TRAINING CITIZEN SCIENTISTS FOR DATA RELIABILITY: A MULTIPLE CASE STUDY TO IDENTIFY THEMES IN CURRENT TRAINING INITIATIVES

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Training Citizen Scientists for Data Reliability
A Multiple Case Study to Identify Themes in Current Training Initiatives

by

Margaret L. Gaddis

Abstract

This dissertation characterized trainings designed to prepare citizen scientists to collect ecological data in natural outdoor settings. Citizen scientists are volunteers who participate in scientific activities under the guidance of professional scientists and organizations. The work of citizen scientists greatly expands the data collection possibilities in natural resource management and increases science literacy among participants and their social communities. The general problem is that some scientists and land managers view the data collected by citizen scientists as unreliable. The specific problem is the absence of educational training measurement in citizen science program design and analysis with which to ascertain the learning gains of trained citizen scientists.

Through a sequenced methodology of data analysis, survey, and semi-structured interviews, deductive descriptors and codes guided a directed content analysis of data collected. The analysis indicated strong alignment between citizen science, andragogy, and social learning theory. The sample revealed a bimodal distribution related to the type of data collected and the subsequent training design. Little training existed when data collection involved photography only. Citizen scientists brought prior skills to the task but did not need to gain new procedural learning to complete their data collection task. When citizen scientists collected more complex measurements, classroom and field mentoring facilitated learning.

Citizen science leaders described their perception of the reliability of their citizen scientists’ data collection efforts. Computer technologies validated photo and water quality data. Therefore, quantitative data analysis supported the perception of data reliability. Terrestrial data had a range of reliability qualifications including video and paper quizzing, field observation of methods implemented, periodic data checks, and follow-up mentoring when data quality was poor. Managers of terrestrial citizen science programs were confident in the reliability of the data for the land management, policy, and research applications required.

Key words*: citizen science, ecology, andragogy, adult education, data reliability, training*

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To my sweet children—I am so happy to be able to hang out with you again! I miss you and love you. A dissertation is a lonely road. Thank you for helping me reach the intellectual destination even though it probably still remains a mystery to you. Let’s talk about it when you are much older. To Aaron—I could write another dissertation about the ways in which you make my life worth living.

Of immeasurable importance to the success of this project is my scholarly support team including Dr. Kim Fonteix, Jeanne Loo, Jaxon Rickel, and my committee. To my colleagues in work and friendship including Dr. Paul Robertson, Dr. Barbara Gaddis, Dr. Anna Sher, and Christine Lowenberg—your science leadership inspires me to keep my dreams alive.

Hard work beats talent when talent doesn’t work hard.

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CHAPTER I: INTRODUCTION

Citizen scientists are volunteers who participate in scientific activities under the guidance of professional scientists and organizations. The work of citizen scientists greatly expands the data collection possibilities in natural resource management (Bonney et al., 2014; Dickinson, Zuckerberg, & Bonter, 2010; Schmeller et al., 2008), connects people with their landscapes (Havlick, Hourdequin, & John, 2014), and increases science literacy among participants (Crall et al., 2013; Rasmussen, 2015) and their social communities (Lynch, 2016). The connection between citizen science training design and participant learning is not described in the literature (Bela et al., 2016; Crall et al., 2011; Dickinson et al., 2010, Newman et al., 2010, Smith, 2015). Without this connection, it is difficult to validate the variable success of citizen scientists who collect field-based scientific data. This dissertation explored this connection to develop understanding regarding best management strategies within the field of citizen science training.

Statement of Problem

The call for theory-based training appeared in the literature as early as 1971 (Campbell, 1971), but it has not yet been applied to the field of citizen science. Results in other fields indicated that theory-based training strengthened procedural outcomes the application of the principles of education to workplace and informal education settings (Mitchell & Sonora, 2012). Analogous to the movement towards standardization and assessment in American education, citizen science has needed assessment parameters to measure the success of the education effort (Becker-Klein, Peterman, & Stylinski, 2016., 2016; Cronje, Rohlinger, Crall, & Newman, 2011; Dickinson et al., 2010; Friedman, 2008). Surveys of citizen science programming abound in the literature, but researchers have not specifically looked at the training parameters that inform the program participants.

The general problem is that some scientists and land managers view the data collected by citizen scientists as unreliable (Crall et al., 2011; reviewed in Dickinson et al., 2010; Gollan, De Bryun, Reid, & Wilkie, 2012). This has resulted in lower confidence in the scientific use of citizen-scientist-collected data. When land managers and scientists lack confidence in citizen scientist-collected data, these data are not analyzed or published in peer-reviewed journals. In turn, the value of using citizen scientists to collect scientific data erodes (Freitag, Meyer, & Whiteman, 2016). The facultative role that citizen scientists play for scientific endeavor is questioned in light of the apparent costs of engaging citizen scientists (Fauver, 2016). The specific problem is the absence of educational training measurement in citizen-science program design and analysis with which to ascertain the learning gains of trained citizen scientists. More research describing how and what citizen scientists learn in these informal training environments is needed (Bonney et al., 2009b; Crall et al., 2013; Newman et al., 2010; Smith, 2015; Rasmussen, 2015). This will inform efforts to increase the quality and therefore acceptance and use of data collected by citizen scientists.

Training research in other disciplines has suggested that training effectiveness is related to training design and the identification of clear learning objectives (Mitchell & Sonora, 2012; Salas, Tannenbaum, Kraiger, & Smith-Jentsch, 2012). Salas, Tannenbaum, Kraiger, and Smith-Jentsch (2012) conducted meta-analyses of training across a broad palate of disciplines and indicated in their results that when "training is designed systematically and based on the science of learning and training, it yields positive results" (Salas et al., 2012, p. 75). Mitchell and Sonora (2012) demonstrated that in the medical, aviation, and military fields, individuals who are well-trained demonstrate the benefits of strong procedural knowledge and application. Educators who design effective training help to reduce human error and save lives (Mitchell & Sonora, 2012).

In the case of citizen science, researchers who collect reliable data contribute to species and environment protection by informing the design of appropriate scientific protocols (e.g., Reynolds, 2016; Storey & Wright-Stow, 2017) and legislative measures based on sound science (National Science Foundation [NSF], 2009; House Resolution [HR] 6414, 2016). Failure to address the specific problem that educational training measurement is absent from citizen science program design and analysis may result in declining engagement of citizen scientists (McDonough Mackenzie, Primack, Murray, & Weihrauch, 2017), which may result in an overall decrease in the data collection that supports species and habitat protection. This dissertation was *a priori* investigation that preceded any attempts to draw causality between training and the success of data collection for citizen scientists.

Purpose of the Study

The purpose of this qualitative comparative multiple case study was to identify patterns and themes in content, instructional design, theoretical alignment, and perceived efficacy of training for citizen scientists tasked with collecting ecological data in the field. The researcher employed three data sources: document analysis, surveys, and semi-structured interviews to characterize the content, instructional design themes, theoretical alignment, and perceived efficacy of training designed to teach citizen scientists how to collect ecological data in the field. As a result of this investigation, the researcher provided a characterizing framework for citizen science training and research in the future. Once scholars and practitioners understand the parameters of current citizen science training initiatives and their perceived efficacy, they can embark on developing theory-based best-management procedures for citizen science training (Freitag, Meyer, & Whiteman, 2016; Kruse, 2014; Newman et al., 2012). This has the potential to increase the quality of citizen-scientist-collected data and increase the science literacy gains of citizen scientists.

Importance of the Study

Citizen scientists are increasingly important to the implementation and on-going assessment of ecological restoration, species identification, and monitoring on natural lands (Bonney et al., 2014; Dickinson et al., 2010; Handel, Saito, & Takeuchi, 2013; Havlick et al., 2014; Maschinski, Wright, & Lewis, 2012; Schmeller et al., 2008). This dissertation characterized citizen science training. The connection between citizen scientist training, learning, and data-collection success needs to be explored further (Bela et al., 2016; Crall et al., 2011; Dickinson et al., 2010, Freitag et al., 2016; Newman et al., 2010) because improving citizen science outcomes has wide-ranging conservation benefits (Bonney et al., 2014; Thornhill, Loiselle, Lind, & Ophof, 2016). Scholarly information about citizen science training is limited to single-organization case studies (Bela et al., 2016; Newman et al., 2010) and training experiments facilitated by contrived field identifications (Buesching, Newman, & Macdonald, 2014; Crall et al., 2011), photography (Van Horn, Zug, LaCombe, Velez-Liendo, & Paisley, 2014; Wal, Mellish, Robinson, & Siddharthan, 2016) and digital technology for species identification (Newman, 2010).

The literature currently focuses on three components of citizen science: the usefulness and economic benefits of volunteers to natural resource management and monitoring (Gollan et al., 2012; Handel et al., 2013), science literacy gains for volunteers who participate in citizen science (Crall et al., 2013; Havlick et al., 2014; Lynch, 2016; Rasmussen, 2015), and the credibility of data collected by citizen scientists (reviewed in Dickinson et al., 2010;

Kremen, Ullman, & Thorp, 2010; Reynolds, 2016; Storey & Wright-Stow, 2017). There are several previous studies in which investigators compared professional scientist- and citizen-scientist-collected data accuracy and reliability (reviewed in Chapter II), but the training parameters were not compared as a nested feature of the experimental design. Likewise, in most of these studies, citizen scientists, regardless of their training experience, were aggregated into one experimental group that was compared to the professional scientist group, providing no room for more nuanced analysis of participant demographics, training experience, or assessment outcomes.

Two studies established analogous training delivery systems for the same learning outcomes and then compared the knowledge gains and performance of the trainees in each delivery system group (Crall et al., 2011; Starr et al., 2014). However, in both, the training validation was a contrived measurement of species identification, not a measurement of field data collection reliability. Since the literature does not quantify or characterize citizen science training as a variable affecting data collection success, it is not possible to make effective experimental comparisons between training and data collection quality (G. Newman, personal communication, February 14, 2017).

Theoretical Framework

This dissertation characterized citizen science training design and its perceived efficacy when the goal was to train citizen scientists to collect ecological scientific data outside in a natural environment. Although the citizen science initiatives investigated here were limited to a specific context involving ecological measurement, this relationship between training and performance success is inherent to myriad professional contexts. Any job involving the implementation of procedural knowledge fits this construct. Procedural knowledge is the knowledge of performing tasks (Martinez, 2010). In the context of the citizen science investigated here, the procedural knowledge might include the measurement of landscape features or organisms, the identification of species, the measurement of water, soil, weather, and/or noise parameters.

While theoretical knowledge about the context in which the measurement is applied might promote the participants' engagement, it is not essential to understanding how to perform the procedural task of measurement. The primary difference between a professional scientist and a citizen scientist is the individual's formal academic training and obtainment of a terminal degree in the discipline. While the use of new technologies facilitates contextual knowledge gains for citizen scientists in ways that approximated modern technologies in higher education (Becker-Klein et al., 2016), the driving theoretical framework behind this investigation is that the acquisition of procedural knowledge is possible in a training setting outside of academia where scientists are formally trained.

Another theoretical framework that drove this inquiry is that educational experiences contribute to learning. Arguably, the entire scholarly community involved in education research is interested in the relationship between education and learning. Training design is a logical parameter to investigate when considering citizen scientists' data collection success; however, only two studies reported in the literature compared modes of training for citizen scientists (Crall et al., 2011; Starr, 2014). In other disciplines, training improvements have led to significant knowledge gains with important impacts on society (Mitchell & Sonora, 2012). Andragogy (Knowles, Holton, & Swanson, 2011) and backwards design (Wiggins & McTighe, 2005) are learning and design principles that are successful in other training contexts (Mitchell & Sonora, 2012; Salas et al., 2012; Smith, 2015; Toman & Shindler, 2006). Andragogy plays a role in defining the learning construct for adults (Chan, 2010).

There are six dimensions to the adult learner that all relate to the voluntary nature of citizen science engagement. Adult learners are self-directed, internally motivated, and ready to learn (Merrill, 2002). They enter learning experiences with an orientation towards learning what they need to know and use their prior experiences, of which they have many, to construct new knowledge. Knowles, Holton, and Swanson (2011) characterized the instructional role called andragogy as *helping adults learn*.

Backwards design is a course design process in which the outcomes of the course are developed first, then the assessments, and finally the learning activities (Wiggins & Mctighe, 2005). This intentional process contributes to accountability in large education systems because it standardizes the instruction to address the pre-determined learning goals. The methodology of this dissertation is exploratory in nature.

The training mode may influence the training design. The possible modes anticipated included live or asynchronous timing, digital or paper-training documents, and the presence or absence of technology-rich instructional tools like videos, podcasts, or other recordings. More research is needed to ascertain what modes of training, learning theories, and design principles are employed in citizen science projects (Friedman, 2008; Newman, 2010). Characterizing current citizen science training initiatives may pave the way for future investigations designed to reveal causal relationships between training design, participant learning outcomes, and citizen-scientist-collected data quality (Crall et al., 2013; Dickinson et al., 2010; Newman et al., 2010).

Research Questions

The research questions developed for this dissertation study probed at the nature of citizen science training. They explored a broad context rather than established discreet variables for comparisons. This research proceeded within the framework of a qualitative comparative multiple case study. Because the causal relationship between training and data collection reliability could not be made in the absence of experimental results, this qualitative approach captured the perceptions of efficacy rather than a numeric measurement of reliability in data collection. These questions also facilitated the collection of thematic data about training design and delivery mode.

R1: What are the characteristics of trainings designed to train citizen scientists to collect ecological data in natural land settings?

R2: How do organizational leaders describe their perception of the efficacy of the trainings to produce reliable data collection?

Overview of Research Design

The purpose of this research design was to identify patterns and themes in content, instructional design, theoretical alignment, and perceived efficacy of training for citizen scientists tasked with collecting data in the field. Organizational users of the CitSci.org database based anywhere in the world who tasked citizen scientists with field-based ecological data collection composed the purposive sample for this investigation. The CitSci.org database operates as a *Software as a Service* (SaaS) platform that is free to use for individuals and organizations conducting citizen science of any kind (CitSci.org, 2017). The Natural Resource Ecology Lab (NREL) at Colorado State University (CSU) developed and currently maintains the database. There are over 400 organizational users of the CitSci.org database. The database is a complete web-based platform for citizen science program communication, information, data collection, analysis, and characterization.

Qualitative case study research involves the collection of both text-based and numeric data into one analytical tool. In contrast, quantitative methods allow for the assimilation of numeric data only. The broader research perspective afforded by qualitative methods is appropriate when studying phenomena involving people, situations, programs, and unique events (Merriam, 1998). Case study researchers collect and analyze multiple, intentional streams of data within the broader framework of qualitative research (Yin, 2013). This study involved a sequential investigation with the following major components: case identification, training document analysis, an organizational survey, and follow-up semi-structured interviews with training leaders from categorically-representative organizations.

Case Identification

General categorization of organizations was the first methodological phase for this investigation. Study inclusion for organizations was based on the presence of training resources for citizen scientists tasked with data collection outdoors in a natural habitat (called herein *the field*). All private users, for example, land owners who store their own data in CitSci.org, were not included because the assumption was that these projects were small in nature and therefore did not train individuals to collect data. Organizations that engaged citizen scientists in activities that did not involve data collection were not included because the research questions here were in direct response to data reliability concerns in citizen science. Organizational types included non-profit organizations, academic institutions, and government agencies.

Data saturation is not achieved at a pre-determined number of samples; rather, it is discovered through the data collection process and is indicated when no new codes arise from additional sampling (Guest, Bunce, & Johnson, 2006). For example, if many organizations are training citizen scientists to collect similar data rather than divergent data, fewer organizations are needed to achieve data saturation. However, this reality cannot be known before conducting the investigation. Based on the standards presented in the literature, the researcher aimed to have 16-30 cases in the case study database (Bertaux, 1981; Mason, 2010).

Document Analysis

After case identification, the case identification and document checklist catalogued the contact information and training documents available for each organization (Appendix B). The researcher performed a directed content analysis of 83 documents (Hseieh & Shannon, 2005). This content analysis informed the development of descriptors in a case study database using Dedoose© software (2017), a web-based application designed to assimilate both quantitative and qualitative data into an analytical system. The proposed framework for descriptors guided the process of document discovery, but as documents were assimilated, the descriptors became more nuanced (more fields added) to capture the information revealed. Designing an analytical tool is a primary tenet of Yin’s theory of case study research because it facilitates credibility and dependability, which are measures of data quality and validation in qualitative research (Yazan, 2015; Yin, 2013).

Organizational Survey

The organizational survey, the next phase of this research, probed for organizational characteristics, citizen scientist demographics, program and training design, data collection and reliability, and leaders’ perceptions of training efficacy for participant learning.

In superior case study designs, researchers use all possible data streams including both qualitative and quantitative data (Yin, 2013). This study included research questions that were inherently qualitative. Nonetheless, the data collected included numeric forms such as length of program or number of citizen scientists engaged. Transformation of some text-based data to categorical data increased the analytical power of this qualitative analysis. Descriptors and their fields characterized quantitative data. The coding system aided the analysis of text-based data preserved as excerpts of text.

Semi-Structured Interviews

In the final phase of this research, organizations' leaders participated in a semi-structured interview. The interview subjects were leaders within the organizations who led the development of or who were leading the on-going management of citizen science training initiatives at the time of this study. The semi-structured interviews triangulated the document analysis and survey data. The interviewer did not probe for new information. The researcher conducted a thematic analysis (Guest, 2012) of the interview data using the case study database. This final sequential step in the methodology completed the data triangulation (Denzin, 2012; Stavros & Westberg, 2009; Yin, 2013).

Definition of Terms

Andragogy: "art and science of helping adults learn" (Knowles, 1980, p. 43)

Backwards design: a principle of instructional design in which the learning outcomes are identified first, followed by the assessments, and then the learning activities (Wiggins & McTighe, 2005)

Citizen science: "In North America, citizen science typically refers to research collaborations between scientists and volunteers, particularly (but not exclusively) to expand opportunities for scientific data collection and to provide access to scientific information for community members" (Citizen Science Central - The Cornell Lab of Ornithology, 2017)

Citizen scientists: volunteers who participate in scientific activities under the guidance of professional scientists and organizations

Informal science education (ISE): a term used by the United States government to refer to citizen science activities and other science learning experiences that occur outside of traditional academic settings (Bonney et al., 2009a)

Science literacy: "the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity. It also includes specific types of abilities" (National Research Council, 1996, p. 22).

Assumptions

The whole phenomenon of citizen science assumes that individuals lacking a terminal degree in science can contribute to the collection of scientific data. This generalization assumes that procedural knowledge may be acquired in a training environment and that the educational experience contributes to learning. Although this seems self-evident, few previous studies have acknowledged the educational experience as a variable in citizen science data collection success.

Methodological Assumptions

A driving assumption of the research methodology for this study was that users of the CitSci.org database made up a representative sample. There were other databases that could have been used, most notably SciStarter.org, but this database was much broader in scope. The projects in CitSci.org are all related to ecological data collection; the use of this database automatically narrowed the sample according to this parameter.

Another assumption was that training themes and codes would arise from document analysis. There had to be enough similarities across programs to create meaningful summations of their training activities. Regarding sample size, there was great similarity between groups because the data collection activities associated with monitoring a particular resource were very similar. This required fewer samples to reach saturation. If, however, the cases had been exceptionally variable, more cases would have been needed to identify themes and codes and reach saturation.

The final methodological assumption was that training would be characterized through secondary materials. No primary observation occurred. This methodology assumed that the documents and media associated with training, and the recollection captured in the survey and semi-structured interviews were enough to characterize the training. Direct observation would have put the researcher at the center of the data collection process, which could have raised issues of bias. This secondary perspective was a neutral approach and one that revealed the true nature of the trainings without the potential bias.

Theoretical Assumptions

The first assumption was that principles of andragogy contribute to an effective learning experience for adults (Knowles et al., 2011). Adults have more life experience and practical needs than children. In a learning experience designed for adults, the adult learners incorporate their personal experiences into the acquisition of new knowledge by drawing connections between prior and current learning (Merrill, 2002). Adults also need a motivation to learn (Knowles et al., 2011), and the practical applications here are many. In the most direct interpretation, citizen scientists need to learn how to collect scientific data in the field for their present citizen scientist engagement. From a sociocultural perspective, public participation in scientific research can result in “transformative effects for democratization of knowledge production" (Bela et al., 2016, p. 990). During analysis, the researcher coded for evidence of andragogy, which is assumed to activate these transformative effects for adult learners.

These assumptions of andragogy, as applied to this dissertation inquiry, were deductive. In qualitative research, researchers have room for on-going interpretation, but this was not grounded theory or phenomenological research in which codes arise purely from the interaction with the research subject. It was more appropriate to use a deductive, directed content analysis in which some categorization and coding were already developed before approaching the data (Hsieh & Shannon, 2005). In essence, the pre-determined, but flexible coding structure tested the forming theory in the literature against the observation of real phenomena.

The second assumption was that principles of backwards design contribute to an intentional and accountable educational experience. Backwards design is an instructional design principle that describes the sequence in which a learning experience should be developed (Wiggins & McTighe, 2005). The first step is to identify the learning outcomes. This is followed by assessment development for measuring attainment of these learning outcomes. Finally, the creation of learning activities ensues (Wiggins & McTighe, 2005). The backwards design process seemed inherent to citizen science programs under investigation here because it was assumed that their common training goal must be to train citizen scientists to collect ecological data in the field. As such, the learning outcome is *citizen scientists will learn how to collect reliable data*. The data collection protocols used by cases were designed by scientists and/or teams of scientists and citizen scientists in advance of the training initiative. These defined the remaining learning outcomes for a program.

Delimitations

Several proposed parameters narrowed the scope of the investigation. This dissertation investigated only organizational users of the CitSci.org database. Private users of the CitSci.org database were not queried. The researcher assumed that they were not training other individuals to collect data on their properties. A professor and college students collecting data for a lesson are another example of an excluded group. The underlying assumption was that these informal or private data collection events were not accompanied by intentional and developed training programs.

This study concerned only citizen science projects involving adults. Although the field of youth citizen science rivals the field of adult citizen science in magnitude (Flagg, 2016), the learning theories and principles of instruction for children and adults are different (Knowles, 1980). Since the overarching learning theories of pedagogy for children and andragogy for adults are dissimilar, the respective training efforts should not be aggregated into one characterized phenomenon.

Finally, there are myriad activities in which interested citizen scientists can engage. These include reading peer-reviewed literature, scanning images taken by satellites, and field-based data collection (Ricci, 2015). This study focused on training intended to inform field-based citizen scientists who collect ecological data. The broader context was natural lands conservation and related sub-disciplines including species identification and monitoring, landscape, and water quality measurement.

Limitations

The sample was one limitation of this study. The hope was that the purposive sample was broad enough to impact organizations beyond the specific cases sampled. Drawing from a single database had the potential to introduce hidden biases that were not under investigation. For example, an organization's decision to use CitSci.org to manage their citizen science projects was not addressed by the research questions of this study, but it might be a relevant variable to explore in the future. Despite the research solicitations directed at the CitSci.org membership only, membership in CitSci.org was not one of the selective parameters. Many managers oversaw multiple projects, some of which used CitSci.org. These additional cases were recruited by a form of snowball sampling; the managers referred the other citizen science projects under their purview. In this way, the purposive sample was more inclusive that predicted.

The lack of direct observation in the methodology proposed was another limitation. This was technically infeasible within the parameters of dissertation research for monetary and temporal reasons. Also, it would have put the researcher at the center of the investigation, introducing a potential bias to a study that attempted an objective perspective on the research topic. A grounded theory design might afford the opportunity for an in-depth observation of fewer organizations and more researcher-centered interpretation. However, in reflection of the current literature, there is a need for broad characterization of citizen science training upon which in-depth qualitative and experimental studies may be designed. Without the *a priori* broader characterization offered in this dissertation, it would be difficult to know which few cases would be most informative to study with in-depth direct observation.

Summary

This comparative multiple case study identified patterns and themes in content, instructional design, theoretical alignment, and perceived efficacy of training for citizen scientists tasked with collecting ecological data in the field. Citizen scientists are volunteers who participate in scientific activities under the guidance of professional scientists and organizations. The work of citizen scientists has greatly expanded the data collection possibilities in natural resource management. The general problem is that some scientists and land managers view the data collected by citizen scientists as unreliable. The specific problem is the absence of educational training measurement in citizen science program design and analysis with which to ascertain the learning gains of trained citizen scientists. Citizen science needs assessment parameters to measure the success of the training effort. Reporting about citizen science programming abounds in the literature, but most papers do not describe the training parameters that informed the program trainees. This study characterized citizen science training and its perceived outcomes. The sequential design of this research study included document analysis, a survey, and semi-structured interviews. This work lays the observational groundwork for developing training themes in citizen science that may lead to improved training programs for citizen scientists and improved data collection procedures.

CHAPTER II: LITERATURE REVIEW

The purpose of this qualitative comparative multiple case study was to identify patterns and themes in content, instructional design, theoretical alignment, and perceived efficacy of training for citizen scientists tasked with collecting ecological data in the field. Citizen scientists are volunteers who participate in scientific activities under the guidance of professional scientists and organizations. In the last decade, the field of citizen science grew from a seminal concept to a widespread phenomenon affecting data collection and scientific analysis in numerous scientific disciplines. This literature review includes discussion of the history and semantics of citizen science, important themes arising from the literature, and a synthesis of existing citizen science training research.

The research questions developed for this qualitative comparative multiple case study probed the nature of citizen science training. They explored a broad context rather than established discreet variables for comparisons. The causal relationship between training and data-collection reliability cannot be made in the absence of experimental results. Therefore, a qualitative approach captured the perceptions of efficacy rather than a numeric measurement of reliability in data collection. These questions also facilitated the collection of thematic data about training design and delivery mode. The research questions were:

R1: What are the characteristics of trainings designed to train citizen scientists to collect ecological data in natural land settings?

R2: How do organizational leaders describe their perception of the efficacy of the trainings to produce reliable data collection?

Search Strategy for the Literature Review

To gauge the size of the citizen science literature base in total, a query of the ProQuest database for the term *citizen science* with no date restrictions returned 553 articles since 1997 (Figure 1).

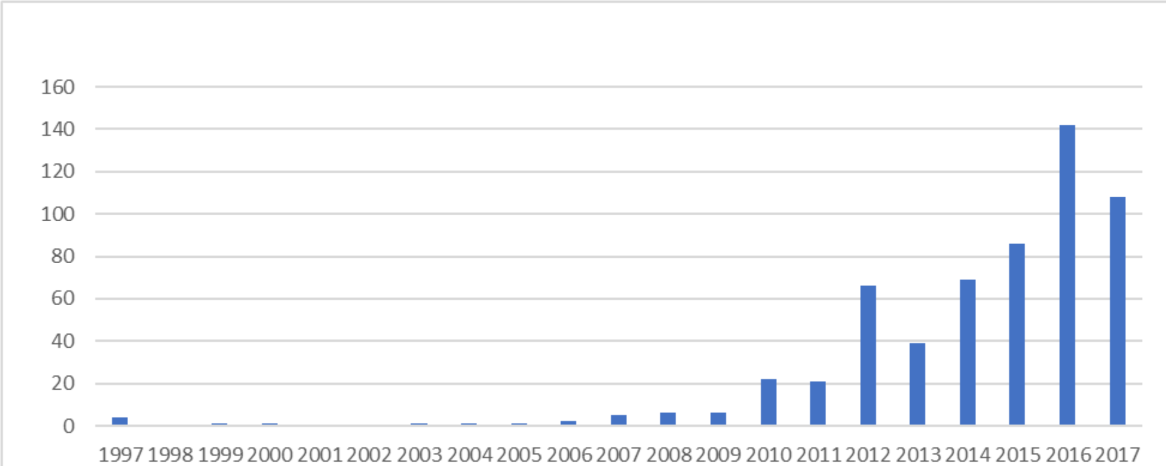

Figure 1. ProQuest literature returns for citizen science with no date restrictions

To narrow down to the focus of training, a query for "*citizen science" AND training* returned 30 articles in ProQuest, 26 in EBSCOhost, 13 in ProQuest Dissertations and Theses, and two in *Citizen Science: Theory and Practice.* To explore the contexts of education and ecological data collection, additional search terms applied included *ecolog** (for ecology, ecological, ecologist), *research needs, education*, and *andragogy*. These terms did not reveal additional training literature, but articles found in these queries rounded out this review's characterization of the citizen science landscape.

The term *citizen science* was first used in the scholarly literature in 1997 (Follett & Strezov, 2015). In 1997, four papers were published, three of which reviewed Alan Irwin's (1995) book *Citizen Science: A Study of People, Expertise and Sustainable Development*. Irwin, a sociologist, is regarded as one of the first authors to employ the term *citizen science* to describe the role of citizens in addressing modern scientific and environmental issues. The fourth is a scholarly article about popular epidemiology as a social movement. None reported scientific data. Only seven more papers with the key word *citizen science* were published in the subsequent decade.

The increase in publications after 2009 may be attributed to the publication of the

National Science Foundation's Center for the Advancement of Informal Science Education (CAISE) Inquiry Group report entitled "Public Participation in Scientific Research: Defining the Field and Assessing Its Potential for Informal Science Education" (Bonney et al., 2009a). This was the first scholarly report to define citizen science as a phenomenon in which the public participated in scientific research, which gave rise to two other terms relevant to citizen science, *informal science education* (ISE) and *public participation in scientific research* (PPSR) (Shirk et al., 2012). The report was written by several seminal authors in the field of citizen science. The funding opportunities that accompanied this initiative (National Science Foundation [NSF] 09-553, 2009) gave rise to several publications authored by the same investigators involved in the CAISE inquiry group.

The funding opportunity, entitled Informal Science Education (ISE) provided $25,000,000 for programs that

> promote lifelong learning of STEM in a wide variety of informal settings. Funding is provided for projects that advance understanding of informal STEM learning, that develop and implement innovative strategies and resources for informal STEM education, and that build the national professional capacity for research, development, and practice in the field. (NSF 09-553, 2009)

There were five categories for funding: "research; pathways; full-scale development; broad implementation; and communicating research to public audiences" (NSF 09-553, 2009). This funding opportunity fell within the Directorate for Education & Human Resources and Research on Learning in Formal and Informal Settings.

A search of *citizen science AND training* in various academic search engines returned up to 30 results since 2009. Google Scholar returned 34,000 papers. The first 30-40 articles were definitively about citizen science. Beyond that, there were additional articles, but without the ability to use Boolean operators effectively, it was hard to limit this search into a comparable sample. Therefore, Google Scholar results were not included in the tabulations of returned results (Figure 2). 553 papers were returned when the term *citizen science* was queried, and up to 30 were returned when the search term *citizen science AND training* was queried. This indicated that approximately 5% the published citizen science literature referenced the training implemented for citizen scientists. This number is surprising small considering that the 2009 NSF funding of $25,000,000 arose from the Directorate for Education & Human Resources and Research on Learning in Formal and Informal Settings.

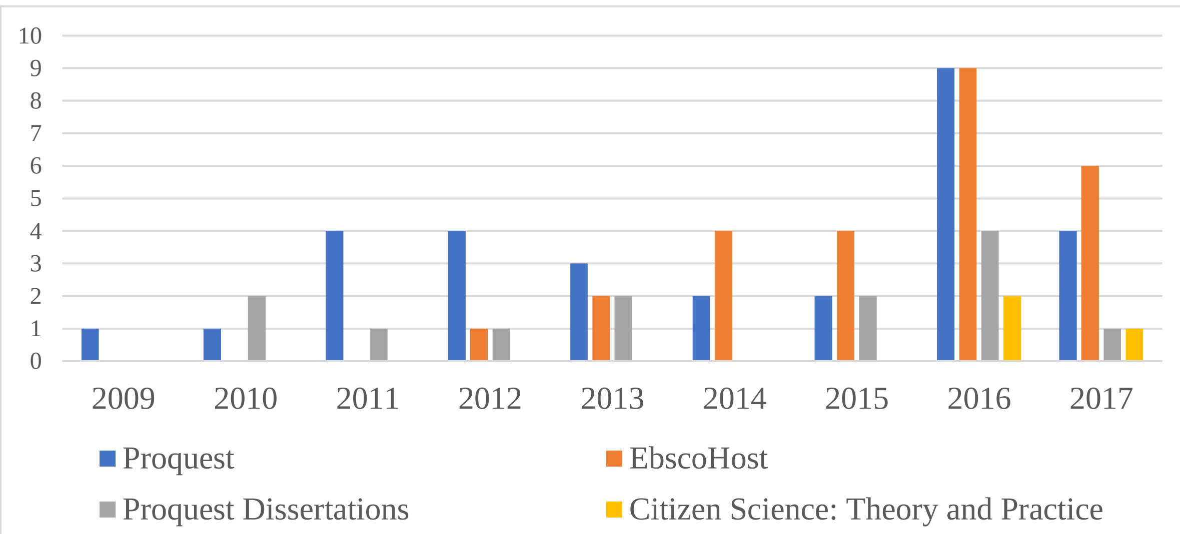

Figure 2. Literature returns for "citizen science" AND training 2009-2017

Citizen Scientist Demographics and Types of Citizen Science Data Collected

Citizen science occurs all over the world (Galbraith, 2013; Roy, Pocock, Preston, Roy, & Savage, 2012), including remote tropical locations where infrastructure is primitive (Danielsen et al., 2014) to the world's largest cities (Handel et al., 2013). It is important to acknowledge who citizen scientists are, what data they are tasked with collecting, and in what environments because these parameters have the potential to influence the learning experiences of citizen scientists. In the following paragraph, the people and the environments in which citizen science occurs are noted. This list is not exhaustive. It is meant to illustrate the diversity of people and projects within the realm of citizen science. Recognizing the diversity of participants is important to any educational program design planning. It characterizes the broader context for citizen science in which the sample queried in this dissertation research resides.

Citizen science engages indigenous human populations (Baker, 2013; Dolrenry, Hazzah, & Frank, 2016), college students (Davis, Belote, Williamson, Larson, & Esch, 2016; Oberhauser & LeBuhn, 2012), students of all ages (Doran & Montmerle, 2012), private land owners (Dickinson et al., 2010), non-profit groups (Clarridge, 2016), and scientific researchers. Citizen science occurs in forests (Danielsen et al., 2014; Davis et al., 2016; Toman & Shindler, 2006), gardens (Birkin & Goulson, 2015), oceans (Koss et al., 2009; Van der Velde et al., 2017), rivers (Kruse, 2014; Storey & Wright-Stow, 2017), the sky (Doran & Montmerle, 2012; Henden, 2011), or from within one's own home or office with the use of computer-accessible cloud-based data (Ricci, 2015).

Although the number of scholarly papers addressing citizen science is on the rise, educational investigation of these projects lags behind program implementation and data collection (Crall et al., 2011; Edwards, 2014). Understanding how organizations train citizen scientists to collect data is an overlooked but essential component to understanding the phenomenon at large. Currently, researchers make the leap from describing the data collected to the reliability of the data, but little attention is paid to the educational experience that train citizen scientists to be effective data collectors. To begin the work of understanding citizen science data reliability, this literature review characterizes training for citizen scientists. The dissertation inquiry for which this literature review was composed investigated training for citizen science efforts involving ecological data collection.

Semantics in Citizen Science

This dissertation concerned *citizen science* training, but the term *citizen science* is rife with variation and implied meaning. It can also be laden with stereotypes regarding the identity of citizen scientists. As a result, within the field of citizen science, semantics is a ripe topic for continued research. Eitzel et al. (2017) published a synthesis paper focused on the current state of citizen science semantics and ethics of language describing citizen scientists. They concluded that terminology can have unintended consequences and influence how knowledge is acquired. This is important to acknowledge in light of what the scholarly community knows about adult education. If participants cannot understand the value of their participation, their retention will suffer (Egizii, 2015). Eitzel et al. (2017) found that the terms organizations use to recruit and refer to citizen scientists can imply a level of value and skill that can have detrimental effects on participation and engagement.

A survey of the American public revealed that the majority of respondents had not heard of citizen science, but 70% demonstrated awareness of the phenomenon when it was referred to by another name (Lewandowski, Caldwell, Elmquist, & Oberhauser, 2017). As a burgeoning phenomenon and academic discipline, the terminology framing the field is varied and related to the type of data collection in which volunteers are engaged, the country in which it occurs, and the varied disciplines in which citizen science arises (Shirk et al., 2012).

Some terms found in the literature include community science (Carr, 2004), volunteer biological monitoring (Lawrence, 2008), participatory monitoring (Bell et al., 2008), and community-based monitoring (Danielsen et al., 2009). Efforts to streamline this terminology arose from the National Science Foundation's Center for the Advancement of Informal Science Education's (CAISE) sponsored inquiry group (Bonney et al., 2009a). Public participation in scientific research (PPSR) encompasses research in a variety of scientific and health disciplines. The term *citizen science* is widely used for ecological data collection initiatives (Shirk et al., 2012); and thus, it was used in this dissertation.

The United States federal government used the term *informal science education* (ISE) in funding solicitations to describe citizen science (NSF 09-553, 2009). Informal science education refers to science learning that engages the general public in informal settings (Dierking, Falk, Rennie, Anderson, & Ellenbogen, 2003). Bonney et al. (2009a) defined ISE as follows:

> In the broadest sense, it encompasses the range of science learning opportunities and activities that people experience across their lifespan outside of school. ISE can be delivered via numerous venues including lectures, TV programs, films, exhibits, websites, digital fames, and community projects that are experiences or viewed in homes, science centers and museums, zoos and aquariums, botanical gardens and nature centers, and youth, community, and after-school centers. (p. 10)

Citizen science is one venue in which ISE can be delivered. ISE is relevant to this literature review because this review probes specifically for information about training in citizen science, which is inherently educational in nature.

Results of the Training Literature Review

The results of searches in four databases and one journal are discussed collectively here. A citation database curated over 150 scholarly documents analyzed for this literature review. Once all the queries and records were reviewed, themes emerged. Each publication entry in the citation database was labeled with these themes to identify how it would be used in this narrative. More than 70 articles were cited in this literature review. A query for *citizen science AND training* in the ProQuest Dissertations and Theses database returned 13 dissertations. Five were dissertations that addressed training and are therefore reviewed in the subsequent discussion. One paper had nothing to do with citizen science, but rather, with science education in Chinese primary schools. Two dissertations addressed the same research effort from a civic engagement or scientific data perspective, two addressed only the data collected by citizen scientists, and five addressed the implementation of novel technologies for use in citizen science projects. These trends indicate that upcoming citizen science researchers will likely investigate technology enhancements, training, and data science for citizen science.

The journal *Citizen Science: Theory and Practice* is the first peer-reviewed journal dedicated to reporting citizen science-related research. Its first issue was published in 2016. *Citizen Science: Theory and Practice* is the academic journal of the Citizen Science Association, formed in 2012, after the Public Participation in Scientific Research Conference, held in Portland, Oregon, in 2012 in association with the Ecological Society of America Conference (Miller-Rushing, 2013). The journal has three issues currently. The entire library of articles ($n = 21$) published in the *Citizen Science: Theory and Practice* journal was reviewed for content involving training, but a query of *training* in the issue archive resulted in three returns. A total of six articles from this journal are cited in this literature review, two of which addressed training. Although the sample size is very small, approximately 10% of the articles in *Citizen Science: Theory and Practice* addressed training, which is slightly better than the body of literature at large in which approximately 5% of citizen science publications described training.

In addition to the ProQuest Dissertations and Theses database and the *Citizen Science: Theory and Practice* journal, the search terms were applied to all ProQuest and all EBSCOhost databases. A query for *citizen science AND training* returned 30 articles in ProQuest and 26 in EBSCOhost, many of which were duplicates. The use of Google Scholar was casual and typically carried out to find a full-text version of an article. Nonetheless, some literature was found in this search engine. It was not included in Figure 2 because the scale of Google Scholar returns is incomparable to other databases.

Science Literacy Gains as a Result of Participation

Citizen science projects are rarely started, if ever, for the sole purpose of enhancing science literacy. Typically, what drives citizen science initiatives is a scientific need for data to characterize, protect, conserve, and/or restore natural phenomena. Nonetheless, citizen science is associated with a variety of positive consequences because of civic engagement (Fauver, 2016). Science literacy gains are important outcomes in ISE. The majority of American adults are scientifically illiterate, and their civic science literacy skills are lower than ever (Cronin & Messemer, 2013). The decline in American science literacy was a driver for the NSF CAISE inquiry group (Bonney et al., 2009b; Shirk et al., 2012) and related ISE funding opportunities (NSF 09-553, 2009).

Lynch (2016) and Forrester et al. (2017) described how citizen scientists became experts and advocates in their social communities, which extended science literacy beyond the citizen scientist who physically participated. Sandhaus (2017) investigated the outcomes of less common co-created citizen science in which citizen scientists engaged in the research design and analysis processes in addition to the data collection task. Participation in co-created citizen science increased participant knowledge and perception of self-efficacy (Sandhaus, 2017). These studies indicated that citizen science activities have positive outcomes for participants and their communities.

A traditional method for assessing knowledge gains involves the implementation of pre- and post-testing (Cobern et al., 2010). Using a quantitative approach to measure learning gains provides opportunities for statistical analysis of learning gains across groups of learners. Quantitative measurement approaches are needed to analyze what training program characteristics result in knowledge gains for participants. Understanding the success of training efforts will inform data reliability measurements and establish variables with which to explore the relationship between training and data collection success in future research.

To improve upon the standard approach of pre- and post-testing to measure learning gains, Cronje, Rohlinger, Crall, and Newman (2011) developed a contextual assessment tool with which to assess citizen scientist knowledge gains before and after invasive species monitoring training. They found that the contextual tool detected knowledge gains when the traditional assessment tool did not. More development and application of this tool may lead to more perceptive assessments of science literacy gains by citizen scientists (Cronje, Rohlinger, Crall, & Newman, 2011). Unfortunately, no use of this assessment tool is published in the current literature. Such a tool has the potential to increase cross-comparison analysis of citizen science training programs and promote training collaborations between organizations.

In his dissertation, Smith (2015) analyzed three case studies to investigate data quality and science literacy gains. He compared the data collection efforts of professional scientists and citizen scientists in analogous data collection schemes. Smith (2015) rejected his null hypothesis that citizen scientist and professional scientist data are similar. He also reported that science literacy gains were unclear after participation in a water quality monitoring citizen science effort. As others have done (Crall et al., 2013), Smith concluded his work by indicating the need for standardization among training and data collection efforts, so cross comparisons could take place between independent citizen science efforts.

Data Quality in the Citizen Science Literature

Discussions of data quality are the most numerous discussions in the literature currently. Nineteen papers analyzed in this review evaluated data quality. Citizen science has the potential to increase the scale of data collection, but data error and bias are poorly understood (Dickinson et al., 2010). In an attempt to investigate data reliability, a single methodology arises as the only evaluative technique. This methods involves the comparison of analogous data collected by paired groups of citizen scientists and professional scientists to ascertain the data reliability of each groups' effort (Clarridge, 2016; Crall et al., 2011; Danielsen et al., 2014; Gollan et al., 2012; Jordan, Sorenson, & Ladeau, 2017; Kremen et al., 2010; Koss et al., 2009; Moyer-Homer, Smith, & Belt, 2012; Reynolds, 2016; Schmeller et al., 2008; Storey & Wright-Stow, 2017).

Schmeller et al. (2008) performed a large meta-analysis of monitoring protocols in five European countries to evaluate the assumption that citizen scientists cannot collect quality data. They concluded that the quality of citizen science data is more likely determined by survey design, analytical methodology, and communication skill than it is a function of participant demography. These findings suggest that the characteristics of training programs affect data quality more than the demography of the participants. Despite this nearly decade-old finding, training has not yet risen as primary variable to relate to data quality measurements.

Danielsen et al. (2014) assessed the data collection by local community members and trained scientists in 34 tropical forest sites in four countries over 2.5 years. Despite disparate cultural, linguistic and educational backgrounds, the data collected by the two groups was comparable. This is the largest study reported in the literature by measures of duration, number of participants, and geographic range. These results should build confidence in citizen scientist-collected data because the sample size is so large and varied. These results also reinforce the findings of Schmeller et al. (2008), that the demography of the citizen scientists is not the leading variable affecting data quality. Finally, these findings suggest that incidences in which citizen scientist data do not meet reliability standards are the exception rather than the normal outcome.

Despite some evidence that land managers and scientists are reluctant to incorporate citizen science into their land management and research agendas (Bruce, Newingham, Harris, & Krumpe, 2014; Lewandowski et al., 2017), many studies, in addition to Danielsen et al. (2014) refute this concern. In the cases of mosquito-habitat identification (Jordan et al., 2017), butterfly monitoring (Clarridge, 2016), benthic stream macroinvertebrates (Storey & Wright-Stow, 2017), and fixed wildlife photography (Reynolds, 2016), citizen scientists performed as well as professional scientists or benchmarks established. Clarridge (2016) specifically noted that citizen science data was of a quality worthy for use by the National Park service. The utility of the data collected by citizen scientists is of central importance to the phenomenon of citizen science.

Although these results are promising, other experimental comparisons of citizen scientist and professional-scientist-collected data suggest that the concern for data quality is warranted, but needs to be nuanced. When comparing the ability of groups of professionals and volunteers to identify pika occupancy and population dynamics, citizen scientists performed as well as professional scientists (Moyer-Horner, Smith, & Belt, 2012). However, when the conceptual and measurement applications were more complex, citizen scientist-collected data became unreliable (Moyer-Horner et al., 2012). Similar results suggesting that citizen scientists are reliable at collecting relatively simple data, but not complex data, are echoed in studies of invasive plant monitoring (Crall et al., 2011), pollinator monitoring (Kremen et al., 2010), water quality monitoring (Smith, 2015), and subtidal species monitoring (Koss et al., 2009). These results suggested that future research should quantify data collection difficulty as a variable relevant to training and data collection success.

These results reflected a variety of data collection contexts with similar conclusions. This suggests that the actual ecological subject matter is not relevant to training success. This bodes well for future efforts to streamline training for citizen scientists across environmental contexts. There are common procedural tasks involved in measuring similar, but not identical, ecological parameters. For example, an understanding of the metric system, reading calibrated devices, and using data management software are learning outcomes universal to all scientific procedures. These are likely to be unifying principles in future collaborative training efforts that arise from more research about citizen science training.

The 2009 NSF funding source that initiated many citizen science programs and research efforts provided funding for projects that "build the national professional capacity for research, development, and practice in the field" (NSF 09-553, 2009). It is important to appreciate the focus on *national professional capacity for research* in a funding opportunity promoted by the NSF Directorate for Education & Human Resources and Research on Learning in Formal and Informal Settings. Citizens are needed to expand the research capacity of the country on the whole. This is a task of great importance and appropriate attention to ensure citizen science data quality effectively builds confidence in the American research output at large.

A troubling reality is that the data collected by citizen scientists, especially in site specific projects, often goes un-utilized (Theobald et al., 2015). One team of researchers analyzed the data outcomes of 388 citizen science projects. Thirty percent of citizen science projects queried collected publishable data, but the data of only 12% of projects appeared in the peer-reviewed literature (Theobald et al., 2014). The discussion of data quality is ever present because in the end, the point of science is to inform. If the information network delivered by citizen scientists cannot be trusted, it is useless as a proxy for professional scientific endeavor (Lukyanenko, Parsons, & Wiersma, 2016). Clearly, authors are eager to disprove the stereotype that citizen scientists cannot collect measurements with the same reliability and precision as professional scientists. However, more research is needed to explain why citizen science data collection efforts have variable reliability.

Training is Needed

Training and learning in citizen science have not been reported in the literature or evaluated as rigorously as the direct comparisons of data collection efforts previously summarized. Freitag, Meyer, and Whiteman (2016) evaluated the credibility-building strategies of 30 citizen science programs. They identified 12 strategies, three of which occurred during the training phase. A study to quantify the effects of these strategies on training success and subsequent data collection success is needed to strengthen the practice of citizen science (Bela et al., 2016).

Following the principle of backwards design (Wiggins & McTighe, 2005), learning outcomes need to be identified in adaptive co-management projects to validate the learning process (Armitage, Marschke, & Plummer, 2008). Standardization among training and data collection efforts is needed so cross comparisons can take place between independent citizen science efforts (Crall et al., 2013). Training assessment is needed, specifically looking at different modes of training, such as online, in-person, live, and asynchronous delivery methods (Dickinson et al., 2010). In the next section, the results of every citizen science training-oriented paper found to date are discussed. While it is customary to synthesize a body of literature, the citizen science training literature base is nascent and underdeveloped. Hence, these seminal papers are discussed in detail. A few case studies are not a strong foundation for building a theory of citizen science training. More citizen science training research is needed to fully understand how to create effective trainings to promote data collection reliability.

Instruction, Learning, and Assessment in Citizen Science

All studies that address training do so in one of two ways. Some authors presented training as a simple fact of the requisite program with little describing detail. Alternatively, authors prepared more than one training mode and divided their cohort among the training modes. Analysis then ascertained if the groups were significantly different in their data collection success. The evaluation was typically accomplished through hands-on demonstration, such as field identification of a biological specimen.

Regarding studies that simply reported the utility of training without any meaningful analysis of its effects, Gallo and Waitt (2011) concluded that volunteers can collect invasive species data useful to scientists. Fuccillo, Crimmins, De Rivera, and Elder (2015) concluded that volunteers can participate in phenology data collection with success when any training is provided. Regarding the identification of Andean bears by phenotype (Van Horn et al., 2014), citizen scientists' identification skills improved with training, such that 24.8% of participants achieved 100% success rate in bear identification. This collection of papers all support a simple conclusion that training is valuable regardless of its design.

Galbraith (2013) found that specialized training of local volunteers helped increase the competency of citizen scientists and the reliability and accuracy of data collected in restoration monitoring on Tiritiri Matangi Island, New Zealand. This result supported the theoretical perspective that a problem-centered orientation to specialized training deepens the citizen scientists' connection with the specific learning task for positive learning outcomes (Knowles et al., 2011). Buesching, Newman, and Macdonald (2014) evaluated citizen scientists who identified deer pellets in field plots. Their skills improved significantly with training and field practice. The authors concluded that it was essential for citizen scientists to be able to communicate with the professional scientists overseeing the project. Following the tenets of adult learning theory, when citizen scientists interact with the professional scientists who utilize the data they collect, it likely promotes motivation and personal engagement for adult learners (Knowles et al., 2011).

The most extensive training research in citizen science conducted to date involved the dissertation research and subsequent research of leading authors, Crall (2010) and Newman (2010). They coordinated two cohorts of research participants: one in Fort Collins, Colorado, and one in Madison, Wisconsin. Each author used the data generated by the training event to investigate different dissertation research questions. After one day of training, citizen scientists and professional scientists in each locale collected analogous measurements of species identification. They designed the two identical online trainings in two modes: static and multimedia delivery, to promote the learning outcomes of species identification, plot set-up, global positioning system (GPS) skills, and plant measurement. There was no significant difference in species identification success between the static and multimedia groups, but professional scientists were significantly better at identification than both citizen science groups. They found no significant difference in plant cover estimates between citizen scientists and professional scientists. Online trainees struggled more with the tangential field skills of GPS and plot establishment (Newman, 2010).

Only one other study, another dissertation revealed by this literature review, compared modes of training delivery in citizen science (Starr et al., 2014). The three levels of the training treatment differed only in the delivery style for the training. All participants were given static documents to study. The control group received no other training. Participants in the experimental groups received either in-person training or video training. Participants in all groups were able to identify species reasonably well (79-92% accuracy). Participants in the video and in-person training groups were not statistically different from each other in their ability to identify species, and they were statistically better at identification than the control group who received only the static documents (Starr et al., 2014). This indicates that engaged training is more effective than a training manual alone.

These dissertation projects (Crall, 2010; Newman, 2010; Starr, 2014) that specifically addressed citizen science training, elucidated important themes instrumental in the design of this dissertation research. Describing the effect of training design on learning outcomes for citizen scientists was an important theme to pursue. For example, the delivery mode was important to the success of citizen scientists when applying field-based skills, but not when learning plant identification. These nuanced findings suggested that there were varied but currently unknown training strategies to promote different learning outcomes for citizen scientists. Fuccillo, Crimmins, De Rivera, and Elder (2015) and Newman (2010) concluded that more research was needed to compare multimedia training to traditional *in situ* training. They also concluded that training should be presented in as many media formats as possible to accommodate trainees with different learning styles, and that assessment should be included in online training (Fuccillo, Crimmins, De Rivera, & Elder, 2015; Newman, 2010). Elucidating these trends in a larger dataset was a goal of this dissertation's research questions.

Crall (2010) found that citizen scientists were proficient at collecting simple data, but their data quality decreased with increasing data collection challenges. Regression analyses did not reveal any correlation between the predictor variables (demographics) and the data collection success rate (Crall, 2010). Other studies mirrored these results (Koss et al., 2009; Kremen et al., 2010; Moyer-Horner et al., 2012; Smith, 2015). The only predictor of success among citizen scientists was their self-identified level of comfort with a specific species (Crall, 2010). This indicated that more research was needed to ascertain what additional variables affected data collection success.

Crall (2010) detected no learning gains with the analytical tools used, but the authors suggested that improved analytical instruments were needed. Other studies have drawn similar conclusions (Koss et al., 2009; Kremen et al., 2010; Mackenzie et al., 2017; Smith, 2015). Cronje et al. (2011) developed a contextual assessment tool with which to assess citizen scientist knowledge gains before and after invasive species monitoring training. They found that the contextual tool detected knowledge gains when the traditional assessment tool did not. More development and application of this tool may lead to more perceptive assessments of science literacy gains by citizen scientists (Cronje et al., 2011).

Although a significant amount of the published research indicated reasonable data collection proficiency among citizen scientists, especially with elementary data collection tasks, one quantitative study provided contradictory results. Mackenzie, Primack, Murray, and Weihrauch (2017) analyzed five years of citizen scientists' collected plant and location data for accuracy. The citizen scientists' confidence in identification and in geographic position were analyzed as well. The results indicated that volunteers made misidentifications more than 30% of the time. They were highly accurate with common species, but they were only guessing randomly when identifying uncommon species. When plants were flowering, citizen scientists were very confident in their identifications, but this was not always correlated with accuracy. These results led to a decommissioning of citizen scientists involved in this project. To this unfortunate end, the authors concluded the often-repeated call for well-planned data collection methods and training (Mackenzie et al., 2017). No specific recommendations about the variables affecting these outcomes can be made when training is not characterized in relation to data collection. This will be a valuable component of future citizen science studies.

Becker-Klein, Peterman, and Stylinski (2016) found that embedded authentic assessments provided valuable information about knowledge gains throughout the training and implementation process. They could validate online tool proficiency before engaging the trainees in content learning. For these reasons, they suggested that practitioners in the citizen science field adopt embedded assessments to evaluate measurement skill development (Becker-Klein et al., 2016). Friedman (2008) developed the *Framework for Evaluating Impacts of Informal Science Education Projects*. Despite calls for citizen science program assessment, no literature reviewed in this effort used the framework as an assessment tool. Program assessment should be a direction for future research to standardize data collection and provide an opportunity for monitoring educational gains within and across programs.

Many authors noted the economic outlook of citizen science programs (Birkin & Goulson, 2015; Clarridge, 2016; Gollan et al., 2012; Reynolds, 2016). One recent dissertation (Fauver, 2016) compared three citizen science projects to three analogous professional projects to compare the costs involved in each approach. The results indicated that citizen science projects were not more affordable, but they had favorable externalities related to participant science literacy, community engagement, and stewardship (Fauver, 2016). Furthermore, training before data collection has more upfront costs, but lower maintenance costs. When impromptu training arose as unsupervised, independent citizen scientists collected data in the field, but higher maintenance costs accrued as staff time to ensure data collection quality (Fauver, 2016).

While the economic viability of citizen science programs is essential for program sustainability, the literature reviewed indicated that the phenomenon of citizen science itself, regardless of training parameters, “promote[s] lifelong learning of STEM in a wide variety of informal settings” ((NSF) 09-553, 2009). The ability of citizen science to contribute to the national professional capacity of research (NSF 09-553, 2009) is the more tenuous goal in question, hence this dissertation’s focus on training and data reliability, rather than on training and science literacy gains.

Concluding Comments

This literature review synthesized the decade-long history of scholarly investigation of citizen science training. The literature review began with a broad query for all citizen science literature and narrowed to a specific analysis of training-related citizen science research. Queries of three major library databases, ProQuest, EBSCOhost, and ProQuest Dissertations and Theses and one content-specific journal *Citizen Science: Theory and Practice* revealed several themes in a narrow field of literature. These themes included general commentary about the value of citizen science, which was cited primarily in Chapter I, semantics in citizen science, science literacy gains as a result of citizen science participation, data quality investigations and discussion, training research needs and examples, and instruction, learning, and assessment in citizen science. These themes were varied, but understanding the existing literature base in these arenas provided a stable foundation for carrying out this qualitative research that investigated both primary documentation regarding training initiatives and qualitative information regarding the perceived efficacy of existing training efforts in citizen science programming.

CHAPTER III: METHODOLOGY

This chapter describes the methodology of this dissertation research, including the procedural design, study population, data collection, and analytical approach. The triangulation process, ethical concerns, trustworthiness of the study, and issues of confidentiality are other topics of this chapter. The intent of the research design was to identify patterns and themes in content, instructional design, theoretical alignment, and perceived efficacy of training for citizen scientist volunteers tasked with collecting data in the field. This qualitative comparative multiple case study research used document analysis, surveys, and semi-structured interviews to characterize the content, instructional design themes, theoretical alignment, and perceived efficacy of training designed to teach citizen scientists how to collect ecological data in the field.

The research questions developed for this dissertation study explored the nature of citizen science training. Because the causal relationship between training and data collection reliability cannot be made in the absence of experimental results, this qualitative approach captured the perceptions of efficacy rather than a numeric measurement of procedural accuracy in data collection. These questions facilitated the collection of thematic data about training design and delivery mode. They explored a broad context rather than established discreet variables for comparison. These research questions proved appropriate for a qualitative comparative multiple case study. The research questions for this dissertation were:

R1: What are the characteristics of citizen science trainings designed to train volunteers to collect ecological data in natural land settings?

R2: How do organizational leaders describe their perception of the efficacy of the trainings to produce reliable data collection?

Qualitative Case Study Design

No observational study currently exists to characterize citizen science training (Danielsen et al., 2014; Smith, 2015), yet scholars have been debating the quality of the data collected by citizen scientists. Just as case studies of data collection phenomena exist in the literature, so too should there exist a characterization of the citizen science training whose learning goals include the procedural task of data collection. Conclusions from this investigation inform future efforts to quantify how citizen scientists learn to collect reliable data in this informal science setting.

The study included within-case (case = organization) and cross-case analysis (Baxter & Jack, 2008; Yin, 2013) within a multiple case study. This case study research involved multiple, intentional streams of data collection and analysis within a broader framework of qualitative research following the guidance of Yin (2013). This dissertation included a sequential investigation with the following major components: case identification, training document analysis, an organizational survey, and follow-up semi-structured interviews with training leaders (Figure 3).

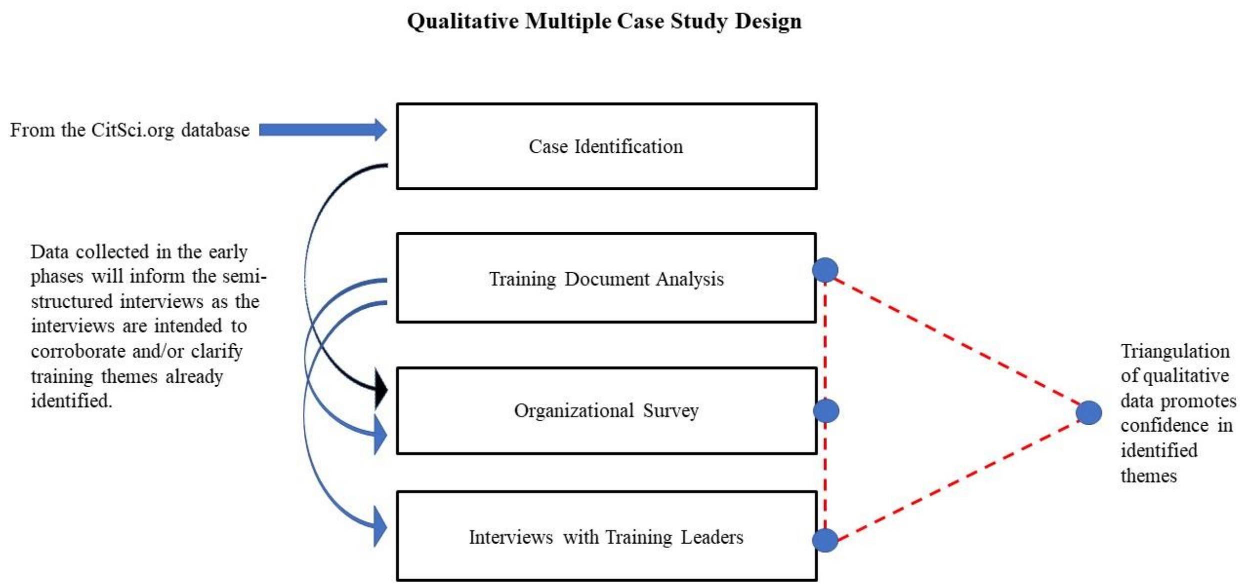

Figure 3. Four components of the qualitative research design: case identification, document analysis, surveys, and semi-structured interviews

There are three leading case study methodologists, Merriam, Stake, and Yin, who presented different approaches to case study research (Yazan, 2015). According to Yazan (2015), each have a different epistemological approach to case study research. Merriam (1998) and Stake (1995) leaned away from the traditional tenets of quantitative research, relying more on the constructivist perspective of knowledge discovery (Yazan, 2015).

Yin (2013) in contrast, sought alignment with positivistic and quantitative research approaches (Yazan, 2015). He urged researchers to adopt a common analytical framework to increase the quality and acceptance of qualitative approaches. This dissertation research aligned with both education and science disciplines. The science community is entrenched in quantitative approaches, and the purposive sample for this dissertation is the scientific community and its affiliated citizen science programs. Therefore, it was most appropriate to follow the case study analysis guidance of Yin. Yin's pillars of credibility, including construct validity, internal validity, external validity, and reliability, and discussion on triangulation provided an analytical framework akin to that provided in quantitative analyses.

Multiple Case Study Design

A multiple case study design was appropriate for this inquiry because it afforded a breadth of information from which themes can be extrapolated. The research design was exploratory in nature, but the sequential investigative steps drove the investigation into the realm of descriptive case study design (Yin, 2013). This was possible with multiple cases because repetitive measures gave a description of the phenomenon itself in three modes: through authentic evidence (training media), through primarily categorical or numeric response data (surveys) and through open-ended response data (semi-structured interviews).

A single case study is only appropriate for rare cases (Yin, 2013) or intrinsic case study research, in which the case itself is the subject of inquiry (Stake, 1995). In this multiple case study design, collection of both qualitative and quantitative data occurred, but the research remained intrinsically qualitative in nature because the research questions explored the nature of a phenomenon rather than a quantification of its parameters (Merriam, 1998). Collecting both qualitative and quantitative data provided a rich description of the phenomenon (Yin, 2013). The numeric data were assimilated using descriptors, and text-based data were assimilated into the coding system in the case study database.

Although cross-case and within-case analysis occurred, this analysis made no attempt to draw causality between variables. The analytical power that might be preferred in a quantitative approach would not have advanced the research questions posed. Alternatives such as a quantitative survey might have reached more cases, but the depth of information would have been limited with numeric data only. A qualitative comparative multiple case study allows for rich descriptive information while affording a breadth of inquiry that contributes to transferability and credibility (Lincoln & Guba, 1985). The qualitative rich description aided understanding of the ecological learning contexts in which citizen science data collection occurred, identified common opportunities across programs, and informed the scholarly community regarding the reliability of citizen science data.

Participant Sample

A purposive sample for this investigation included organizational users of the CitSci.org database who tasked volunteers with field-based ecological data collection. The CitSci.org database operates as a *Software as a Service* (SaaS) platform that is free for individuals and organizations to use to conduct citizen science of any kind. The database was developed by Newman (2010) and is maintained by the Natural Resource Ecology Lab (NREL) at Colorado State University (CSU). There are 400 organizational users of the CitSci.org database. The database is a complete web-based platform for organizational communication, information, data collection, and analysis for citizen science programs.

Sample Size

The field of citizen science is burgeoning, but it is still relatively small. The sample size captured by these qualitative methods was a notable quantity of cases among the entire field of citizen science to which these specific study population parameters could be applied. Greater similarity between groups required fewer samples to reach saturation. Notably, the citizen science programs investigated shared similar goals and occurred in limited ecological contexts. These similarities are discussed in detail in Chapters IV and V.

Mason (2010) presented a systematic review of dissertations to provide some guiding numeric advice for qualitative research pursuits. Of 179 dissertation case studies involving interviews, the mean sample size was 36 (Mason, 2010). Among 42 dissertations that involved content analysis, 28 was the mean sample size (Mason, 2010). Bertaux (1981) contended that qualitative studies required a minimum of 15 samples regardless of methodology. In light of these scholarly recommendations, the target sample size for this study was 15-36 organizations.

There are over 400 members of the CitSci.org website. A user survey sent out to the CitSci.org membership last year by another researcher resulted in 94 responses (G. Newman, personal communication, November 28, 2017). This previous survey's response rate provided what seemed a measure of assurance regarding this researcher's effort to secure an adequate sample. Because the researcher assumed that some organizations would start, but not complete the data collection process for this dissertation, the goal was to initiate document analysis and subsequent data collection with as many cases as could be identified, rather than limit the cases to a random sample of organizations meeting the case identification parameters.

Case Identification

General categorization of organizations was the first methodological phase for this investigation. To be included, organizations (i.e., cases) needed training resources for volunteers tasked with data collection outdoors in a natural habitat (called herein *the field*). This study included stand-alone non-profits and chapter non-profit organizations, academic institutions, and government agencies.

All non-organizational members of CitSci.org, including but not limited to land owners storing their own data and teachers and students engaging in lessons were not included. These groups were omitted because the assumption was that their data collection efforts were personal, requiring no training for a group of participants.

Despite hopeful expectations, case identification was one of the biggest challenges in the process. Pre-planned, contingency delimitations were not necessary. It was a great task to recruit the cases. The response rate from the previous organizational survey was not indicative of the recruitment challenge faced. This is discussed in detail in Chapter IV. As such, this multiple case study included a total of 22 cases.

Informed Consent Process

The informed consent process began as soon as a case was identified. Although no personal data were collected in this multiple case study research design, the researcher sent a letter of informed consent to each participant (Appendix A) in advance of each sequence in the research. The letters of informed consent, although very similar, reflected the process of each research stage including the document analysis, the survey, and the semi-structured interview. The redundancy in the informed consent process was necessary since there were different procedures for each data collection stage in the sequence. The informed consent documents were sent and received via email.

Data Saturation

A pre-determined number of samples does not necessarily predict data saturation; rather, data saturation is discovered through the data collection process and indicated when no new codes arise from additional sampling (Guest et al., 2006). For example, if many organizations were training volunteers to collect similar data, fewer organizations would need to be sampled to achieve data saturation; however, this reality would not be known before conducting the investigation. In the cases identified through this investigation, clear codes arose. Although not every ecological context for citizen science was queried, the researcher found no new codes arising after the first four cases completed the sequence. There is clearly a bimodal training phenomenon within citizen science. This bimodality relates to the types of data collected.

Data Collection Methods

Document Analysis

Once delivered with the informed consent from the organizational contact, the training documents submitted for each case were organized in the case identification and document checklist (Appendix B) and used in a directed content analysis (Hsieh & Shannon, 2005). From these documents, the researcher developed descriptors and fields related to organization type, document type, document purpose, training design, ecosystem, and resource monitored. The general process of document analysis refined the functionality of the case study database because as documents were assimilated, the framework became more nuanced to capture the information revealed.

Organizational Survey

The organizational survey, the next phase of this research, collected information about organizational characteristics, volunteer demographics, citizen science program and training design, and leaders' perceptions of training efficacy for participant learning and data reliability. This qualitative investigation assimilated all possible data streams including qualitative and quantitative data to make the characterization robust (Yin, 2013). These data included numeric data such as length of program or number of volunteers engaged, categorized numeric data (e.g., Likert scale questions), and categorized text-based data for frequency analysis. Open-ended questions provided text-based excerpts for coding.

As Merriam (1998) described, analysis occurs throughout the data collection process and becomes more rigorous as more data are collected. Themes and codes identified become nuanced through the rich descriptive process of the multiple case study design. When discrepant data arose from a case, they were explored more deeply in the next sequence of the investigation, the semi-structured interviews. Field testing, which is an attempt to measure reliability and validity with a smaller initial sample, occurred naturally as an outcome of the on-going analysis capable with the case study database. The goals of field testing occurred with the addition of each new case. Each case presented an additional opportunity to ascertain whether or not the training media, survey, and interview data were aligned. After analyzing only a few cases, it seemed clear that an excess of data was being collected. The survey questions are in Appendix C.

Semi-Structured Interviews

The final phase of data collection involved follow-up semi-structured interviews with organizations' training leaders. The target interview subjects were leaders within the organizations who led the development of or who were leading the on-going management or implementation of training initiatives during the time of this study. In all cases, the person who responded to the research solicitation became the research participant. The semi-structured interview questions followed the script of the survey questions closely to facilitate triangulation between the data collection sequences. The semi-structured interview questions are in Appendix D. The researcher conducted a thematic analysis (Guest, 2012) of the interview data using the case study database. This final sequential step in the analysis triangulated the data collected in each sequence (Denzin, 2012; Stavros & Westberg, 2009; Yin, 2013).

Interviewees' telephone numbers or Skype names were contacted using Skype. The researcher recorded, transcribed, and coded the data arising from the semi-structured interviews. The transcripts were incorporated into the case study database where the coding occurred. Even though it was possible to meet some respondents in person, all semi-structured interviews occurred via web application to standardize the interviewing protocol and experience.

Data Analysis Process

The case study analysis identified common descriptors and codes across cases. As Merriam (1998) described, analysis occurs throughout the data collection process and becomes more rigorous as more data is collected. Descriptors identified became nuanced through the rich descriptive process of this study's multiple case study design (Merriam, 1998). The document analysis informed the development of the descriptors in the case study database. The survey constituted the primary data collection tool. The semi-structured interviews triangulated the document analysis and survey. The survey and semi-structured interview questions can be found in Appendix C and D. The questions were pre-coded according to the type of question, their inquiry theme, and the research question they addressed. This facilitated the importing and coding of the survey and semi-structured interview data. This case study database was sortable by descriptors, their fields, and the codes identified in the text analysis. The information categories included program overview and history, parameters of training documents, program evaluation, learning assessment, data collection, and program and training design. These phrases that prefaced the questions related to this coding effort aided the triangulation between the survey and semi-structured interview questions.

Analysis occurred as new cases were added to the database and as each case advanced through the data collection sequence. Within the case study database, analysis and visualization of data were possible as new data were added. Numeric data, in the form of demographic or program statistics, were incorporated into the database along with qualitative, text-based data. The final triangulation analysis involved graphical visualization of the interactions between the frequencies of text-based codes as compared to numeric and categorized data in descriptors and their associated fields.

Data Analysis for Document Analysis

After case identification, training documents submitted by each organization (case) were assimilated into the case study database. Training documents included static documents (text-based documents), multimedia documents (visual presentation with some text and no audio), dynamic documents (web pages, blogs that were regularly updated), and videos. These media, once in the case study database, informed the development of database descriptors and related fields.

Data Analysis for the Surveys

The descriptors and fields that arose from the document analysis framed the subsequent survey data analysis through a sequenced methodology of data analysis, survey, and semi-structured interview. As the researcher received new surveys, they were incorporated into the database, which already contained the training documents. In addition to the case study database, some statistical analysis of survey data alone occurred in the SurveyMonkey© platform.

The survey data revealed demographic and program statistics not summarized in the training documents. The researcher did not request annual reports from the cases in the document analysis stage; and thus, this demographic information came through the survey responses. These demographic data contributed additional descriptors and related fields to the case study database. These descriptors in conjunction with the codes arising from the text-based survey data and the text-based semi-structured interview data formed the analytical framework for this investigation.

Data Analysis for Semi-Structured Interviews

The semi-structured interview questions were closely aligned with the survey questions. The semi-structured interview data contributed to the coding system of the case study database. Interviewing training leaders triangulated the previously-collected data and clarified gaps in the researcher's understanding of a case that arose in the document analysis and survey analysis sequences. No semi-structured interview data contradicted document and survey data for a case. The methods exhibited data reliability because repeated measures within each case confirmed the emerging information, indicating saturation in data collection within a case.

Data Reliability in Qualitative Data Analysis

Triangulation facilitates qualitative data trustworthiness. Lincoln and Guba (1985) established four parameters with which to assess qualitative data. Credibility is a concept akin to quantitative internal validity; it describes how accurately the data collected represented the phenomena under investigation. Transferability is a parameter to describe how applicable the data collected are to other analogous contexts. Dependability, like quantitative reliability, describes the repeatability of a study. Confirmability, akin to quantitative objectivity, describes the independence between the researchers' biases and the data collected (Lincoln & Guba, 1985).

Member checking is a qualitative analytical tool used to increase validity in qualitative research (Birt, Scott, Caver, Campbell & Walter, 2016). Lincoln and Guba (1985) recommended member checking as a means of ensuring that the participants' perspectives of a phenomenon are adequately represented. Member checking was not used in this dissertation to validate citizen science training themes and theoretical alignments, the focus the first research question. Since this research question did not address human perception, this would have been an inappropriate use of member checking.

The second research question addressed training leaders' perceptions of the efficacy of their training to promote data reliability. Member checking is an appropriate analytical tool for this research question. However, while member checking may increase validity in this inquiry stream, it may also bias the results. One critique of member checking is that it can transform an authentic data collection experience into a cultivated data artifact that portrays a specific intent, success, or outcome (Birt et al., 2016). It is also most appropriate in ground theory research in which the definition of a phenomenon is enhanced by a co-created process of knowledge creation (Birt et al., 2016).

The authentic perception of citizen scientist collected data reliability is the only possible measure by which training success may be characterized because the second research question arose from the literature that suggested some land managers and scientists who might have used the types of data collected by citizen scientists did not trust citizen-scientist-collected data. A co-evolved perspective of data reliability in citizen science might have amplified this bias. As such, the authenticity of an individual manager's perception could have lent more reliability than a cultivated response. For these reasons, member checking was not used as a means of validation. Instead, triangulation of the sequence of data collection provided data validation.

Trustworthiness Concerns in Qualitative Studies

Collecting multiple streams of analogous data facilitated the establishment of qualitative data quality by creating a redundant inquiry system through which descriptors and codes were validated with frequency and interaction analysis. When multiple streams of data collection reinforce codes and themes, data credibility is demonstrated (Yin, 2013). When these codes and themes are applicable to many cases, transferability and dependability are illustrated. When independent researchers arrive at similar codes and themes in independent analysis, confirmability is demonstrated. Achievement of these criteria was the goal when analyzing and coding the multiple case study database created during this investigation. The subsequent analysis exhibited these characteristics of data quality.

As the interviewer and each respondent moved through the sequence of questions, some answers were already known by the interviewer; and thus, the interviewer offered the notes or understanding already gathered, and the respondent confirmed, reflected, and expanded on the interviewer's understanding. By the end of the interviews, the feeling of saturation was very apparent as there seemed to be little more that could have been said to expand on the research questions.

Role of the Researcher, Researcher Bias

In this study design, the researcher played different roles in the sequential steps of the investigation. In the phase of document analysis, the researcher communicated with case contacts and compiled primary documentation about training initiatives for each case. The researcher uploaded into the case study database the training documents in their original form. Using these documents, the researcher developed descriptors and their related fields. The descriptors and fields were the researcher's interpretation of how to categorize the documents and the programmatic details evident in them. In the survey sequence, the researcher imported the survey data from SurveyMonkey© into the case study database. The researcher applied the previously developed descriptors and fields to the numeric and categorized data, and began the process of developing codes to reflect the text-based data. During the semi-structured interview sequence, the researcher conducted the interviews, transcribed them, uploaded them into the case study database, applied the previously created codes to these text-based data, and created new codes when appropriate.

Assumptions

The whole phenomenon of citizen science assumes that individuals lacking a terminal degree in science can contribute to the collection of scientific data. This generalization assumes that procedural knowledge can be acquired in a training environment and that educational experiences contribute to learning. Although these seem self-evident, few previous studies have acknowledged the educational experience as a variable in data collection success.

Methodological Assumptions

A driving assumption of the proposed research methodology was that users of the CitSci.org database were a representative sample. There were other databases that could have been used, most notably SciStarter.org, but this database is much broader in scope. The projects in CitSci.org are all related to ecological data collection; therefore, the use of this database automatically narrowed the sample according to this parameter. Furthermore, the projects were cross-referenced into SciStarter.org; and therefore, the CitSci.org sample still existed in this expanded membership, but it would have been more difficult to extrapolate from a much larger membership database. It might have been possible to employ snowball sampling, or to find cases through Internet research. However, these techniques would have biased the results to already-connected organizations and organizations large enough to have a web presence.

Another assumption was that training themes and codes arise from document analysis. Reviewing the training materials first provided an authentic entry point into the citizen science program because it was analogous to the on-boarding process for trainees, with the exception of live components that the researcher did not attend. There were adequate similarities across programs to create meaningful cross-comparisons of training activities using the training documents only. Regarding sample size, greater similarity between groups required fewer samples to reach saturation. If the cases were exceptionally variable, more cases would have been needed to identify descriptors and codes and reach saturation.

The final methodological assumption was that training can be characterized through secondary materials. No primary observation occurred, since direct observation would have put the researcher at the center of the data collection process, which would have raised issues of bias. The methodology used in this study assumed that the documents and media associated with training, and the data captured in the survey and semi-structured interviews were enough to characterize the training. This sequential but secondary perspective was a more neutral approach and one that revealed the true nature of the trainings.

Theoretical Assumptions

The first assumption was that principles of andragogy contribute to an effective learning experience for adults (Knowles et al., 2011). Adults have more life experience and practical needs than children. A learning experience designed for adults incorporates the learner's personal experience into the acquisition of new knowledge by drawing connections between prior and current learning, by solving real-world problems, and by applying knowledge to their own world (Merrill, 2002). These andragogical parameters provide a motivation to learn (Knowles et al., 2011). In the most direct interpretation, citizen scientists need to learn how to collect scientific data in the field for their present citizen scientist engagement. From a sociocultural perspective, public participation in scientific research can result in "transformative effects for democratization of knowledge production" (Bela et al., 2016, p. 90). When reviewing training materials, the researcher looked for evidence of andragogy, assumed to activate these transformative effects for adult learners.

The second assumption was that principles of backwards design contribute to an intentional educational experience. Backwards design is an instructional design principle that describes the sequence in which a learning experience should be designed (Wiggins & McTighe, 2005). The first step was to identify the learning outcomes. This was followed by assessment development for measuring attainment of these learning outcomes. Finally, the creation of learning activities ensues (Wiggins & McTighe, 2005). After reading the literature and through the personal experiences of the researcher, this backwards design process seemed apparent to the concept of citizen science. The common learning outcome expected for these programs was *citizen scientists will learn how to collect credible data*. Since all citizen science programs apparently exist to address a learning outcome, the researcher assumed that a backwards design might be used inherently to design citizen science training. As such, instructional design parameters were part of the analytical coding system developed for this research.

Ethical Concerns and Confidentiality

Regarding ethical concerns, the participants in this study were organizations and their training programs. The individuals who participated in the training program were not objects of the study design. Therefore, their ethical protection was not a concern. The informed consent process was directed towards organizations and regarded the usage and investigation of training materials and training programs. This research collected general demographic data about training programs' participants but did not ask specific information about their identities. The informed consent notice is in Appendix A. Organization identity was linked to the data in the database for the purposes of facilitating the sequential process of the methodology. All information relating data to specific organizations will be anonymized in publication.

The data collected were stored in a password-protected case study database. This case study database will be preserved in a password-protected state for five years following the conclusion of this research effort. At that time, the electronic case study database will be destroyed.

Generalization of the Study

Scholarly information about citizen science training is limited to single-organization case studies (Bela et al., 2016; Newman et al., 2010). This dissertation research was the first scholarly attempt to aggregate training information into a multiple case study database where the information was analyzed for training themes and content. Although there are myriad contents in which citizen science occurs, the data revealed many similarities among cases. Similarities across training programs aided the development of descriptors and codes in the case study database. Contrasting results revealed naturally occurring, unique study groups and theoretical frameworks that became the variable parameters for descriptors and codes in this research and for use in future research. Describing these similarities and differences through content analysis provides researchers a construct from which to design future research studies that experimentally assess the learning outcomes and data collection success of volunteers trained with different methods. It also revealed to the citizen science community the types of trainings that are used in contexts generalized to their ecological contexts and to the types of data collected. Within that characterization, certain opportunities for program improvements, collaboration, data storage, and analysis are likely valuable recommendations for citizen science programs beyond the scope of this multiple case study.

Summary

This qualitative, comparative, multiple case study characterized citizen science training programs designed to educate citizen scientists tasked with ecological field data collection. The sequential design of this case study research cataloged the training documents associated with these programs, and collected survey and semi-structured interview data. The data analysis facilitated by a case study database triangulated the three data sequences of each case. The within-case analysis indicated internal validity for each case. The cross-case analysis revealed common descriptors and codes across citizen science training programs, and indicated transferability. Citizen science programs designed for photo data collection had very limited training resources, but the organizations and their partnering scientific communities considered photo data to be research-grade data. Therefore, this relationship between minimal training and data collection reliability is serving the programs' needs.

On the other end of the spectrum, programs that required citizen scientists to collect a variety of measurements, especially using specialized equipment, required more robust training programs. Evidence of andragogy was apparent in the ways program leaders described the personal motivations, real-world applications, and problem-solving scenarios inherent to citizen science endeavors. Beyond the early identification of citizen science program learning outcomes, there was no evidence of backwards design. The greatest opportunity for citizen science programs is the implementation or expansion of training program evaluation. Thematic analysis revealed that programs had clear objectives and well-vetted training resources, but no plan for gathering, handling, responding to, and reporting feedback from trainees. This feedback would inform training leaders of knowledge gaps before the data collection process began and could potentially address data collection errors before they occurred, thereby increasing data reliability.

CHAPTER IV: RESULTS

Citizen scientists are volunteers who participate in scientific activities under the guidance of professional scientists and organizations. The general problem is that some scientists and land managers view the data collected by citizen scientists as unreliable. The specific problem is the absence of educational training measurement in citizen science program design and analysis with which to ascertain the learning gains of trained citizen scientists. The research questions addressed by this investigation are:

R1: What are the characteristics of trainings designed to train citizen scientists to collect ecological data in natural land settings?

R2: How do organizational leaders describe their perception of the efficacy of the trainings to produce reliable data collection?

A sequence of three stages of data collection revealed interesting patterns and themes throughout the content, instructional design, and learning theory alignments. Previous chapters explored the theoretical context and methodology for this investigation. This chapter presents an assimilation and analysis of the data collected in light of the theoretical foundations that frame citizen science. The discussion is organized into subsections that address the specific coding themes in the analysis, including the citizen science context, instructional design themes, the perception of citizen data reliability, and theoretical alignment.

Preliminary Data Collection

The sequential nature of this investigation forced a gradual induction of each case into the study. Only one case responded to the initial solicitation sent through the CitSci.org database to the members of the citizen scientist organization. Reviewing this first case provided field testing opportunity to gauge the training materials that might come through the document analysis. This provided an opportunity to adjust data collection strategies and to address the variability and volume of materials arriving from just one case. For example, each case submitted training materials in numerous formats including webpages, static documents, multimedia documents, and videos. All of these files could not be contained in a single computer-based folder bearing the name of the case. As such, additional layers of categorization were worked out with this first case.

Academic affiliates reviewed the survey to offer feedback before data collection. Feedback from the University of the Rockies internal review board (IRB) process indicated that the survey may have been too long. The reviewers' feedback added weight to this recommendation. Some questions were removed because it became clear through the early document analysis process that the organizational contacts with whom this investigation was communicating were not also the people who could calculate organization-wide demographics impacts.

Another adjustment made to the survey in an effort to reduce its length involved the removal of questions that were repeated. The survey designed contained questions in triplicate. These bimodal, Likert scale, and open-ended questions had the potential to increase analytical power. However, after the early review, some were removed to reduce the length of the survey. The resulting analysis still reflected triangulation between the document analysis, the survey data, and the semi-structured interview data.

Qualitative Analysis

Sample

The sample was collected through a series of solicitations. The first research solicitation was delivered through a CitSci.org newsletter article linked to a blog post that continued to reside on the website until the end of the study. This effort solicited only one case. This was a disappointing start, but as previously mentioned, it provided the opportunity to use a single case for field testing the methodology.

After this initial solicitation, CitSci.org staff provided two membership databases. One tracked membership from the most recent engagement through the beginning of 2017. The other contained the membership data from all time. The research solicitation sent via email parceled these contact emails into lists of 20 contacts for a total of 540 programs contacted, to reduce the number of solicitations that were returned as spam mail. This email effort produced an additional seven cases. Several emails were returned and not delivered. An attempt to find new emails for these organizations was a time-consuming process, but it resulted in additional cases.

The third effort included emailing project managers from within the CitSci.org platform. Following the list of projects on the CitSci.org web platform from first to last, the solicitation reached each project manager via email. This granular effort allowed for personalization of the email, even if it was just to add the contact person's first name to the salutation. This third effort returned more cases. The actual CitSci.org platform appeared to contain more accurate email data because it is resulted in more case adoptions, even though these cases were already contacted in the membership email-based effort. That being said, because the CitSci.org platform did not indicate which internal messages failed to reach a recipient, this conclusion bears no confidence; receiving no response might have meant that the contact was not interested or that the email did not work.

The final analysis included 14 organizations representing a total of 22 cases. An unforeseen nested design arose in which one manager oversaw multiple projects. As such, the target number of cases (15-36), did not result in the same number of surveys and interviews entering the analysis as documents. This is indicative of the apparent nature of citizen science engagement; therefore, it was appropriate to evaluate the multiple cases arising from a single organization. In addition, in all instances, the training related to the different cases was unique, and these nuances were indicated in the open-ended survey and semi-structured interview questions, but not through duplicate surveys and interviews.

Data Collection

After IRB approval, the solicitation process was ongoing while analysis of existing cases at all data collection sequences co-occurred. When an organization's contact responded to a solicitation, s/he received via email the informed consent for the document analysis with a request to forward the training documents when s/he returned the informed consent. When the training documents arrived via email, the next email delivered the second informed consent for the survey. Upon receipt of this signed document, the survey link followed. When the survey was completed, the informed consent and scheduling information for the semi-structured interview passed from the investigator to the participant. With the last informed consent received, the interview process ensued using Skype as a communication and audio-recording tool.

The training media delivered came in many formats including web links, static documents, videos, and presentations. Training media organized in the case identification and document analysis checklist acted as a table of contents to direct the process of research, including contact information, informed consent, research sequence progress, interview scheduling, and location of all relevant files associated with the case. The very first case delivered files of every type; thus, the great organizational task began. The document analysis process unfolded with the use of Excel spreadsheets for organizing, note taking, and developing the descriptors for the analysis. If assimilated documents did not fit the descriptors and fields already installed, new descriptors and/or fields helped to organize the media.

SurveyMonkey© hosted the survey portion of this research. The Dedoose© case study software was integrated with SurveyMonkey©, allowing for the importation of the survey data directly into the case study database. The survey included yes/no, multiple-choice, open-response, and Likert-scale questions. Survey respondents recorded the name of the organization so these data could be triangulated with the document analysis and semi-structured interview data; however, no identifying references to the organizations' identities were made in the narrative analysis, nor will they be made in future publications. Upon completion of the data collection, the survey data were downloaded and will be stored on the investigator's password-protected computer for five years and then deleted.

The semi-structured interviews occurred via calls using Skype© with audio only. This helped standardize the process for both domestic and international cases. It also facilitated the recording and transcription of the semi-structured interviews. The recorded and transcribed audio files integrated into the case-study database. The semi-structured interview transcripts, along with the survey data, informed the codes that were developed.

Data Analysis and Results

The sequential design of the study was in itself adherent to principles of learning. The sequenced methodology allowed for repetitive interaction with a case, which improved the researcher's familiarity with the case. Several themes and articulations related to the content, instructional design, theoretical alignment, and perceived efficacy of training for citizen scientists arose in the analysis. The directed content analysis was informed by the deductive insights from the literature, but left room for exploring unpredicted trends and issues.

The proposed sample target was 15-36 cases. There were 22 cases in the research process. These 22 cases arose from 14 organizational contacts who responded to one of the research solicitations. The first step in developing the case study database was the establishment of descriptors. These facilitated the analysis of quantitative and categorical data. The descriptors helped to determine the organization of the training documents and the categorical or numeric data from the surveys.

The document analysis was driven by the first research question. The coding system in the case study database facilitated the organization of the open-ended survey responses and semi-structured interview data. The codes already designed and prompted in the survey and semi-structured interviews provided the framework for analyzing these data. These were based on deductive reasoning of existing theory and literature. They followed the themes of program characteristics including types of data collected, ecological context, backwards instructional design principles, and cues to adult learning theory. This process of pre-determined deductive codes to which the data were applied is known as directed content analysis (Hsieh & Shannon, 2005). The nuances of codes developed with new data additions into the case study database.

Citizen Science Context

The ecosystem type descriptor categorized the habitat in which the citizen scientists worked. The fields included Atlantic Ocean-coastal US, international ocean, Pacific Ocean-coastal US, riparian mountain, riparian eastern, riparian central, riparian pacific, terrestrial mountain, terrestrial eastern, terrestrial central, and terrestrial pacific. The boundaries between these fields followed the time zones in the United States. These descriptors were reduced to terrestrial, aquatic, and marine since the sample size did not permit greater categorization between the groups. Thirty-six percent of cases collected data in terrestrial ecosystems, 36% of cases collected data in riparian ecosystems, and 26% of cases collected data in marine ecosystems. These fields corresponded to natural groups relating the data collection effort with each ecosystem type. There was some overlap between groups regarding the data collection process. Specifically, both terrestrial and marine groups collected photo data. All groups collected location, habitat, and species data.

The descriptor describing the resource monitored contained the fields ecosystem health (water, flora, and fauna), aquatic flora, aquatic fauna, marine flora, marine fauna, terrestrial fauna, terrestrial flora, air quality, soil quality, and water quality. In two instances, cases measured across these categories in distinct measurement protocols within the larger measurement parameters. Two other organizations collected an equal amount of data in all categories, therefore warranting a separate field to describe these efforts as ecosystem health measurements. The goal of those collective measurements was to arrive at a score describing the habitat resource itself, hence, this unique descriptor. The rest and majority of cases measured within the resource-specific fields with the caveat that many cases also collected site-identification parameters that could be classified as data in other fields. These field classifications reflected the primary data collection goals of each case rather than the complete data parameters measured.

Measurement of specific faunal species was the most abundant citizen science programming sampled. Water quality measurements were also frequent across cases. The multiple case study included no citizen science programs that measured aquatic flora, aquatic fauna, marine flora, or air quality. The field of soil quality included two cases, one that measured erosion dynamics and one that identified areas of resource damage, specifically illegal dumping and campfires, both of which contaminate the soil. No classic soil testing case in which soil was collected and analyzed for chemical and texture analysis was represented, although it is likely that such citizen science programs exist. There is also a high likelihood that citizen science programs exist that measure aquatic flora such as invasive duckweed, aquatic fauna such as fish populations, and marine flora such as kelp forests, but they were not represented in this multiple case study. Of note, two programs measured macroinvertebrates in aquatic waters, but their measurements were coded as ecosystem health measurements since the macroinvertebrate data collection was in concert with water measurements and habitat assessments.

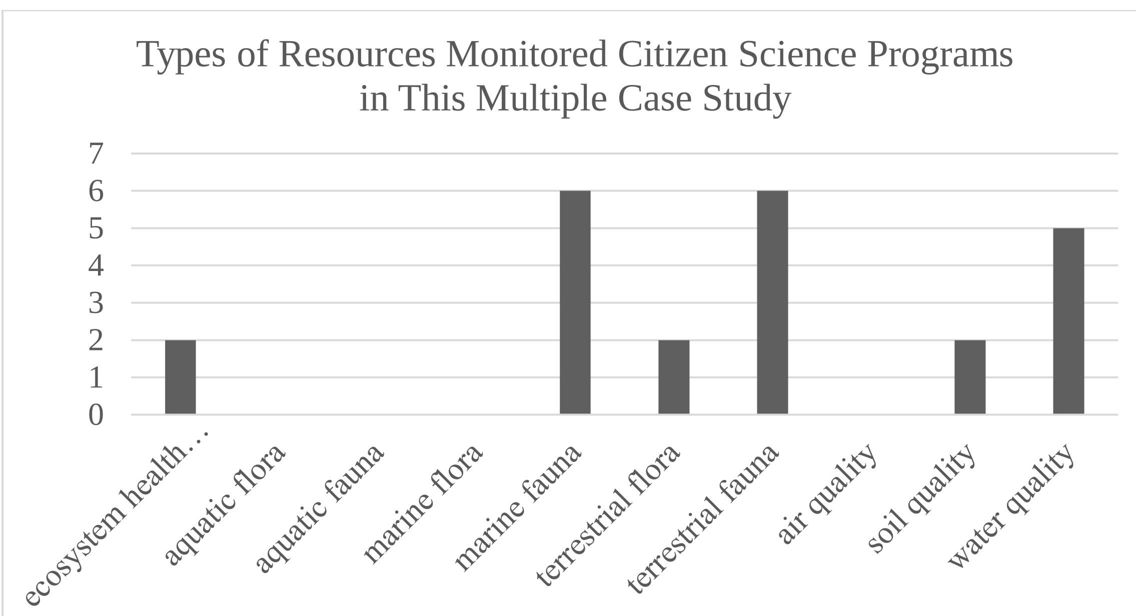

Figure 4. The types of resources and number of programs measuring these resources that are included in this multiple case study

A majority of the citizen science programs in the multiple case study commenced from a single concerned person or a small group of concern people addressing ecological issues in their communities. In a few instances, a larger statewide organization initiated the effort, but this was in response to resource damage or concerns. The organization type descriptor categorized the identity of the organizations from which citizen science programs originated. The organization type descriptor included academic institution, government agency, non-profit chapter, stand-alone non-profit, and others. One-hundred percent of the organizations hosting citizen science programs were non-profit organizations, three of which were university-affiliated (Figure 5). No cases arose from government or other types of organizations. However, many programs exist in research and/or funding partnership with government agencies. These results triangulated across the data collection sequence. The survey and semi-structured interview data revealed that cases represented a two to 32-year range of citizen science engagement. These cases involved 6-15,000 citizen scientists per year. A larger sample size could shed light on the interactions between organization type, program size, duration and other nuances of the training design and data reliability outcomes.

The distinction between non-profit organizations that standalone and ones that are chapter organizations was a deductive choice, following the conclusion from the literature that larger organizations have more resources to devote to citizen science programming. The analysis indicated that this was true in the cases represented. In fact, among the cases, there were two instances in which standalone non-profit organizations cited the training resources of a larger non-profit organization as part of the external resources used in the smaller organization's training. In these instances, both the chapter organization and the standalone organization were cases, but the standalone organizations were not chapters of the chapter organization. In other words, they were not conducting the same exact citizen science program and protocols, but rather, they had used the openly available resources the larger organization provided to cultivate parts of their own citizen science program.

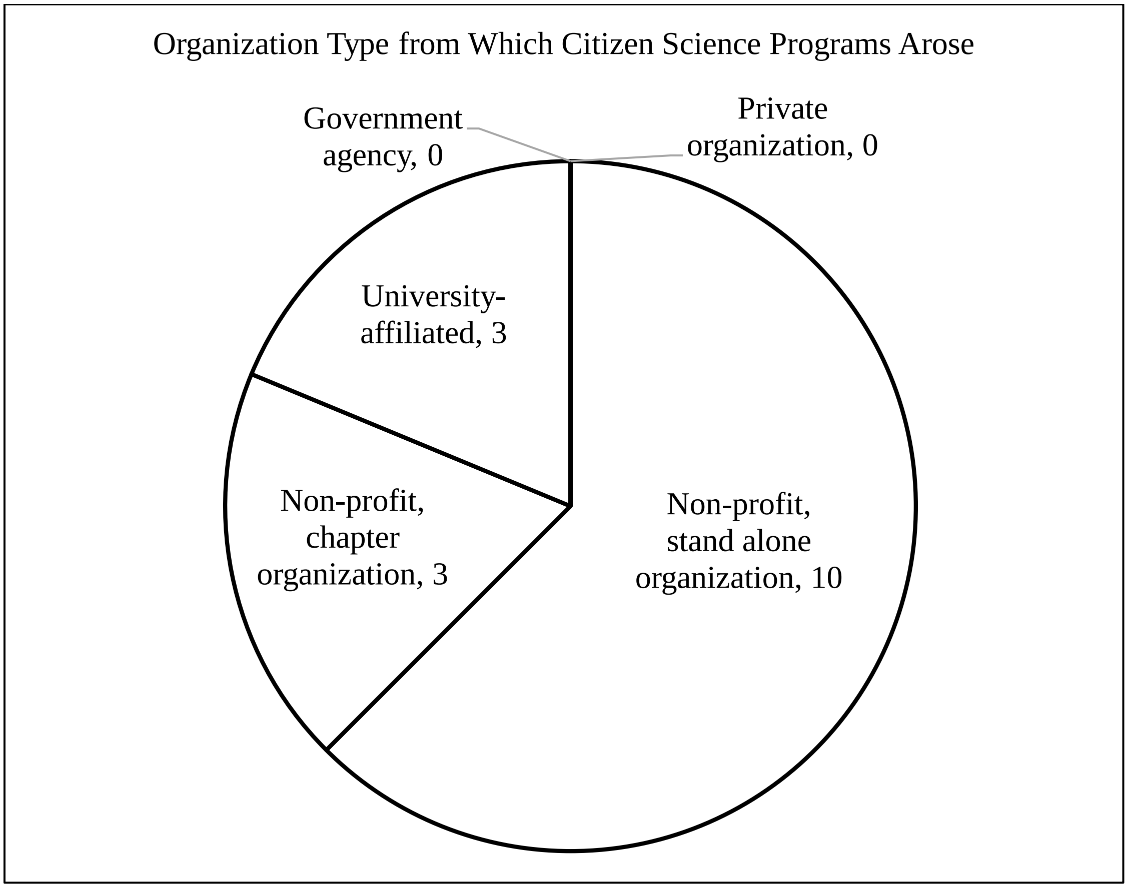

Figure 5. All of the cases arose from non-profit organizations.

Instructional Design Analysis

Several descriptors aided the training and organizational characterization that arose from the document analysis and survey data collection. These descriptors included document type, document stage, ecosystem type, resource monitored, organization type, training stage, and post-training learning evaluation. The document type descriptor had the fields audio-visual (AV - images, text, and audio), dynamic document (blog/web page, newsletter), multimedia presentation (visuals, some text, no audio), and static document (text, few images) (Figure 6). The document analysis included 83 training artifacts.

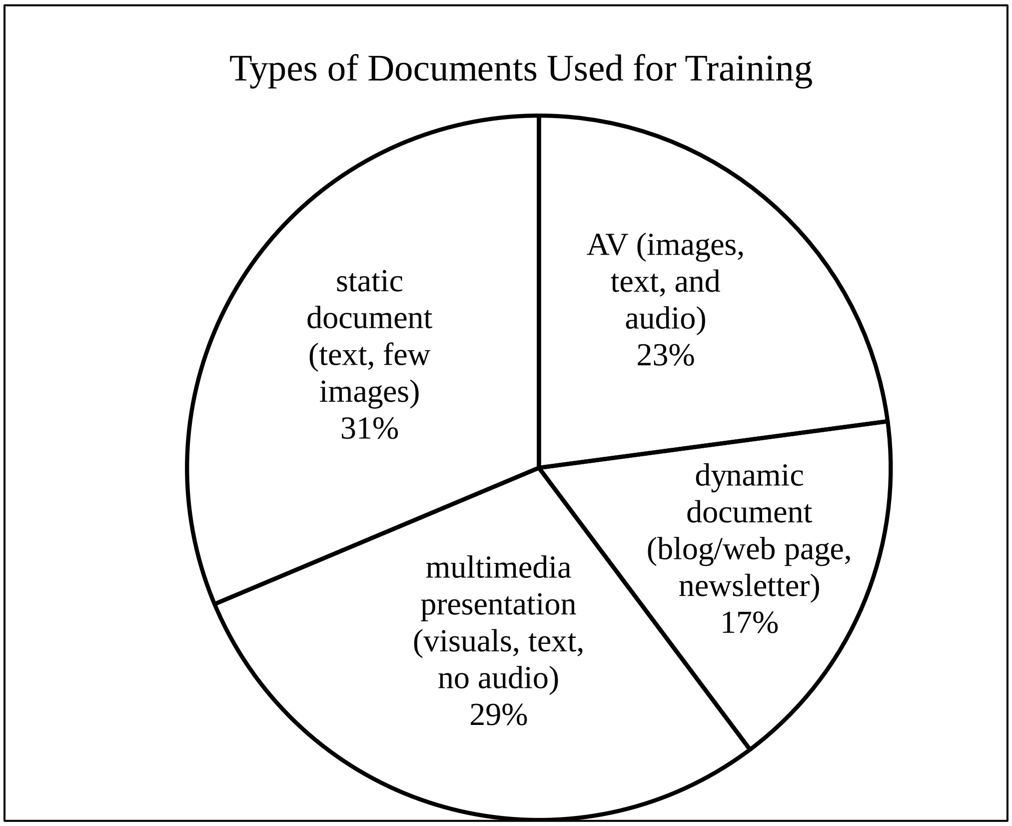

Figure 6. The types of documents used by citizen science programs in this multiple case study

Static documents were either short instructional pages or lengthy training manuals that compiled all of the resources for a trainee. The latter are best described as compilations of resources that included background on the specific data collection effort, instruction on how to collect the data, and additional resources that described the habitats and species of interest to each program. It was assumed by respondents that trainees used these manuals to facilitate continued education, especially right before a data collection task. In most cases, citizen scientists do not help author the training materials. However, in a few cases, the person who initiated the program was a citizen scientist by definition, i.e., a concerned citizen or academic who educated him or herself to get the program started; in these cases this individual also helped developed the training materials.9

The majority of the multimedia presentations included in the document analysis were delivered at live trainings, but then made available online for continued education. These were almost exclusively lecture-style presentations. The training time descriptor included the fields asynchronous/self-paced, live in-person training on a set date, no training necessary (photos only). The analysis revealed a bimodal distribution of training design. With the exception of one case, all cases either had minimal training because only photos were collected, or they had live in-person training on set dates. The descriptions of trainings provided in the semi-structured interviews indicated that live trainings were didactic events in which training leaders presented materials to the trainees. Most of these trainings were followed by field events in which live demonstration of the data collection task followed by hands-on training rounded out the training experience. Many cases reported that hands-on training was a strength to retain in future training events.

With the exception of one case, all citizen science programs had most of their materials freely available on the organization website. One case charged for complete files of curricula that the organization produced. They were franchising the citizen science program and had no specific contact with the purchasers of their curricula. In this way, the purchase cost was a means to scale the program rather than be a profit-driven measure. In turn, this case represented the end of the spectrum in which the citizen science program was completely developed, including all the materials needed to teach the program to another tier of participants. The code that arose from the analysis to describe this phenomenon was *train the trainer*. Two cases specifically designed documents to train leaders who then trained other cohorts of citizen scientists. Two additional cases were related to certification programs that afforded leader training, but these were not specifically citizen science programs; their associated citizen science programs were the cases, but the certification program curricula were not represented in this multiple case study.

These classroom trainings were either directly followed or followed after some period of time by a field engagement. These field engagements were coded as instances of mentoring and social learning. They were also coded as instances of ad hoc evaluation. This characterization illustrated a training schema quite similar to a classroom science class and its associated lab. Video-facilitated quizzes and written refresher quizzes were other evaluations of citizen scientist learning. In one case, the instruction, although still delivered in a didactic format, was delivered through openly-accessible instructional videos.

The document stage descriptor referenced the programmatic stage in which the document was used. The fields for the document stage descriptor included extra resources, evaluation, data collection, and training (Figure 7). The field of extra resources was removed in the final analysis because it was too challenging to count all of the embedded links on webpages. The majority of documents analyzed supported the training effort (86%), while the remaining documents supported data collection (23%) and evaluation of learning (16%). Of the evaluation documents submitted, all were quizzes for citizen scientists to take at the end of training. Over half of the survey respondents and semi-structured interviewees indicated that they offered training evaluations at the end of live trainings to assess the training quality and written quizzes to evaluate trainee learning, but these were not represented in the training materials collected. Therefore, it is likely that the document analysis underrepresented evaluative components of citizen science training.

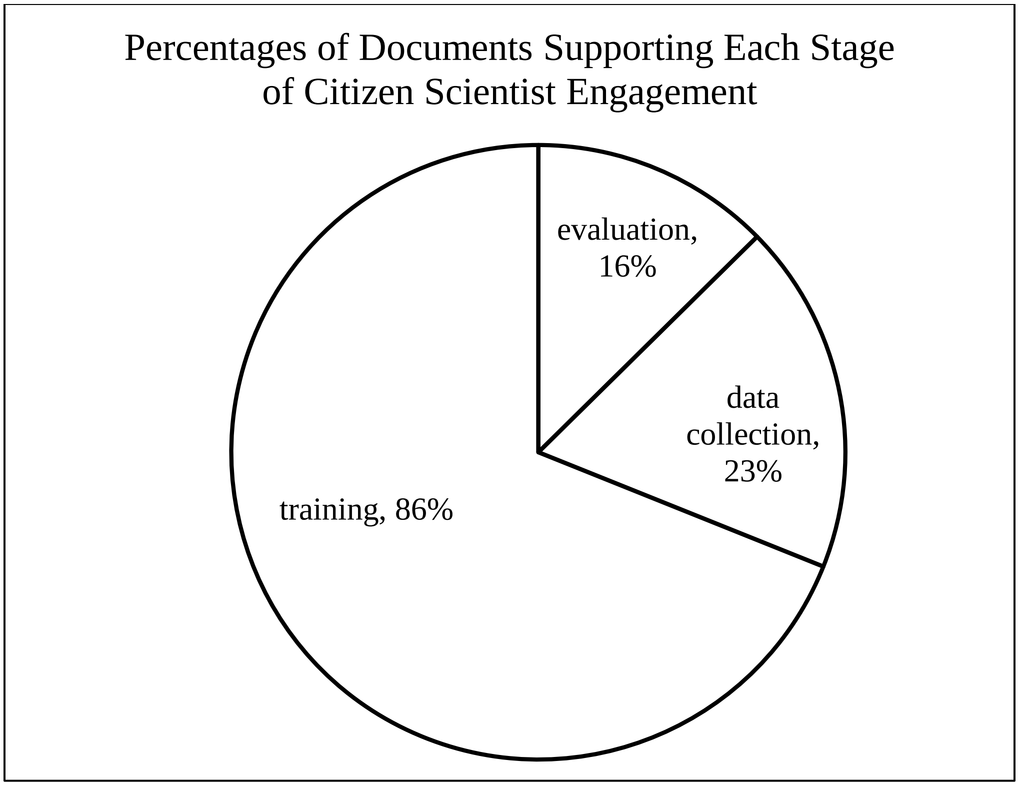

Figure 7. The majority of documents collected address the training stage of citizen science programming.

As aforementioned, one modality of citizen science training illustrated a classic transmission of information in a formal classroom setting followed by field interactions that provided hands-on learning experience and social engagement. The other modality of citizen science training and data collection was a simplistic training platform that reflected the simplicity of photo data collection. In these cases, single-page instructions on how to upload photos and location data to the data storage site were the only documents submitted along with the URLs for the data storage website. In these cases, additional resources included species identification tutorials available on the organizational website for continued education.

There were several cases in which photo collection data commenced with no training at all, but citizen scientists could register for trainings at any time to increase their knowledge and capacity to collect additional species data. In one case, the instructional videos that composed the training platform could be accessed at any time, thereby promoting continuous recruitment and refresher education opportunities.

Perception of Data Reliability

The survey and semi-structured interview data shed light on the perception of data reliability among citizen science training leaders. When asked, "Do you think your citizen scientists are collecting reliable data," 100% of survey respondents replied "yes." When asked to rank their response to the question "How reliable do you think the data is that your citizen scientists collect," 82% ranked 6 of 7 in the Likert scale. The semi-structured interview data confirmed these responses. By whatever variable means in place, all cases were confident in the data collected by their citizen scientists. All cases had some strategy for validating the data or the data collection process either by statistical analysis or by ad hoc data checking and visual assessment of citizen scientists' implementation of the measurement protocol.

The question "How do you assess the learning of your citizen scientists" solicited the most varied response among all questions in the semi-structured interview. One case used an annual refresher quiz, and one used a pre- and post-test after training, but not at regular intervals. Two cases had video quizzes that provided images or sounds that the participant had to identify.

Three cases had a formal quality analysis/ quality control (QA/QC) processes. These were all water quality programs in which some metric was used to determine what percentage of samples should be analyzed for quality analysis. For this subset of samples, citizen scientists recorded their own data and collected a water sample that was sent to a water chemistry lab. One case reported that the last QA/QC effort reported a near 100% accuracy in the citizen science data. Among hundreds of data entries, there were only two errors. These remarkable data reliability results were not reported in the literature. The two other cases that employed QA/QC processes reported a quantitative data reliability of over 80%.

One respondent provided the following summation of citizen scientists' role in scientific research:

> Site specific and regional analysis led to the conclusion that this data is analogous to what has been collected by professional scientists and in partnership with the state university. The scientists are doing research and they are working with our volunteers to expand their data collection capacities.

Theoretical Alignment

A series of questions linked to the tenets of adult education. The theory of adult education describes how adults first activate their prior knowledge, of which they have a great deal as compared to child learners. They then apply this knowledge to their own world (Merrill, 2002). Some respondents described the practicality of knowing how to collect the data for the citizen scientist role, but more described a cultural phenomenon that the scholarly literature portrays as science literacy. Recall that one of the goals of the federal funding for public participation in scientific research (Shirk et al., 2012) was to increase science literacy. When prompted with "Describe how the new learning from training is applied to the citizen scientists' world," every respondent described increases in science literacy and a radiation of the conservation issue to the broader community through the people who participated in the trainings and who subsequently collected data. In this way, the original funding from which the American citizen science movement blossomed met its goal of increasing science literacy.

When asked "How do you motivate citizen scientists to persist in their role," respondents described social contexts in which learning was reinforced either in the classroom, at volunteer appreciation events, and during field data collection events, commonly called BioBlitzes, although that term was not employed by all cases. A few cases mentioned the t-shirts and gifts bestowed on their citizen scientists; however, the majority described the motivation associated with caring about the cause and engaging with other people. One respondent used these words, which summarize well the general sentiment of the cases:

> There are two types of motivation. External motivation, for example, 'we will give you a bagel,' or internal motivation, for example, people like diving with sharks. When people start our program, we provide no external motivation. We rely on the internal motivation because people who collect our data are self-selected and self-motivated. Due to the nature of our projects, we do not need to motivate them.

This quotation provides direct evidence for adult learning theory. If viewed from a reflexive lens, one might ask, "Could an adult be motivated by a bagel?" Although an adult might be hungry, the value of the bagel is not comparable to an adult's time, values, and knowledge. The theory of education is framed around the concept that adults have to be intrinsically motivated. Their self-driven behavior encourages learning because it is practical and relates to the concerns and interests of the citizen scientists involved.

When asked "How do you activate citizen scientists' prior knowledge in training," respondents reflected again on the importance of self-motivation. All citizen science engagements relate to the conservation concerns, recreational interests, or human health issues of the communities in which the programs exist. Many individuals self-recruit to citizen science programs because they have specific professional or recreational skills to lend to the task. Skills mentioned by respondents included deep water diving skills, underwater camera operation, information technology skills, forestry skills, knowledge of the land from recreating in it, and/or allied academic research. In these ways, citizen science is a natural platform from which the principles of adult education arise. Participants find practical use for the knowledge they already have and also increase their own knowledge through the new procedural application of data collection.

Interestingly, in response to this question in the semi-structured interview, no one answered in more abstract terms. One survey respondent mentioned math skills. For example, more abstract skills might be verbal, technology use, or critical thinking skills to the new problem presented by the citizen scientist role. These might seem self-evident traits of adults, but it is an important distinction to make as it reinforces the importance of applying principles of adult learning to citizen science rather than pedagogical concepts of learning in which these skills of thinking, computing, and communicating cannot be assumed.

When asked "How do you engage citizen scientists in solving real world problems," which was the final question in the semi-structured interview script, the answer seemed self-evident to all. One respondent concluded that “all of this is real-world.” Indeed, several cases had conception stories that involved a single person or small group of people who set out to solve a real-world problem. Cases shared inspiring stories of citizen science engagement that included the tagging of hundreds of thousands of invertebrates to track their intercontinental migration, and the immediate reporting of water quality issues with real effects like the cessation of resource extraction until resource damage issues were addressed. Others described tracking declining populations of large marine mammals in all waters of planet Earth. In the application of real-world skills as a function of adult learning, citizen science appears to meet this tenet directly.

Conclusion

The results of this multiple case study to investigate content, instructional design themes, education theory alignment, and training leaders' perception of data reliability revealed several themes and conclusions. Citizen science programs in the multiple case study collected data about marine, terrestrial, and aquatic ecosystems, including water quality, species identification and location, habitat assessment, and resource damage.

Nearly all trainings followed a bimodal characterization. When data collection involved numerous measurements, live trainings were central to the training schema. These live trainings were similar to classroom science courses, with a lecture component followed by a hands-on lab component in which trainees practiced the measurement protocol, either in the field or in the classroom. One case involving complex measurements used asynchronous web-based instructional video training required for program entry. Despite standing alone as the only asynchronous training platform, the design of the training was similar to live training events with lecture followed by field mentoring and practice. All respondents noted that the field and hands-on components were strengths to retain.

In contrast, cases involving only photo data collection offered simplistic, web-based training tutorials to facilitate the management of photo data with openly accessible additional web-based resources for self-learning. Some cases in both training characterizations offered live mentoring events that were available periodically, but were not required to commence citizen science participation. In all training characterizations, associated managers were confident that their volunteers were collecting quality data and therefore felt their trainings were effective. All noted that improvements could be made, and several specifically addressed the learning opportunity presented by participation in this research process. The questions in the survey and semi-structured interview motivated them to seek new ways to improve their training curricula and program evaluation.

Evidence of andragogy was apparent in the ways program leaders described the personal motivations, real-world applications, and problem-solving scenarios inherent to citizen science endeavors. Beyond the early identification of citizen science program learning outcomes, there was no evidence of backwards design. The greatest opportunity for citizen science programs is the implementation or expansion of training program evaluation. Thematic analysis revealed that programs had clear objectives and well-vetted training resources, but no plan for gathering, handling, responding to, and reporting feedback from trainees, which could have informed training leaders of knowledge gaps before the data collection process began and address data collection errors before they occurred, thereby increasing data reliability. These conclusions inform future citizen science training initiatives and citizen science data collection reliability.

CHAPTER V: DISCUSSION

For this multiple case study, 22 citizen science programs that task volunteers with ecological data collection in the field provided their training documents and participated in a survey and a semi-structured interview. This data collection sequence informed the following research questions:

R1: What are the characteristics of trainings designed to train citizen scientists to collect ecological data in natural land settings?

R2: How do organizational leaders describe their perception of the efficacy of the trainings to produce reliable data collection?

The first section of this discussion characterizes the nature of citizen science programs, including their basic program design, their geography and ecological context, and their data collection parameters. The second section describes the instructional design themes that arose through this multiple case study. Citizen science data reliability and theoretical alignment are the topics addressed in the third and fourth sections respectively. The limitations of the study, the implications for theory and research, implications for practice, and recommendations for further research follow the interpretation of findings.

Interpretation of Findings

Citizen Science Ecological Context

Ecological context. The cases in the multiple case study database were all non-profit organizations. Three were university-affiliated and three represented large national non-profit organizations with many chapters around the United States and the world. None originated from a government agency or private organization. However, there was evidence that many programs originated or sustain themselves with government funding, either through university affiliation or through funding from federal grants received by the non-profit organization. This speaks to the community-oriented nature of most citizen science programs.

The ecological contexts identified before analysis included eight descriptors cross-referencing geography with three ecosystem types. The geographic regions were the time zones (Pacific, mountain, central, eastern). The ecosystems were riparian, marine, and terrestrial. The sample size was not large enough to make specific comparisons between ecosystem and geography. Furthermore, some citizen science training programs radiated beyond these geographic boundaries. Therefore, in the final analysis, the descriptor set was combined to reflect only three fields, which were the ecosystem types. This was the more appropriate condensation because training methods interacted with ecosystem type, but not with geography.

Kinds of data collected. The data collected by the cases in this multiple case study exhibited a bimodal. These data related to the ecological context in which the program was situated. Riparian citizen scientists collected data about water chemistry, habitat features, stream conditions, macroinvertebrate species, and their abundance. Marine citizen scientists collected photographic data only. Terrestrial citizen scientists measured a variety of species including amphibians, butterflies, birds, and plants. They also measured landscape conditions related to recreational and resource extraction impacts.

All of the marine cases and many terrestrial cases required only photo-based data collection representing the simplest data collection engagements. These cases had limited training documentation and very simple, if any, data collection documents. It is important to note that the data collection procedures for these cases were quite simple, with the photo uploading process being the main topic of any training documentation. However, the skills required to engage in the citizen science efforts were all acquired prior to engagement. Adults who might participate in these citizen science programs have those skills already. To make an academic analogy, those are prerequisites for participation in the citizen science effort. Further, it was likely their interest in the citizen science program itself arose from those interests and not from a specific motivation to participate in scientific engagements.

For example, one case of citizen scientists needed to be able to 1) dive at depths, 2) swim with sharks, and 3) know how to use an underwater camera to participate in the citizen science effort. All marine citizen science programs required at least diving skills and underwater camera skills. Therefore, the burden of training lay not on the shoulders of the citizen science programs. Instead, citizen science provided a deeper engagement for an individual already interacting with the ecosystem in which the citizen science program resided.

In contrast, the riparian and terrestrial programs required the most equipment and procedural knowledge gain to carry out the data collection task, however, the specific recreational skills required to enter these citizen science programs were few and included the ability to hike in uneven terrain to access measurement sites. Complexity in the data collection effort itself required far more robust procedural training on the use of various measurement tools. Riparian citizen scientists measured water chemistry, habitat and stream conditions, and macroinvertebrate species and their abundance.

To carry out these tasks, riparian citizen scientists needed to know how to use water chemistry tools like digital monitors and indicator papers. They needed to know how to assess the habitat and stream conditions using a visual assessment including stream order, clarity, flow parameters, degree of sedimentation, and the bottom surface type of streams. They needed to know how to identify and count macroinvertebrates living in the stream environment. The datasheets associated with these programs were complex. This data collection challenge was met appropriately with robust training in multimedia formats.

Terrestrial citizen science exhibited the most variability with few similarities between cases. Therefore, it was difficult to generalize a category of terrestrial citizen science. Some terrestrial citizen scientists tracked the presence and abundance of terrestrial fauna, in some cases, at high altitudes or across continental boundaries. Others terrestrial citizen scientists measured ecological parameters of public lands including incidences of resource damage. Cases responded to site specific issues and research questions in most cases.

In the broadest characterization, there is a fundamental difference in the training required to identify a species and its location versus monitoring habitats. In almost all instances of species identification, photos can validate the identification of the species. In this way, there is inherent data reliability and a reduced demand for rigorous training. In contrast, habitat monitoring requires broader procedural skills with technical field equipment and an enriched understanding of habitat analysis. As a result, broad stereotypes about data reliability in citizen science are not appropriate. As previous authors noted, the qualities of the data collection procedure are more relevant to data collection success than the identity of the citizen scientist (Danielsen et al., 2014; Schmeller et al., 2008). The characterizations provided in this analysis offer a deeper view into the nuances within training design and data collection with which to compare quantitative data reliability measurements in future research.

Instructional Design Themes

Instructional design themes arose from all sequences in the data analysis. The document analysis provided the basic framework for the kinds of training documents used across cases. These included static documents, dynamic documents like webpages and blogs, videos, and multimedia presentations. These were employed in a variety of ways depending on the parameters of the trainings. Survey and semi-structured interview responses described the parameters of the trainings, providing more context for the documents' use. This process facilitated the characterization of trainings.

Most cases that required extensive data collection offered live trainings. After the live training, trainees received in paper format all materials used in the training including lectures slides and videos. In all cases, if a live training was offered, the paper materials from the live training were also accessible via a webpage. In the one instance when training was offered at any time in the engagement, the training materials were also available for purchase via the website. In either scenario, via open access or purchase, it was common for the citizen science program manager to not know the extent of use of web-accessible training materials.

In the marine citizen science programs in which previous knowledge and skill were required to enter the citizen science effort, there was no mandatory training; but the organization's website provided many supplemental resources for species identification. In these cases, a single instructional sheet was all that was delivered at the point of engagement. The primary instruction delivered regarded the uploading of data collected (photos).

In all cases, the training materials provided guidance related to procedural skills and additional resources for species identification. Some training materials described in depth the ecological problem that gave rise to the citizen science effort. An assumption of this research was that procedural skills could be learned in training settings. No assumptions were made about a training program's ability to impart instruction about the ecological theory supporting the context evaluation of training is fodder for data collection. Nonetheless, program managers reported that the data collected by their citizen scientists was reliable. This indicated confidence in the training program to impart procedural skills. Furthermore, these perceptions reported by the managers were supported, in many cases, with quality assurance systems that validated the quality of the citizen scientists' data collection effort. In conclusion, the data collected in this analysis validates the deductive assumption that training can impart the knowledge required for citizen science participation. To put it in a different light, this multiple case study lends evidence that citizen scientists who, by definition, do not have terminal degrees in science can contribute to scientific enterprise with data collection appropriate procedural training.

Evidence of backwards design. The literature review indicated that the inherent learning outcome in most citizen science programs was likely *after training, citizen scientists will learn how to collect reliable data*. This suggested that an inherent backwards design might be at play in citizen science programs. The backwards design process, however, is predicated on not just the identification of learning outcomes, but also the development of assessment parameters before the development of training parameters.

Only 16% of the training documents processed in the document analysis related to evaluation. Over half of the survey respondents indicated that they used an assessment to gauge citizen scientist learning. The rest of the cases reported ad hoc evaluation that does not enter the training curriculum development cycle. The multiple case study analysis does not indicate strong alignment with backwards design simply because evaluations, although present among the data collected, were not apparently leading the instructional design process. Furthermore, no evidence suggested that any regional or national assessment for citizen science knowledge gains existed.

When prompted “Describe how your citizen science program started,” and “What is your process for developing training materials,” many cases described an earlier event in the past in which the citizen science program’s training materials were developed. No evaluative processing of training results and subsequent instructional design revisions were apparent from any sequence in the data collection. More attention to the evaluative aspects of their training programs might create opportunities for just-in-time teaching and refinement of instruction about specific learning outcomes related to the measurement task. Clarifying knowledge gaps could have positive outcomes for data reliability.

Only one case reported using a pre- and post-test to gauge learning from training. Without a pre-training assessment, and in light of the previously gained skills that some citizen scientists brought to their citizen science effort, it was hard to attribute specific learning gains to the parameters of the training. An evaluative process that occurred during the data collection stage rather than the training stage of citizen science engagement for one case represented a different but equally valuable process for learner assessment. One case described their annual refresher quiz. An unacceptable score on this refresher quiz triggered data verification processes to check the reliability of this citizen scientists' data. This was in the context of water quality data collection where a sample of water collected with the citizen scientist’s measurement provided unequivocal data validation.

Learning assessment is an opportunity for citizen science programs because it lends quantitative data to support the training effort, which in turn, could support data reliability in citizen science. The development of a regional or national assessment related to identified categories of resource measurement could provide meta-analytical data about the success of training engagements for citizen scientists. Furthermore, it provides a very specific opportunity to respond to trainee knowledge gaps with just-in-time training. For example, published literature indicated that citizen scientists struggled with, specifically, the application of GPS and plot set-up skills (Newman, 2010). A post-training assessment or semi-annual assessment might forecast data reliability issues and provide an opportunity for supplemental training on this skill alone.

Just-in-time teaching that arises from participant evaluation of training is fodder for future curriculum improvement, creating a culture of continuous improvement rather than one in which developing training is a box that the organization checks off as it launches a new program. This is analogous to the trend in higher education for adaptive learning. When assessments are embedded throughout the learning process, the instructional outline is adapted to reinforce knowledge gaps during instructional time. Becker-Klein et al. (2016) developed an adaptive assessment tool for use in citizen science applications, although evidence of its use is not present in the literature. The analysis presented here suggests that such a tool is valuable to citizen science training since there remains an apparent gap in training evaluation and assessment.

Citizen Science Data Reliability

Some studies from the literature review indicated that citizen scientists are successful at collecting reliable data when tasked with a relatively simple data collection task (Smith, 2015, Crall et al., 2011, Koss et al., 2009; Kremen et al., 2010,). In an example from the literature, in the case of floral species identification, when identifying species of similar morphology (a more difficult task) as compared to identifying species with distinct morphological differences (a simpler task), the latter produced more reliable results (Crall, 2011). In one interview, the respondent expressed the following commentary when asked "Do you think the data collected by your citizen scientists could be used in scientific analysis? What leads you to this conclusion?"

> I do think so, but some measures are inherently going to have more error than other. The temperature of the stream and air are very reliable, but there is more variance in taxa richness because it depends on so many factors. Even though everyone is taught the same protocol there is observer bias.

This comment supports the literature conclusions that the reliability of citizen scientist-collected data may be related to the skill required to perform the data collection task (Danielsen et al., 2014; Schmeller et al., 2008).

A surprising outcome of this research is that more citizen science programs have QA/QC processes than are reported in the literature. An even more surprising, but perfectly rational conclusion was that photos are considered research-grade data. This analysis sheds light on the nuances of citizen science and its related training. Photo data are inherently reliable as long as citizen scientists can properly identify the location in which the photo was taken and the photo is clear enough for species identification. Water quality data are inherently analytical and can be verified with research grade laboratory QA/QC. Habitat assessment is the most variable and therefore potentially least reliable type of data that citizen scientists could collect. However, when multiple measurements characterize a single site, the broad characterization provides valuable information despite potential errors.

A major conclusion of this research is that categorical judgments about data reliability in citizen science are inappropriate. The literature already concluded that the demographics of citizen scientists do not matter to their data collection success (Danielsen et al., 2014; Schmeller et al., 2008). This dissertation suggests that the identity of *citizen science* is less relevant to the probability of data collection success than are the methods of resource monitoring. This supports the specific conclusions of Schmeller et al. (2008) who performed a large meta-analysis of monitoring protocols in five European countries to evaluate the assumption that citizen scientists cannot collect quality data. They concluded that the quality of citizen science data is more likely determined by survey design, analytical methodology, and communication skill rather than by a function of participant demography.

Another interesting theme that arose regarded the quality of photo data. One case said that their program and its scientist partners considered photos to be research-grade data. Other cases repeated those sentiments in less direct language. One described how the project founder had modified a computer algorithm designed to identify stellar constellations to identify sharks that had a freckling pattern on their heads. From just a photograph, the constellation of facial markings could identify not only the shark species but also the individual sharks. They used these data to track the locations and possible international travel routes of these sharks. This was a novel and creative way of expanding the use of technology tools to different science disciplines.

In the instances of terrestrial photo collection data, most cases used iNaturalist to support their photo data collection. iNaturalist is a cloud-based photo data storage software used most prominently for identification of plants, although iNaturalist does support species identification across a much wider range of organism types. When a citizen scientist uploads a photo to iNaturalist, the photo, whether identified by the uploader or not, is compared to the database of photos. iNaturalist suggests a species and critical thinking about the suggested species' range and the number of occurrences in the photograph location give predictive power to this process. Then, the identification may be promoted to a research-grade identification if "the community agrees on species-level identification or lower, i.e., when more than two-thirds of identifiers agree on+9 a taxon" (iNaturalist, 2018).

The main point in describing these identification processes is to illustrate that in these scenarios of citizen science, data collection engagement is accessible, requiring only a camera and the ability to upload the photo. A conclusion of this analysis is that this simplicity of training is apparently not related to data reliability. The data verification step is disconnected from the citizen scientists' engagement; and therefore, it is not related to their identity as a citizen scientist.

In the spectrum of citizen science engagement (Shirk et al., 2012), these citizen science engagements are contributory in nature. The citizen scientist comes in, collects the data, and exits the engagement. In the contributory model and when photos are collected, the fact that they are collected by citizens bears no effect on the research at hand. On the other end of the spectrum, in cases that are examples of co-created citizen science, citizen scientists participated in the full process of science including project design, data collection and analysis, and science communication about the results. In this latter scenario, the fact that it is citizen science is inherent to the process. This analysis indicates that either form of engagement has little bearing on the quality of the data collected as evidenced by the QA/QC reported. The literature does not make a distinction between these groups. While lumping all phenomena into a universal term of citizen science facilitates partnerships and resource sharing, it also poses a potential threat to some data collection efforts. Specifically, data collection efforts that have analytical QA/QC components, and data collection efforts that are photographic in nature do not deserve generalized apprehension about their data quality, as was reported in the literature.

Theoretical Alignment

As the interviewer, it was inspiring to hear how programs began from one person or a group of people who were concerned with an ecological dilemma in their local ecosystem. The tone of the interviewees, in all cases, was matter-of-fact and humble. Listening collectively to the nexus stories portrayed an aspect of American culture that is democratic and problem-solving. Democracy and problem-based learning are tenets of adult education. This analysis shows citizen science inheren9tly applies andragogical approaches to learning contexts involving adults.

When asked the semi-structured interview questions that specifically keyed into the tenets of adult education, respondent answers were self-evident. These questions were asked at the end of the interview script; and as interviewees paused to digest the language of education theory, it seemed the conversation was centered around these concepts all along. If the sample was larger, it would have been interesting to compare the response to these questions if asked at the beginning of the interview versus the end. This would be an interesting research question with mostly theoretical implications, but a primary conclusion is that andragogy is inherent to citizen science, whether or not citizen science participants have any idea of what this is.

While many cases reported continuing education in the form of field mentoring, one case provided regular supplemental training. In this latter case, the interview respondent emphasized repeatedly that citizen scientists could enter the data collection process with the knowledge they already had and seek additional training to expand their skills. This is an example of adult learners applying their prior knowledge to enter the citizen science engagement and then seeking additional knowledge as they are self-motivated to do so because the need for more knowledge becomes practical to advance their own knowledge and role as a citizen scientist. One case offered asynchronous training facilitated by web-based instructional videos, which facilitated flexible recruitment and offered always-available continuing education. The use of instructional media could expand the concept of continuing education for all citizen science programs. Any field mentoring event may be recorded for future viewing, for example.

In a case involving a fishing community and the regional river monitoring program there, it was the concern for fishing and a cultural heritage that drew people to the citizen science effort. This interviewee captured this motivational phenomenon with these words when asked, “Describe how the new learning from training is applied to the citizen scientists’ world? How do you activate citizen scientists’ prior knowledge in training?

> We have many recreational experiences around water, living near the river, memories of having fun or the cultural and historical significance of the river. Many people learned how to fish as children, or they like to fish. After attending training and participating, people understand how these tiny animals we measure [macroinvertebrates] are food for the fish and the water quality is important to humans, fish, and their animal food sources.

The code *social learning* emerged but was not predicted prior to analysis. Respondents expressed how important an element of community was to the motivation and retention of the citizen scientists. In one case, the entire citizen science effort was a cohort of graduates from the state Master Naturalist Program, a program that is sponsored in several states by the extension office of the state university. This small groups invented their citizen science effort to satisfy the service requirement for their Master Naturalist certification. After receiving elementary training on invasive species in the certification program, they trained themselves on different invasive woody species, each taking the lead on one species or aspect of the project. They would then go out into the field, mentor each other, and perform the data collection, which in this case also involved the removal of the invasive species measured. At one point the respondent said that motivating the group came down to an email saying, "Come on guys, we better get out there."

This shows that the social aspect of the citizen science engagement is the driving reason for the program’s existence. The ecological dilemma is there and will be there whether or not someone takes an interest in measuring it. Therefore, it must be something else that makes citizen science happen. It was apparent from the analysis of interview data specifically, that social learning was an inherent part of the citizen science phenomenon. As such, training was just one step in the engagement. Attending the trainings, performing the data collection task, and attending continuing education field events were all learning experiences enhanced by social engagement.

Bandura’s (1992) social cognitive theory posited agency as a central aspect that connects thinking, doing, and learning. The environment and the people within the environment provide stimulus for thought and action; and in so doing, provide a unidirectional landscape for continual mental processing and behavioral action. While great evidence for andragogy exists in these data, clearly social learning is also at work.

Limitations of the Study

A post hoc query of the CitSci.org database projects using the search term *plant* returned 10% of the projects in the membership. Two of 22 cases in this multiple case study measured flora (9%). This is a reasonable approximation of the relative plant cases in the purposive sample. Nonetheless, a larger sample would likely describe this subset of cases in greater detail. Since the researcher only solicited the CitSci.org database for a purposive sample, it is likely that plant-specific citizen science programs were under-represented because the leading data management tool for botanists is iNaturalist.

The literature review did not predict the plethora of photo-based citizen science programs that entered the multiple case study. These programs had minimal training, and several cases replied to the research solicitation by saying they didn't have much to offer. The researcher encouraged their participation by saying in so many words *that's still data*. As a result, the bimodal characterization of citizen science training became apparent in the analysis. If these organizations had declined to participate, this would have been a gap in this dissertation's findings. Nonetheless, it is possible that a number of potential cases perceived that they did not qualify on account of their lean training resources. Therefore, the null cases of little-to-no training are likely under-represented in this sample.

The researcher did not directly participate in or observe any trainings for the multiple case study. As such, all data collected were second-hand accounts of training experiences lived by other people or primary documentation. The three sequences in this methodology aided triangulation of these data in the absence of direct observation. Nonetheless, the researcher is an experienced educator and thus could have lent expert interpretation to the trainings experienced firsthand.

Implications for Theory and Research

In the cases involving marine fauna data collection, marine citizen scientists brought their previously acquired skills to the citizen science effort, a tenet of adult learning theory. The concepts of training and assessment were reduced because there were no procedural skills to impart in a training beyond the indication of sites to monitor and instructions on uploading photo data. When asked "Why do you think you need a training program for your citizen scientists," the response followed the bimodal nature of data collection found in this analysis, with photo collection cases noting that little training was required, and all other data collection cases reporting that training was necessary for procedural knowledge gain of the data collection task.

Two cases made references to how the training itself increased science literacy and motivated trainees to get out to do the data collection. The subject of science literacy is a major theme in the citizen science literature. It was not the subject of this inquiry, but it did enter the conversations several times, especially when referencing the codes for andragogy.

The data validation of both marine and terrestrial photo data collection occurred in a phase of research that followed the citizen scientists' engagement. Although citizen scientists identified the species, ultimately, the species validation occurred using software or professional scientific identification of the photo. The photo collection citizen science programs described in this multiple case study are examples of contributory citizen science in which the citizen scientists enter and exit the citizen science process at the data collection phase.

Following the spectrum of citizen science engagement (Shirk et al., 2012), it is likely that more science literacy outcomes are achieved when citizen scientists are involved in collaborative and co-created citizen science projects. This suggests an apparent trade-off. Engagement in contributory citizen science might, by way of the methods employed, result in more data reliability but fewer science literacy gains among participants. This suggestion is predicated on the conclusion from this multiple case study that the citizen science identity of data collection efforts is less relevant to the probability of data collection success than are the methods or resource monitored.

The topic of scholarly publication was one of the least conclusive elements of this analysis. Theobald et al., (2014) found that 30% of citizen science projects queried collected publishable data, but the data of only 12% of projects appeared in the peer-reviewed literature. The results of this dissertation indicated similar findings. The document analysis revealed no peer-reviewed publications as extra resources for training curricula. The surveys more confidently affirmed scholarly publication than the semi-structured interviews indicated, but no specific paper was ever mentioned and it seemed, on the whole, that even the citizen science leaders, who were predominantly paid employees of non-profit organizations, were not part of the scholarly publication process, even though many were responsible for producing data interpretations for their partners, funders, citizen scientists, policy makers, and communities. As such, the case contacts who were the respondents in this research were engaged in the citizen science spectrum at the levels of collaborative and co-created citizen science, but not at the level of collegial contributions (Shirk et al., 2012).

Considering the impressive but unpublished QA/QC data collected by citizen science programs in this multiple case study, a huge opportunity for theory and research is more analysis and publication of these large datasets, with parametric power impossible in case study research. A follow-up study could pursue quantitative meta-analysis of this QA/QC data across programs. This would be possible because all the cases that reported QA/QC data were collecting water quality data. Therefore, their measurement parameters could be analyzed across cases, comparing the relative accuracy of citizen scientists' data to lab-generated data. Although some studies exist that make the comparison between citizen science data and professional scientist-collected data, these were all cases involving field simulations of plant identification training, not comparisons of water chemistry data, or other data types actually collected in a citizen science effort.

Implications for Practice

When asked "Do you think your training could be improved? In what ways," all interviewees expressed a sentiment that any training initiative could be improved. Specifically, they thought more hands-on activities and more repetition with the measurements would lead to increased learning. One case described a training space that had a stream running right through the classroom (dream big!). In other cases, respondents highlighted the field training that followed the in-class training. Clearly, hands-on engagement is a strength to retain for all citizen science training programs.

A repetitive theme in the data collected includes instructions for using data management tools. Several cases had step-by-step instructions for using apps, including iNaturalist, Citsci.org, WildBook, and Field Scope despite the presence of such instruction on the data storage websites. iNaturalist has an impressive training video resource, but it is not being used by the cases in this analysis. There is value in having project-specific training tools. To honor this, data management platforms might consider reviewing and curating training videos produced by their users. Similar to how CitSci.org populates a pick-list of variables so that multiple projects may use similar parameters for meta-analysis across projects, a central location for all data management tutorials could be quite valuable and efficient. Simple repetition, as noted by case respondents, provides great support for learners of any procedural knowledge, including platform learners.

In the same vein, a central repository of training media has the potential to assist the learning curve for users by providing instant resources in a broad spectrum of citizen science disciplines. It may also expand citizen science programs' capacity by providing cloud-access to citizen science programs' whole features. The findings of this investigation encourage aggregation in citizen science programming because this affords greater resources to apply to more ecosystems. For example, some cases sponsored training materials that influence citizen science programs on both the Atlantic and Pacific coasts of the United States. In this multiple case study, there were two cases in which one case cited some of the training resources of a case arising from a larger organization. This movement of open access to data and information resources among the citizen science community is already afoot. Researchers should take note and consider meta-analyses that aggregate citizen science data for quantitative analysis. Scholarly focus facilitates funding opportunities and support for on-the-ground citizen science programs. The year 2019 is the decade anniversary of the PPSR funding that gave rise to exponential interest in citizen science in America. It is an appropriate time to reflect on the American citizen science movement.

Interviewees responded to the questions "Does anyone on your training team have specific training or credentials as an educator of any population of individuals? If yes, please describe these credentials." One case reported that their staff included a trained classroom teacher. Several reported the involvement of professors who likely had subject-specific degrees; and others reported that staff had environmental education experience. A practical opportunity might be the alignment of citizen science with environmental education as a discipline.

The credentialing of environmental educators has been increasing in the last two decades, including certification programming offered by non-profits and degree programs offered by academic institutions. For example, environmental education master's programs exist at American institutions of higher education, including Stanford University, Bard College, Antioch College, and Western Washington University. Connecting with this adjacent community of environmental stewards might increase academic and professional credentialing for citizen science programs. It is unfortunate that semantics divide us because the general learning outcome for both environmental education and citizen science is an awareness and scientific perspective towards environmental dilemmas of the modern age.

To environmental education, citizen science provides the additional parameters of procedural learning and civic engagement in scientific research. Instruction of procedural learning is the focus of citizen science trainings. This is the strength that the cases in this multiple case study impart; they are able to educate their participants about the data collection efforts. The environmental education community can and does facilitate the recruitment of new citizen scientists by inciting their motivation to care, by couching the learning in a sense of urgency for the health of natural ecosystems on the planet, and by imparting the ecological narrative, which is called interpretation in environmental education. Where citizen science leaders excel in procedural learning, environmental educators excel in science communication. In these ways and likely many more, alignment between the citizen science and environmental education communities may be mutually beneficial.

With regard to the handling of training evaluation feedback, an opportunity exists to quantify training feedback. Although this may not seem immediately necessary for the success of the citizen science programs, the valuation of the quality of the training through evaluative feedback is one way that citizen science programs can promote reliability and confidence in citizen science data collection. For example, if an evaluative feedback metric indicated that citizen science trainees did not feel prepared upon completing the requisite training, this would be an important metric in the discussion of data reliability. If post-training evaluations indicate that citizen science trainees don't feel prepared, one might conclude that the data they will collect might require additional quality analysis. Likewise, assessment can indicate knowledge gaps that may be addressed through just-in-time teaching, continuing education, and training revision. Finally, public reporting on evaluative training feedback might increase transparency and thus increase the perception of data reliability among land managers and scientists who are wary of data collected by citizen scientists.

Recommendations for Further Research

Future investigations should probe the motivational relationship between the proximity of citizen science programs to hobbies and livelihoods that involve the same habitats and species. *Sense of place* was a topic of great scholarly interest in recent decades. Scholars might find renewed interest in this sense-of-place phenomena when viewed from the lens of citizen science. This future research may shed light on adult learning theory in the context of citizen science. We can already characterize the adult learner as one who is personally motivated, sees practical value in the application of the learning, who has previous experiences from which to draw knowledge in this new context of learning, and one who desires to solve real-world problems (Merrill, 2002). This dissertation research measured the presence of andragogy in citizen science programs. Future research could apply the tenets of adult learning theory to citizen science recruitment and retention.

It is possible that the lag in assessment is a function of the volunteerism tied to citizen science. Most citizen scientists are volunteers, but they also may be students, concerned citizens, indigenous groups, or private land owners. The United States defines citizen scientists as individuals lacking a terminal degree in a scientific discipline (Citizen Science Central - The Cornell Lab of Ornithology, 2017). This definition captures the true identity of the citizen scientists without layering on assumptions of volunteerism. However, it is possible that assessment lags behind instructional development because negative assessment results may decrease volunteerism within the organization, which might influence funding streams. This is a topic that should be investigated further to unlock the correlation between assessment and volunteerism.

Finally, as expressed throughout this dissertation, this investigation reveals data regarding the reliability of citizen-scientist-collected data that is available, but not published. As an immediate call for engagement, citizen science programs should rise up to the collegial task of publishing the data they collect about the reliability of their citizen scientists' data. Many managers expressed that their programs' primary goal was to inform land management decisions. This is accomplished through grey literature and semi-annual reporting. Publication in the scholarly literature affects the field in a more philosophical sense by showing the adjacent academic community that the work of citizen scientists can be scientifically sound as well as practically important to solve the environmental dilemmas of modern times.

Conclusion

This dissertation characterized trainings designed to teach citizen scientists how to collect ecological data in natural land settings through a sequenced methodology of data analysis, survey, and semi-structured interview. Deductive codes guided a directed content analysis of data collected. The results of the analysis indicated strong alignment with andragogy and social learning theory. The theory of backwards design was not well-supported.

Training design followed a bimodal distribution related to the type of data collected. When photo data was collected, little training existed. Citizen scientists brought prior skills to the task but did not need to gain new procedural learning to complete their data collection task. When more complex measurements were collected by citizen scientists, classroom and field mentoring facilitated learning. This classroom learning was didactic in nature but complimented by hands-on field components that citizen science leaders cited as important strengths to retain in their existing programming.

Through survey and semi-structured interview, citizen science leaders described their perception of the reliability of their citizen scientists' data collection efforts. Photo and water quality data were validated with computer technologies and quantitative analytical techniques. Therefore, the perception of data reliability among managers of these data types was supported by quantitative data analysis. Terrestrial data had a range of reliability qualifications including video and paper quizzing, field observation of methods implemented, periodic data checks, and follow-up mentoring when data quality was poor. Aggregating all citizen science training and data reliability concerns into one scholarly discussion does not appropriately describe the citizen science training environment.

The greatest opportunity for citizen science programs is the implementation or expansion of training program evaluation. This analysis revealed that programs had clear objectives and well-vetted training resources but no plan for gathering, handling, responding to, and reporting feedback from trainees, which could inform training leaders of knowledge gaps before the data collection process begins and potentially address data collection errors before they occur, thereby increasing data reliability. Data reliability concerns are the primary hindrance to citizen science proliferation in America. This investigation characterized existing citizen science training programs to shed light on the nature of training and data collection in citizen science. The themes described here may guide and improve future research and practical efforts in citizen science.

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Appendix A: Informed Consent – Document Analysis

Please review this information before proceeding.

Title of the Study

Training citizen scientists: A qualitative, comparative, multiple case study to identify theoretical and instructional design themes in current citizen science training initiatives

Investigator: Maggie Gaddis, PhD Candidate, University of the Rockies
Contact information of the investigator: [redacted]
Dissertation Chair: Dr. Kimberly Fonteix, [redacted]
If you have any questions regarding your participation in the study or if you want to verify the authenticity of the study, please contact the University of the Rockies IRB Chair [redacted]

Purpose of the Study

The purpose of this qualitative comparative multiple case study is to identify patterns and themes in content, instructional design, theoretical alignment, and perceived efficacy of training for citizen scientists tasked with collecting ecological data in the field. The sequential design of this dissertation includes document analysis, a survey, and a semi-structured interview. This is the case identification and document analysis component of this dissertation.

Procedure to Be Followed – After initial email from organization in response to research solicitation

Please review this informed consent document. If you agree, sign your name where prompted to accept the informed consent. Attach the informed consent as the cover letter of any materials you compile for the document analysis. If you do not agree to participate, contact the research administrator to withdraw your participation from the study.

You must be 21 years or older to participate as an organizational representative.

Level of Risk or Discomfort for Research Subjects

Participation in this case identification and document analysis is completely voluntary and you may elect to stop participating at any time, for any reason, and without penalty for doing so. This process does not require you to reveal any personal or identity information. This research investigates the characteristics of the organization's citizen science program and its participants. The researcher is not collecting data on human subjects, but rather on the citizen science training programs in which humans might engage. There should be no risk or discomfort involved in participating in this research.

Benefits of the Study to the Subjects and Community

Citizen scientists are volunteers who participate in scientific activities under the guidance of professional scientists and organizations. The work of citizen scientists greatly expands the data collection possibilities in natural resource management, fosters a sense of place, and increases science literacy among participants and their social communities. The connection between citizen science training design and participant learning is not described in the literature. The general problem is data collected by citizen scientists is often viewed as unreliable by the scientists and land managers who might use it. The specific problem is the absence of educational training measurement in citizen science program design and analysis with which to ascertain the learning gains of trained citizen scientists. More research is needed to investigate how and what citizen scientists learn in these informal training environments. Your participation in this research may further the cause of improving training for citizen scientists.

Duration of Subjects' Participation in the Study

This stage of the research does not involve a specific time engagement. The duration depends on how long it takes to compile the organization's training materials. This might be as simple as sharing a URL with the researcher, or it might involve something more complicated, like the photography and/or copying of paper-based training materials and tools. This all depends on the way your organization curates the training materials. The subsequent data collection components, the survey and the semi-structured interview each will take one hour to complete.

Compensation for participation in the study

Participation in this case identification and document analysis is voluntary and no compensation is afforded.

If you agree to participate, please sign your name and proceed with the case identification and document checklist. If you do not agree to participate, contact the administrator to withdraw your participation from the study.

I understand this informed consent agreement. I also confirm that I have the authority to represent my organization and share the requested information and/or documents with the researcher.

______________________________	______________________________
Participant Name	Participant Signature
______________________________	______________________________
Organization Name	Date

Appendix B: Informed Consent – Survey

Please review this information before proceeding.

Title of the Study

Training citizen scientists: A qualitative, comparative, multiple case study to identify theoretical and instructional design themes in current citizen science training initiatives

Investigator: Maggie Gaddis, PhD Candidate, University of the Rockies
Contact information of the investigator: [redacted]
Dissertation Chair: Dr. Kimberly Fonteix, [redacted]

If you have any questions regarding your participation in the study or if you want to verify the authenticity of the study, please contact the University of the Rockies IRB Chair at [redacted]

Purpose of the Study

The purpose of this qualitative comparative multiple case study is to identify patterns and themes in content, instructional design, theoretical alignment, and perceived efficacy of training for citizen scientists tasked with collecting ecological data in the field. The sequential design of this dissertation includes document analysis, a survey, and semi-structured interviews. This is the survey component of this dissertation.

Procedure to Be Followed - After your organization submits training documents, and upon receiving an email from the researcher

Please review this informed consent document. If you agree, sign your name where prompted to accept the informed consent. Return this informed consent via email and you will be sent the survey link in response. If you do not agree to participate, contact the research administrator to withdraw your participation from the study. You may close your browser at any time to cancel your participation before you submit the survey. You may decline answering any question included in the survey.

You must be 21 years or older to participate as an organizational representative.

Level of Risk or Discomfort for Research Subjects

This survey is completely voluntary. You reserve the right to withdraw from the study at any time, for any reason, and without penalty for doing so. No questions require you to reveal any personal or identity information. This research investigates the characteristics of the organization's citizen science program and its participants. The researcher is not collecting data on human subjects, but rather on the citizen science training programs in which humans might engage. The majority of the questions in this survey address the characteristics of the organization's citizen science program and the general demographics of its participants. There should be no risk or discomfort involved in participating in this research.

Benefits of the Study to the Subjects and Community

Citizen scientists are volunteers who participate in scientific activities under the guidance of professional scientists and organizations. The work of citizen scientists greatly expands the data collection possibilities in natural resource management, fosters a sense of place, and increases science literacy among participants and their social communities. The connection between citizen science training design and participant learning is not described in the literature. The general problem is data collected by citizen scientists is often viewed as unreliable by the scientists and land managers who might use it. The specific problem is the absence of educational training measurement in citizen science program design and analysis with which to ascertain the learning gains of trained citizen scientists. More research is needed to investigate how and what citizen scientists learn in these informal training environments. Your participation in this research may further the cause of improving training for citizen scientists.

Duration of Subjects' Participation in the Study

Your organization has already completed the case identification and document checklist. The survey will take one hour to complete. The subsequent semi-structured interview will also take one hour to complete.

Compensation for participation in the study

This survey is voluntary and no compensation is afforded.

If you agree to participate, please sign your name, return this consent via email, and proceed with the

survey, which will be emailed to you. If you do not agree to participate, contact the research administrator to withdraw your participation from the study.

I understand this informed consent agreement. I also confirm that I have the authority to represent my organization and share the requested information and/or documents with the researcher.

______________________________ ______________________________

Participant Name Participant Signature

______________________________ ______________________________

Organization Name Date

Appendix C: Informed Consent – Semi-Structured Interview

Please review this information before proceeding.

Title of the Study

Training citizen scientists: A qualitative, comparative, multiple case study to identify theoretical and instructional design themes in current citizen science training initiatives

Investigator: Maggie Gaddis, PhD Candidate, University of the Rockies
Contact information of the investigator: [redacted]
Dissertation Chair: Dr. Kimberly Fonteix, [redacted]

If you have any questions regarding your participation in the study or if you want to verify the authenticity of the study, please contact the University of the Rockies IRB Chair at [redacted]

Purpose of the Study

The purpose of this qualitative comparative multiple case study is to identify patterns and themes in content, instructional design, theoretical alignment, and perceived efficacy of training for citizen scientists tasked with collecting ecological data in the field. The sequential design of this dissertation includes document analysis, a survey, and semi-structured interviews. This is the survey component of this dissertation.

Procedure to Be Followed - After survey completion, and upon receiving a scheduling email from the researcher

Please review this informed consent document. If you agree, sign your name where prompted to accept the informed consent. Attach the informed consent to the email in which you confirm your interview date and time. If you do not agree with this informed consent, contact the research administrator to withdraw your participation from the study.

You may terminate your participation in this research at any time by declining your interview appointment. You have a right to refuse to answer any question, for any reason and without penalty or further questioning. Your responses will be recorded for further analysis if you check the box indicating your approval on the signature page.

You must be 21 years or older to participate as an organizational representative.

Level of Risk or Discomfort for Research Subjects

This survey is completely voluntary. You reserve the right to withdraw from the study at any time, for any reason, and without penalty for doing so. No questions require you to reveal any personal or identity information. This research investigates the characteristics of the organization's citizen science program and its participants. The researcher is not collecting data on human subjects, but rather on the citizen science training programs in which humans might engage. The majority of the questions in this survey address the characteristics of the organization's citizen science program and the general demographics of its participants. There should be no risk or discomfort involved in participating in this research.

Benefits of the Study to the Subjects and Community

Citizen scientists are volunteers who participate in scientific activities under the guidance of professional scientists and organizations. The work of citizen scientists greatly expands the data collection possibilities in natural resource management, fosters a sense of place, and increases science literacy among participants and their social communities. The connection between citizen science training design and participant learning is not described in the literature. The general problem is data collected by citizen scientists is often viewed as unreliable by the scientists and land managers who might use it. The specific problem is the absence of educational training measurement in citizen science program design and analysis with which to ascertain the learning gains of trained citizen scientists. More research is needed to investigate how and what citizen scientists learn in these informal training environments. Your participation in this research may further the cause of improving training for citizen scientists.

Duration of Subjects' Participation in the Study

Your organization has already completed the case identification and document checklist. The survey will take one hour to complete. The subsequent semi-structured interview will also take one hour to complete.

Compensation for participation in the study

This survey is voluntary and no compensation is afforded.

If you agree to participate, please sign your name and proceed with the semi-structured interview appointment scheduling. If you do not agree to participate, contact the administrator to withdraw your participation from the study.

I understand this informed consent agreement. I also confirm that I have the authority to represent my organization and share the requested information and/or documents with the researcher.

☐ I agree to have my interview recorded.

______________________________ ______________________________

Participant Name Participant Signature

______________________________ ______________________________

Organization Name Date

Appendix D: Case Identification and Document Checklist

Case Identification and Document Analysis Checklist

Case Name			
Case Contact Name			
Case Contact Email			
Case Website			
Case Training File Location (web/paper)			
Informed Consent Signed? (mark when complete)	Yes		
Case Data Collection Progress (mark when complete)	Document Analysis	Survey	Semi-Structured Interview
File Name	File Type (doc, ppt, mov, pdf, etc.)	File Location (URL/ Hard Drive location)	File Description - link to survey categories (Training, Evaluation, Learning Assessment, Program Design, Data Collection basic communication)

Appendix E: Survey Instrument

Survey Questions and Possible Responses

Question Text	**Response**
What is your relationship to the organization that hosts the citizen science program that is the subject of this inquiry?	open response
What is the tax status of your organization?	501(c)3 Government agency University-affiliated Private organization
How many employees does your organization have?	1-3 4-10 11-30 More than 30
Is your organization a chapter or branch of a larger organization?	Y/N
How many volunteers total does your organization engage, on average per year?	0-10 11-50 50-100 100+ 1,000+
How many years have you engaged volunteers in work that involves data collection (whether or not you called it "citizen science")?	enter number
How many volunteers participate in data collection activities?	enter number
How many years have you had a formal citizen science program?	enter number
How many hours do citizen scientists contribute per year (total for all volunteers)?	enter number
Describe your citizen scientists. You can select different categorizations. Order them according to abundance with the most abundance volunteer age group as #1 and the least abundant is a #4.	Youth under 18 18-30 31-50 50+
Do you train your citizen scientists?	Y/N [If no, skip the rest of the questions with heading ending in Training Materials]
Do you train your citizen scientists? Please describe the training.	open response
Do you produce the training materials?	Y/N

Do you produce the training materials?	We have produced training materials in the past, but we no longer do this. We produce training materials regularly in response to learning needs as they arise (ad-hoc training). We produce training materials only when we start new citizen science programs (formal training). We have never produced training resources. We use training resources produced by an outside authority? other
To what degree does your organization use outside resources to train citizen scientists? On a scale of 0-7, 7 is 100% of the training materials, 0 is 0% of the training materials.	Likert scale
If you use training resources produced by an outside authority, please provide identifying information here and describe these resources.	open response
How are your training materials disseminated to citizen scientists?	We give our trainees printed materials. We email them after we recruit the volunteers. We have them always available on our website, YouTube channel, or other web-based location. We have them in cloud storage and send links to share them. We have a secured login area of our website.
Written training materials: Do you train your citizen scientists with written training resources? [If no, skip the following questions tagged with the phrase written training materials].	Y/N
Written training materials: What kind(s) of written training materials do you provide for your citizen scientists [check all that apply]?	Written training materials on paper Written training materials in electronic files (e.g. presentation files, pdf, word documents, etc.)

	We compile the resources into our own training manual. Training materials published by an outside authority
Written training materials: If you use written training materials published by an outside authority, please write in the title and author here, or write N/A	open response
Written training materials: Please describe the written materials you provide for your citizen scientists for training purposes?	open response
Written training materials: Do your written training materials include photos?	Y/N
Written training materials: Do your citizen scientists help to author the written training materials?	Y/N
Multimedia training materials: Do you train your citizen scientists with multimedia training resources?	Y/N [If no, skip the following questions tagged with the phrase multimedia training materials].
Multimedia training materials: What kind(s) of multimedia training materials do you provide for your citizen scientists [check all that apply]?	We offer our volunteers no multimedia training materials [If no, skip the rest of the multimedia training materials questions]. Webpages designed for the training effort Videos Audio recordings Web-based tutorials Television programming Digital presentations Other, please describe:
Multimedia training materials: If you use multimedia training materials published by an outside authority, please write in the title and author here, or write N/A	open response
Multimedia training materials: Please describe the multimedia training materials you provide for your citizen scientists for training purposes?	open response
Evaluation: Do your citizen scientists provide evaluative feedback for training improvement?	Y/N
Evaluation: If your citizen scientists provide evaluative feedback for training improvement, how is it provided?	By informal request for email or verbal response Citizen scientists submit an evaluation form we provide for them

	Other: please describe [open response]
Evaluation: Please describe how your organization handles evaluative feedback once it is received?	open response
Citizen Scientist Learning Assessment: Do you give your citizen scientists any learning assessments?	Y/N
Citizen Scientist Learning Assessment: Do you give your citizen scientists any learning assessments?	a written quiz a verbal question and answer situation to validate knowledge citizen scientists have to provide a physical demonstration of data collection protocol citizen scientists have to write out the protocol after learning it in an experiential context other, please describe: [open response]
Citizen Scientist Learning Assessment: Do you use a pre- and post-test to measure citizen science learning outcomes? Pre- and post-tests are analogous assessments that are given before and after training to measure the learning gains during the training.	Y/N
Citizen Scientist Learning Assessment: Describe how you know that your training is providing the knowledge gains you intend?	open response
Citizen Scientist Learning Assessment: Do you think your training could be improved? In what ways?	open response
Citizen Scientist Data Collection: Do you think your citizen scientists are collecting reliable data?	Y/N
Citizen Scientist Data Collection: How reliable do you think the data is that your citizen scientists collect? On a scale of 0-7, 7 is 100% reliable, 0 is 0% not reliable at all.	Likert scale
Citizen Scientist Data Collection: Do you think the data collected by your citizen scientists could be used in scientific analysis? On a scale of 0-7, 7 is absolutely yes, 0 is definitely not.	Likert scale
Citizen Scientist Data Collection: Is the data collected by your citizen scientists currently used by scientists? If so, how?	open response
Citizen Scientist Data Reliability: Describe the process by which you teach your citizen scientists to collect data.	open response

Citizen Scientist Data Collection: How is the data collected by your citizen scientists? [check all that apply]	Data are recorded on paper. Data are recorded on paper and transferred to digital forms later. Data are recorded digitally in the field. Data are recorded using a technology platform. Data are recorded on citizen scientists' phones.
Citizen Scientist Data Collection: What happens to the data after you collect it? [check all that apply]	Data are stored on a computer. Data are stored on a paper file. Data are encrypted for security. Data are shared with interested parties upon request. Data are shared through an open source technology platform. Data are shared on our organization website. Data are shared with resource and land managers.
If you use a technology platform to support your data collection, please note which one here, or write N/A.	open response
Citizen Scientist Data Collection: Who analyzes the results of the data collection effort with statistical analysis?	staff within our organization the scientists with whom the organization partners an external organization to whom we send the data the data are not analyzed other, please describe [open response]
Citizen Scientist Data Collection: Describe the data your citizen scientists collect? [check all that apply]	Plant data Animal data Habitat area/condition data Water quality data Weather data Ecological parameters Marine data Aquatic data Terrestrial data Restoration data User data Other, please describe [open response]

Citizen Science Program Design: What are the objectives of your citizen science program? Please copy them verbatim here.	open response
Citizen Science Training Design: Does anyone on your training team have specific training or credentials as an educator of any population of individuals?	Y/N If yes, please describe these credentials. [open response]
Citizen Science Training Design: Why do you think you need a training program for your citizen scientists?	open response
Citizen Science Training Design: Please describe how your citizen scientists are mentored, if at all. If they are not mentored, please note that.	open response
Citizen Science Training Design: If you do not have a formal training program, how do you impart the procedural knowledge needed to complete the data collection task?	open response
Citizen Science Training Design: If you could implement any training program you can envision, what would it look like? Why do you think this would be the best design?	open response
Citizen Science Training Design: How do you motivate citizen scientists to persist in their role?	open response
Citizen Science Training Design: Describe how, if ever, citizen scientists observe a demonstration of their data collection task? If no demonstration occurs, please note that.	open response
Citizen Science Training Design: Describe how the new learning from training is applied to the citizen scientists' world?	open response
Citizen Science Training Design: How do you activate citizen scientists' prior knowledge in training?	open response
Citizen Science Training Design: How do you engage citizen scientists' in solving real world problems?	open response

Appendix F: Semi-Structured Interview Questions

Question Text	**Response**
How do you train your citizen scientists?	open response
What is your process for developing training materials?	open response
If you use training resources produced by an outside authority, who is this? How did you encounter these training materials for the first time? What kinds of training resources are available? What kinds of professional development or on-going support does the outside authority provide?	open response
How are your training materials disseminated to citizen scientists? Is this an on-going process, or a one-time sharing of all the resources available, or some other arrangement?	open response
Written training materials: Please describe the written materials you provide for your citizen scientists for training purposes? Do you disseminate these on paper or by electronic file? Do these paper files include photos?	open response
Written training materials: Do your citizen scientists help to author the written training materials? How do they participate in their own education process?	open response
Multimedia training materials: What kind(s) of multimedia training materials do you provide for your citizen scientists?	open response
Multimedia training materials: Please describe the multimedia training materials you provide for your citizen scientists for training purposes? How are they delivered? Do they reside in an openly accessible web location? Do you need a password to access them? Can your citizen scientists edit, add, or delete multimedia training resources from wherever they are stored?	open response
Evaluation: How do your citizen scientists provide evaluative feedback for training improvement?	open response
Evaluation: Please describe how your organization handles evaluative feedback once it is received? Is there one person who fields this feedback privately? Does it come into a public forum where anyone can react to it and add comments?	open response
Citizen Scientist Learning Assessment: How do you assess the learning of your citizen scientists?	open response
Citizen Scientist Learning Assessment: Do you use a pre- and post-test to measure citizen science learning outcomes? Pre- and post-tests are analogous assessments that are given before and after training to measure the learning gains during the training.	open response
Citizen Scientist Learning Assessment: Describe how you know that your training is providing the knowledge gains you intend?	open response

Citizen Scientist Learning Assessment: Do you think your training could be improved? In what ways?	open response
Citizen Scientist Data Collection: Do you think your citizen scientists are collecting reliable data? What leads you to this conclusion?	open response
Citizen Scientist Data Collection: How reliable do you think the data is that your citizen scientists collect? How do you quantify this?	open response
Citizen Scientist Data Collection: Do you think the data collected by your citizen scientists could be used in scientific analysis? What leads you to this conclusion?	open response
Citizen Scientist Data Collection: Is the data collected by your citizen scientists currently used by scientists? If so, how?	open response
Citizen Scientist Data Reliability: Describe the process by which you teach your citizen scientists to collect data.	open response
Citizen Scientist Data Collection: How is the data collected by your citizen scientists? Describe the whole process from initiation to storage.	open response
Citizen Scientist Data Collection: What happens to the data after you collect it?	open response
Citizen Scientist Data Collection: Who analyzes the results of the data collection effort with statistical analysis? Is it someone within your organization? Does one of your partner organizations or scientists analyze the data?	open response
Citizen Scientist Data Collection: Describe the data your citizen scientists collect. What kinds of data, in what physical contexts?	open response
Citizen Science Program Design: Describe how your citizen science program started.	open response
Citizen Science Program Design: What are the objectives of your citizen science program?	open response
Citizen Science Training Design: Does anyone on your training team have specific training or credentials as an educator of any population of individuals? If yes, please describe these credentials.	open response
Citizen Science Training Design: Why do you think you need a training program for your citizen scientists?	open response
Citizen Science Training Design: Please describe how your citizen scientists are mentored, if at all. If they are not mentored, please note that.	open response
Citizen Science Training Design: If you do not have a formal training program, how do you impart the procedural knowledge needed to complete the data collection task?	open response
Citizen Science Training Design: If you could implement any training program you can envision, what would it look like? Why do you think this would be the best design?	open response

Citizen Science Training Design: How do you motivate citizen scientists to persist in their role?	open response
Citizen Science Training Design: Describe how, if ever, citizen scientists observe a demonstration of their data collection task? If no demonstration occurs, please note that.	open response
Citizen Science Training Design: Describe how the new learning from training is applied to the citizen scientists' world?	open response
Citizen Science Training Design: How do you activate citizen scientists' prior knowledge in training?	open response
Citizen Science Training Design: How do you engage citizen scientists in solving real world problems?	open response