necessary to make any changes to the training materials provided by UNC?
5. Thinking about this experience and the training you received from UNC? Is there anything that you learned that you will put into practice going forward? Anything you will do differently in the future?
6. Were all citizen scientists trained to conduct all surveys and water quality tests?