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The Influence of a Citizen Science Project: Student Attitudes, Sense of Place, and Understanding of Science Practices

Amy Lorenz
University of Wyoming

The Influence of a Citizen Science Project:
Student Attitudes, Sense of Place, and Understanding of Science Practices

By

Amy Lorenz

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Masters Committee:

Professor Ana Houseal, Chair
Professor Brian Barber
Robert Fuhrmann, M.S., National Park Service
Shelby Jones, Ph.D., Gardiner Public Schools

Abstract

Citizen science is a form of public participation in scientific research in which volunteers can engage with scientists in authentic research projects. Citizen science projects have been studied to understand participant and scientist motivations and outcomes, particularly in scientific literacy and attitudes. Recently, citizen science projects have become more common in classroom settings, but the few studies document these outcomes using robust methodology. The current study was developed to measure local high school students' understanding of science practices, attitudes toward science, and sense of place during a semester-long citizen science project in Yellowstone National Park using a mixed-methods design. Qualitative interviews revealed rich insight into students' sense of place, attitudes toward science, understanding of science practices and nature of science, and impressions of citizen science. Results indicated that students in this gateway community exhibited place attachment and an increased understanding of place after participating in a PhotoPoints project. Many attitudes shifted to reveal their enjoyment of science through this project. Students displayed an increased understanding of scientific process, but maintained many misconceptions about the nature of science. Students also revealed that their impressions of citizen science include the value of citizen perspective to scientific research. These findings supported the hypothesis that citizen science projects can influence students' scientific knowledge, sense of place, and attitudes. Additionally, students' impressions of citizen science suggest this practice may contribute to democratizing science in classrooms. Instead of considering the influence of citizen science on individual dimensions, this study suggests that citizen science can be used as holistic, place-based tool to connect these dimensions and develop the whole learner.

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CHAPTER ONE

Introduction

Citizen science engages volunteers in scientific research and connects the public with professional researchers (Dickinson et al., 2012; Raddick et al., 2013). The practice of citizen science covers diverse fields of study and methodologies including analyzing online datasets, collecting field-based ecological data, and observing animal behavior (Raddick et al., 2013; Cronje, Rohlinger, Crall, & Newman, 2011; Evans et al., 2005). The goals of citizen science projects are broad, and generally include the compilation of data by participants for use in scientific research and the potential for enhancement of scientific literacy (Dickinson et al. 2012). Current literature identifies three major categories of such projects. Contributory projects engage volunteers primarily in the collection of data, collaborative projects allow volunteers to share ideas in project design, and co-created projects connect citizens to the entire project. In most cases, participation remains contributory, including the collection of and occasionally the analysis of data (Bonney et al. 2009; Rotman et al. 2012).

Citizen science projects allow data to be compiled over large spatial and temporal scales with large groups of observers, which is especially important to current environment research (Dickinson et al., 2012). In this process, citizen science may generate ecological knowledge, understanding of science, and place-based experiences and stewardship for the public (Dickinson et al., 2012). Assessing the scientific literacy of participants in citizen science projects has been a key challenge in meeting the goals of citizen science (Cronje et al., 2011). However, many qualitative case studies suggest that volunteers who participate in citizen science projects often identify improvement of scientific literacy and attitudes toward the scientific process (Cronje et al., 2011).

The motivations and expectations of participants and researchers also influence the viability of a citizen science project. Motivations of citizen science volunteers drive individuals to participate in and collaborate with scientists to collect information, and may strongly influence their learning outcomes (Raddick et al., 2013). Rotman et al. (2012) and Raddick et al. (2013) demonstrated that motivations are dynamic throughout collaborative process and are highly variable among participants of different demographics. Raddick et al. (2013) measured twelve motivational categories of almost 11,000 participants in an online citizen science project. Results indicated that the desire to contribute to a scientific project was by far the most common motivation among participants. Similarly, Rotman et al. (2012) identified motivations of participants and scientists in collaborative citizen science projects. The authors found that volunteers were initially motivated by a personal interest in the material or project. However, the motivations affecting ongoing participation and continued engagement in projects included receiving recognition and feedback from scientists and becoming involved with scientific communities (Rotman et al., 2012).

Problem and Purpose

Citizen science is becoming an increasingly common method to carry out various large-scale scientific projects. It aligns well with goals of informal and formal science education programs, including the Science, Technology, Engineering, and Math (STEM) field. It also addresses national and state science standards that call for an increased understanding of scientific process (Bonney et al. 2009). While many projects traditionally rely on individual volunteers to contribute their time and energy to projects, some have recruited K-12 and undergraduate students to aid in data collection (Galloway, Tudor, & Haegen 2006).

There is high potential, yet mixed research regarding improvement of participants' scientific literacy and attitudes toward science (Cronje et al., 2011). However, most research on citizen science motivations and outcomes has focused on adults in general citizen science projects. As described earlier, volunteers in citizen science projects tend to be highly motivated by a personal interest in science or the material, and display positive attitudes toward participation. However, these volunteer participants tend to emerge from a very narrow demographic: white, middle-aged, affluent, and well-educated people with an interest in science or education (Brossard et al. 2005). While results from studies of volunteer-based citizen science projects suggest that citizen science can benefit participant motivations, scientific knowledge, and attitudes toward science and scientists, findings cannot necessarily be generalized to larger populations, including student populations.

Potential benefits of citizen science in addressing scientific literacy and attitudes could be very applicable in formal education. Students participating in projects as a class, because they do not actively choose to volunteer, are a specific type of citizen science participant. They likely have different motivations and attitudes toward science. Several studies have investigated student participation in citizen science and reported anecdotal evidence that participation can influence student attitudes toward science and scientific literacy (Patterson 2012). However, few studies that have investigated citizen science projects in the classroom have evaluated student motivations and outcomes using robust methodology.

Robust research has been conducted on another type of informal science project that shares characteristics with citizen science. Dr. Ana Houseal of the University of Wyoming studied content knowledge growth and changes in attitudes toward science of students and teachers through Student-Teacher-Scientist Partnerships (STSPs) in Yellowstone National Park (Houseal, Fouke, Sanford, Fuhrmann, & Petrick, 2010). STSPs are partnerships “in which students, teachers, and scientists work together to answer real-world questions about a phenomenon or problem the scientists are studying” (Houseal, Abd-El-Khalick, & Destefano, 2014, p. 86). As a component of this project, Houseal designed the Mammoth PhotoPoints project, which has since been adapted into a citizen science project. Participants of this project took photographs of the dynamic travertine deposits of Mammoth Hot Springs in Yellowstone National Park from specific locations around the pedestrian boardwalk in order to document change of these magnificent geological features over time.

The purpose of this Master’s project was to examine the influence of participation in the Mammoth PhotoPoints citizen science project on local high school students’ attitudes toward science, sense of place, and understanding of science practices. Students from a gateway community outside Yellowstone National Park participated in this project as a part of their Yellowstone Science class in the spring semester of 2014. Students collected data by photographing hot springs weekly as a supplement to learning about Yellowstone’s diverse and dynamic ecological communities, including microbial mats in Mammoth Hot Springs. They analyzed photos and recorded changes of hot springs over time in a culminating assessment. This project used the Next Generation Science Standards (NGSS) as a guide and platform on which to evaluate students’ understanding of particular components of the standards: science and engineering practices. In addition to measuring students understanding of these practices and concepts, this project aimed to uncover the influence of citizen science participation on a students’ sense of place.

Research Questions

Based on the increasing interest in the role of citizen science in informal and formal education settings and previous research on impact of citizen science projects, the following questions were created to guide the current project.

1. Does participation in the "Mammoth PhotoPoints" citizen science project in Yellowstone National Park influence local high school science students' attitudes toward and understanding of science practices?
2. How does participation in a citizen science project influence a student's sense of place?

It is hypothesized that participation in the PhotoPoints study will increase students' understanding of science practices and reveal positive attitudes toward science. Because students live inside or just outside Yellowstone National Park, one of the most iconic areas in our country, it is expected that students will demonstrate a stronger connection and understanding of their place after participating in this project. Previous research on impact of volunteer-based citizen science projects and student-teacher-scientists partnerships provides significant evidence that these projects would have similar influences on high school students.

CHAPTER TWO

Literature Review

Introduction

The following literature review describes the theoretical framework upon which this project was built and explores the citizen science landscape at a general scale, then investigates the use of these projects in formal education settings. It first defines the field of informal science education and the various types of participatory science research, including citizen science. It then outlines citizen science fields of study, types of projects, and tools and technology. Next, the literature describes volunteer demographic, motivations of participants and scientists, and scientific, educational, and social outcomes.

After defining traditional citizen science projects, this chapter explores efforts to apply informal science projects including student-teacher-scientist partnerships and citizen science projects in classroom settings. Literature refers to these projects as citizen science, but the voluntary parameters of traditional projects might exclude students in formalized settings. Specific case studies are evaluated for opportunities and challenges that arise in formalized settings, as well as how citizen science can potentially address scientific literacy, encourage positive attitudes toward science, and foster a sense of place. The chapter concludes with an analysis of the opportunities and challenges of citizen science projects and the ways in which the current study aimed to adopt opportunities and address challenges in bringing these projects into the classroom.

Informal Science Education

Americans spend less than five percent of their lives in a classroom, which leaves a large amount of time for people to learn about science in other ways (Falk & Dierking 2010). The wide array of free-choice learning opportunities in the United States may act as non-school resources of scientific knowledge for Americans over their lifetimes (Falk and Dierking 2010).

According to Falk and Dierking (2010), there is a "widespread misconception that out-of-school educational experiences only support superficial science learning and the recreational interests of a limited percentage of the curious public, rather than the learning of real science by all citizens" (p. 486). International test results demonstrate an interesting relationship between age and scientific literacy compared to other countries. Elementary students from the United States generally perform as well or slightly better than students in other countries. Older students often perform below their international counterparts. However, adults consistently score higher on scientific literacy measures than adults in other countries. The authors suggest that this pattern may be due to science learning that occurs outside of school (Falk and Dierking 2010).

Informal science education encompasses these educational experiences available outside of a formal classroom, including museums, nature centers, television and movies, community projects, and the Internet to name a few (Bonney et al. 2009). First conceptualized in the 1940s as the "Public Understanding of Science," informal science education has evolved over the past 75 years. Early informal science was shared with the public in the form of lectures, exhibits, and media. Over time, the focus has shifted from delivering content-heavy presentations to engaging people in relevant experiences and scientific practices (Bonney et al. 2009). There are many approaches to engaging and educating citizens, including students, in the scientific process through informal science education. Three of these practices are particularly relevant to engage citizens and students in participating in the scientific process and connecting with scientists from a local to global scale: (a) participatory action research (PAR), (b) student-scientist partnerships or student-teacher-scientist partnerships (STSPs), and (c) citizen science (Krasny & Bonney 2005).

These approaches are not mutually exclusive and may overlap in order to increase the success and impact of projects for all stakeholders. Participatory action research involves connecting local people and scientists through defining a community issue and developing a research project to improve the problem. "Community members involved in PAR learn and become empowered through the data collection process and through subsequent community action" (Krasny & Bonney 2015, p. 293). This method is particularly relevant when barriers such as language occur between scientists and citizens. Student-teacher-scientist partnerships (STSPs) are inquiry-based science investigations focused specifically on linking scientists, students, and teachers in formal education settings. A specific study using this method by Houseal, Abd-El-Khalick, & Destefano (2014), which inspired the current research project, is discussed further below. The final approach and focus of the current project is citizen science a blossoming field and "growing worldwide phenomenon" (Cohn 2008, p. 193) for scientists, citizens, teachers, and students.

Citizen Science: Defining the Field

Citizen science is a branch of informal education in which volunteers engage in scientific research and connect with professional researchers (Dickinson et al. 2012, Raddick et al. 2013). While citizen science projects likely occurred informally for several hundred years, the earliest documented public participation in scientific research occurred in the late nineteenth century. According to Bonney et al. (2009), lighthouse keepers collected data on bird strike incidents in the 1880s. In 1889, enthusiastic amateur stargazers founded the Astronomical Society of the Pacific. The National Weather Service Cooperative Observer Program began in 1890 (Bonney et al. 2009).

Since the turn of the twentieth century, participation in such projects has increased dramatically. Perhaps the most well-known long running citizen science project is the Audubon Society's Christmas Bird Count. In 1900, the Christmas tradition of participating in a "side hunt" was popular. This consisted of spending Christmas morning shooting as many birds as possible in one's backyard. In response, Frank Chapman of the Audubon Society started a new Christmas tradition in which bird enthusiasts of any experience level could help count birds in a circular area instead. Today the Christmas Bird Counts occur across North America and a few international locations (M. Carling, personal communication, February 4, 2014). Public participation in science has a rich history, and has expanded in the past several decades into a diverse field with a large number of projects and platforms for recruiting volunteers, connecting public to professional researchers, and sharing data.

Types of Citizen Science Projects. The Cornell Lab of Ornithology scientists have tracked hundreds of citizen science projects in North America, and researchers believe there may be thousands worldwide (Cohn 2008). Bonney et al. (2009) defined three types of public participation in citizen science projects. The Center for Advancement of Informal Science Education (CAISE), an inquiry group consisting of scientists from the Cornell Lab of Ornithology, environmental education professors, and the director of the Carnegie Museum of Natural History, classified citizen science projects as (a) contributory, (b) collaborative, or (c) co-created. A project can be classified according to the extent to which the public can engage in the scientific process. The steps of the scientific process are defined by the authors as (a) choosing a question, (b) developing a hypothesis, (c) designing methods, (d) collecting data, (e) analyzing samples, interpreting data to draw conclusions, (f) translate conclusions, and (g) share results and ask new questions (Bonney et al. 2009).

Contributory projects. Far and away the most common form of citizen science, contributory projects are driven by researchers and supported by volunteers. These projects are commonly large-scale over geographic area or time and rely on volunteers to collect enough data for researchers. Data collection is generally the only step of the scientific process that engages volunteers (Bonney et al. 2009). Most global and national citizen science projects fall into this category, including the aforementioned Christmas Bird Count. Other examples include: (a) MEGA-transect Appalachian Trail project. In 2006, a coalition of sponsors along the Appalachian Trail including the Appalachian Trail Conservancy, National Park Service, U.S. Geological Survey, and Smithsonian Conservation Biology Institute, began a project to monitor effects of climate change and other environmental changes along the Appalachian Trail. Over 36,000 members and 5,000 active volunteers participated in the first two years. Citizen scientists collect data on phenology of trees and other plants, pollinators, birds and measure physical properties like pH in water systems and atmospheric pollution (Cohn 2008).

Project BudBurst is as education and outreach project that gathers large-scale data on plant phenology observations from across the continent for scientific research. The project aims to monitor seasonal changes of plants in response to environmental or climate changes. Students, naturalist, hikers, and others can participate. Participants receive simple training materials to identify and record observations of plants. Volunteers can choose one of two protocols: to monitor a specific plant through the seasons, or to observe a single plant for 15 minutes one time. Participants record data online and share with an online community (Mayer 2010).

Collaborative projects. Collaborative models engage participants in more steps of the scientific process. In these projects, research scientists define the research question and hypothesis, but participants collaborate with scientists to collect and analyze data. Participants may also help design methods, interpret data, and share conclusions. An example of a collaborative model is the Salal Harvest Sustainability Study in Washington state, a project sponsored by the Community Forestry and Environmental Research Partnership that measured the impact of harvest intensity on crop output. Participants were undocumented workers who depended on salal harvest for livelihood, a unique condition for a citizen science project. This project was considered collaborative because participants played an important role in developing questions, hypothesis, and design. Participants assessed treatment plots as part of their work during the harvesting season and recorded data. According to the project, participants' knowledge of scientific concepts and skillset improved (Bonnet et al. 2009).

Co-created projects. Finally, co-created models are driven by participants and supported by researchers. These projects often arise in response to a community concern. Participants define the problem and research question, develop hypotheses, and enlist scientists to help design and carry out the project. Volunteers participate in all steps of the scientific process. While far less common, these projects may have significant educational and social outcomes for participants and researchers alike (Bonney et al. 2009). An example of a co-created project is the Reclaim the Bay project, a shellfish and habitat-monitoring project in Barnegat Bay, NJ. The project began as a local education effort, but leadership was soon transferred to citizens who received 501(c)3 status for the project. Participants rear shellfish and release into the bay. They monitor shellfish growth and water quality. This is considered co-created because volunteers are involved in all aspects of the scientific process, from identifying research questions and hypotheses to developing alternative methods to raise shellfish. They help analyze data and spread awareness for project (Bonnet et al. 2010).

Comparing Project Types. The type of project may influence participant outcomes (Bonney et al. 2009). For example, co-created projects and collaborative projects focus more on relationships in community-designed projects. Additionally, it has been found that engagement is high when participants form their own questions about the data they collect such as through collaborative or co-created models (Dickinson et al. 2012). Mueller, Tippins, and Bryan (2012) argued that most popularized contributory citizen science projects are “top-down” and do not allow participant collaboration with scientists, democratization, assessment of ideas, and working in relation to others. According to Dickinson et al. (2012), “whether contributory, collaborative, or co-created, ecologically based citizen science projects are a natural fit for scientific endeavors with important environmental or public-policy implications because they engage affected populations from the start” (p. 2).

Fields of study and project platforms. The citizen science landscape is exceptionally diverse, covering fields of science from molecular biology to ecology to astronomy. Diverse projects in these fields led to development of a spectrum of participation platforms including field surveys for ecological studies to using web portals for classification of galaxies. Wiggins and Crowston (2011) analyzed 30 citizen science projects and defined a typology to classify projects into general categories. The authors analyzed 80 dimensions of each practice within the categories of research discipline, demographics, project goals, demographics, organizational features, participation, educational outcomes, technologies, and volunteer and data management. Dimensions measured were comprehensive. For example, dimensions within organizational features included funding sources, tax status, and affiliations. Five “mutually exclusive and exhaustive types of projects" (p. 5) emerged primarily based on project goals and supported by other project dimensions: (a) action, (b) conservation, (c) investigation, (d) virtual, (e) education. It is important to differentiate this typology from the Bonney et al. (2009) contributory, collaborative, co-created model that analyzed projects by participant involvement in the scientific process.

Action projects are community-driven, bottom-up projects whose primary goal is to use scientific research and consultation to address local environmental issues. These projects are small in scale, but often engage a community for a long duration. Action projects also encourage learning as the community drives the scientific process. Co-created projects described earlier also meet criteria for action projects.

The primary goals of conservation projects are to generate data to inform natural resource decision-making and promote stewardship and education. Researchers and federal agencies generally design and fund conservation projects. The MEGA-Transect study, also a contributory project, is an example of this type of project

Investigation projects have a main goal of gathering data from physical environment for scientific research, and also values education. Many large-scale contributory projects exemplify investigation projects. These projects are commonly funded by research institutions, rather than by conservation organizations or government agencies. The Community Collaborative Rain, Snow, and Hail Network illustrate this project. Participants collect precipitation data, then input into a web-based form that adds data to a large database. Users can access and utilize data from the database at any time.

Similarly, virtual projects aim to collect data for scientific research, but in a fully virtual environment. These projects allow participants to go beyond what they can observe in their physical environments. Most virtual projects do not have an explicit educational component, but a focus on engaging user interfaces to maintain volunteer interest (Wiggins & Crowston 2011). The GalaxyZoo project, a web-based galaxy classification project, exemplifies virtual projects. Participants in this project view online images of galaxies captured by the Sloan Digital Sky Survey and determine the shape and rotation of each galaxy. This particular project has an enormous web presence, and as of 2010 had engaged over 200,000 users from around the globe (Raddick et al. 2010). The project has also resulted in over 50 research studies and 16 peer-reviewed articles, illustrating the scale that citizen science volunteers can help achieve.

Lastly, educational projects are designed primarily to educate participants, while also compiling data over time. These inquiry-based projects expose students to the scientific process. The authors describe the ‘Fossil Finders’ project, facilitated by Paleontological Research Institution, in which students investigate fossils. Students ask questions and explore their own hypotheses using data they collect. Additionally, the program offers teachers classroom materials for additional lessons. Table 1 compares the five types along several dimensions: primary goal, participation, scope, organization style, and challenges.

Table 1

Citizen Science Typology

Type	Goals	Participation	Scope	Organizational Style	Challenges
Action	Use scientific research to address local concerns	Small scale community-driven with scientist consultation	Local	Bottom-up	Funding from community
Conservation	Data to support natural resources decision-making, Promote stewardship and education	Volunteers collect data using formal protocol, managers validate and generate public data	Generally regional	Top-down, middle-out by researchers and federal agencies	Sustainability of volunteers, dependence on government funding
Investigation	Data from physical environment to support scientific research, education strongly valued	Large number of participants contribute largely biological data following formal protocol, scientists validate and use data	Regional to international	Top-down by academic scientists or nonprofit organizations	Assuring data quality, sustaining volunteers
Virtual	Data from virtual environment to support scientific research, minimal focus on education	Participants use web-based systems to contribute and analyze data across fields of astronomy, paleontology, microbiology, and others; validated through algorithms and expert review	Global	Top-down by academic scientists	Assuring data quality, maintaining engagement in online platform
Education	Focus on education and outreach; exposure to scientific process	Student-teacher-scientist partnerships; participants contribute data to project and use data to test own hypotheses	Variable	Top-down through partner organizations and teachers	Projects are designed for specific audiences, not general public

Note: Synthesized from "*From Conservation to Crowdsourcing: A Typology of Citizen Science*," by A. Wiggins & K. Crowston (2011). Syracuse

Tools and Technology. The first documented citizen science projects required citizen report observation data through the mail (Raddick et al. 2013). Technology has drastically changed project design and expanded the scope and scale of public participation in scienti research. New electronic technology “makes participation faster and easier and has also gı improved the process of converting citizen observations into usable data” (Mayer 2010, p. Technology is the primary mechanism for data collection and analysis, but also increases ı interest and learning impacts. Many citizen science projects have incorporated smartphone online databases, and other simple web tools as inexpensive data management systems tha aggregate, filter, and organize data. These platforms allow participants to transcribe handv data from historical observations and studies. Social media sites, such as Facebook and Fl can also act as platforms for communication between participants and scientists (Dickinso 2012; Mayer 2010).

Additionally, many existing online citizen science databases (i.e. SciStarter, Citize Science Alliance, Zooniverse.org, citsci.org, GLOBE.gov) offer tools and resources with materials, best practices for carrying out projects, and databases to connect individuals wit projects and with scientists. For example, CitSci.org offers a tool for designers to create customized data-entry forms for volunteers. Sites also host discussion forums, news, upco conferences and events, and a professional network. These features, paired with social me have the potential to increase participation and project development. Still other online plat such as iNaturalist.org, facilitate communication between citizens and scientists (Newman 2012). “New technologies such as mobile applications (apps), wireless sensor networks, a online computer/video gaming, show great promise for advancing citizen science” (Newm al. 2012). eBird and iNaturalist.org users can now enter observations into mobile apps that store observations, locations, photos, and sightings lists.

Who participates in citizen science and why?

With the diversity of citizen science projects covering projects from ecological field surveys to computer-based analysis, there are opportunities for people to become involved in many different steps of the scientific process. Citizen scientists are "typically people who care about the wild, feel at home in nature, and have at least some awareness of the scientific process" (Cohn 2008, p. 195). Commonly these people have an interest or enthusiasm about a particular topic, like birds or astronomy, but may also be scientists in other fields, teachers, students, outdoor enthusiasts, and have an interest in learning something new. Although it may seem that there is "something for everyone" in citizen science, the nature of these programs can both appeal to particular populations and exclude others.

General demographics. Countless citizen science studies have reported that participants tend to emerge from a very specific demographic: white, middle-aged, affluent, and well-educated. For example, in a study of Cornell Lab of Ornithology's The Birdhouse Network project, a sample consisted of 798 individuals of which 98% were white, 65% middle-aged (30-60), 79% had at least 4-year degree, over 80% had taken science classes in college, and half were in an education-related field (Brossard et al. 2005). Neighborhood Nestwatch project reported similar demographics comprised of senior citizens, singles or couples between 30 and 50, and young families. Similar to The Birdhouse Network 80% of participants held at least a bachelor's degree. Researchers also interviewed participants in the Washington, D.C. area, of which less than 10% of citizen science participants represented urban communities (Evans et al. 2005). While these demographics are common among informal science programs, many practitioners see this small pool of participants as representative of a major citizen science challenge, that of engaging diverse populations. According to Evans et al. (2005), engaging participants from underrepresented demographics will “enrich the program and provide one avenue for sharing science with people who may be underserved by informal science education programs” (p.593) including families and those in urban settings. Researchers interested in the social and educational impact on participants should consider collaborative and co-created projects to engage diverse audiences.

Motivations and Recruitment. The success of citizen science projects depends on enough public participation to reach the goals of given scientific requirements, the geographic range, and repeated observations at a site. However, there are several crucial steps to recruit and engage participants in citizen science programs. According to Miyoko, Leonard, & Stevenson (2012), “volunteers are motivated by a desire to help others, they also perceive benefits to themselves, such as the satisfaction of being productive or the enjoyment of interacting with others during volunteer activities” (p. 70). Citizen science projects aim to match volunteers’ motivations with activities so that participants remain engaged.

Because citizen scientists have potentially different motivations than other volunteers to participate in projects, Raddick et al. (2013) studied the motivations for contributing time and energy to participate in the Galaxy Zoo online galaxy classification project (Raddick et al. 2013). Twelve categories of motivation emerged from interviews with participants, and participants rated the degree to which each category influenced their motivation. The twelve categories defined were: (a) contribution (excited to contribute to scientific research), (b) learning (a way to learn about astronomy), (c) discovery (can see things that few others have), (d) community (meeting other people), (e) teaching (can use to teach other people), (f) beauty (enjoy looking at beautiful images), (g) fun (enjoy categorizing galaxies), (h) vastness (amazed by scale of universe), (i) helping (enjoy helping), (j) interest in GalaxyZoo project, (k) astronomy (interest in astronomy), and (l) science (interest in science).

The highest values were contributing to science and beauty, while the lowest values were community, teaching, and learning. Women ranked most motivations significantly higher than men. Men rated “science” more highly, while women rated “beauty” more highly. Men were significantly more likely to choose contribute, astronomy, and science as motivations, while women were significantly more likely to choose beauty, vastness, and fun (Raddick et al. 2013).

They also collected demographic information about users. Demographic results revealed that the sample consisted of 82.1% men, and 17.9% women, and men outnumbered women at all ages, with an underrepresented group above age 60. Seventy percent of respondents held at least a bachelors degree, which is significantly higher than the U.S. average. Using only U.S. respondent data, these demographics are significantly different from general population of Internet users in the U.S. in age, gender, and education as compared to U.S. census data (Raddick et al. 2013).

Motivations of volunteers vs. scientists. As different motives influence volunteers to engage in citizen science programs, scientists also have many different reasons to engage in citizen science. As discussed throughout this review, one of the clear purposes of citizen science is to conduct long-term, large-scale research projects (Bonney et al. 2009). However, the various forms of public participation in scientific research indicate that scientists’ motivations lie along a spectrum between science and education to impact volunteers’ content knowledge, understanding of scientific processes, attitudes toward the environment, appreciation of the natural world, and ability to engage through hands-on research (Brossard et al. 2005, Cohn 2008).

Rotman et al. (2012) aimed to understand the motivations that engage scientists and volunteers to work together in collaborative citizen science projects. They designed a study to (a) uncover the factors that motivate scientists and volunteers to participate in projects, (b) identify barriers that deter collaboration, and (c) create a model that represents scientist and volunteer involvement in citizen science. They measured four types of motivations for social participation: egoism, altruism, collectivism, and principlism through interviews and surveys. Egoism is a motivation to ensure personal welfare. Altruism is concerned primarily with the welfare of others. Collectivism seeks to increase the welfare of one’s own, specific group. Principlism is the motivation to uphold one’s personal morals and principles (Rotman et al. 2012).

The researchers compared survey responses for motivational categories within each group of participants and between scientists and volunteers. Volunteer responses were similar across categories, while scientists reported a significantly lower score for collectivism. Between groups, volunteers reported significantly higher motivation for egoism and collectivism than scientists. Results from interviews suggest that volunteers’ initial interest was personal interest (egoism), and ongoing interest was influenced by recognition from scientists, feedback, and community involvement. The major motivation for scientists was to facilitate a large-scale research project, with education and policy as secondary motivations. Volunteers also expressed obstacles to collaboration in feeling intimidated by scientists.

Using this information, the authors created a model of dynamic engagement for use in future collaborative citizen science projects (see Figure 2).

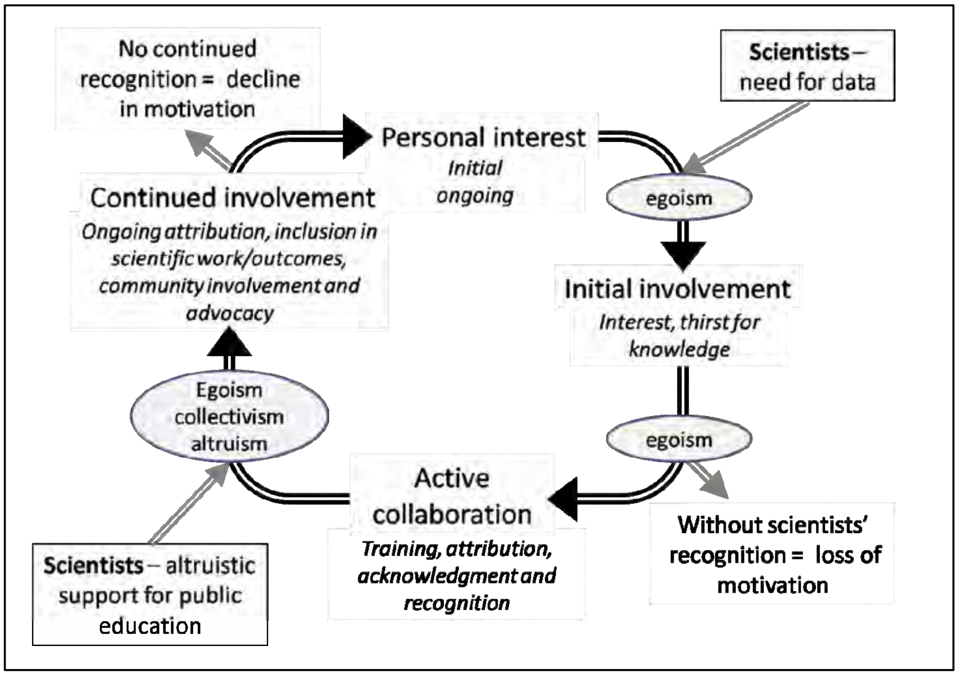

Figure 2. A process model of volunteers and scientists involvement in citizen science projects (Rotman et al. 2012, p. 224). This diagram shows the flow and intervention points for volunteers and scientists to maintain engagement through entire project.

The authors highlight the importance of timing in the cycle of participant engagement. While scientists' motivations remain generally constant, volunteers' motivations continuously change. They suggest that "time has a significant effect on motivation: when volunteers' motivations are explicitly recognized they will engage further in active contribution to collaborative projects. Where these motivations are ignored … volunteers participation will decline" (Rotman et al. 2012, p. 224). Thus, the intentional design of projects is integral to maintain volunteer engagement from start to finish. Understanding the motives of volunteers informs the outcomes of citizen science programs.

Outcomes of Citizen Science

Citizen science organizers have long promoted the benefits of citizen science projects for volunteers beyond contributions to research. Numerous studies have explored the educational and social benefits of volunteering that may also influence ongoing participation in citizen science. In particular, practitioners have been interested in understanding how citizen science projects can influence people's content knowledge, understanding of the scientific process, and attitudes toward science and the environment (Brossard et al. 2005).

Scientific Knowledge and Attitudes. Brossard, Lewenstein, and Bonney (2005) evaluated the impacts of The Birdhouse Network, a Cornell Lab of Ornithology project in which participants place birdhouses on their properties and record observations following a specific protocol. Participants gather data on bird clutch sizes, nest composition, site selection, and calcium intake by monitoring nest every few days. To participate, volunteers paid a small fee, and received educational materials and supplies. Cornell Lab of Ornithology researchers surveyed volunteers before and after participation to measure scientific knowledge and attitudes toward science and the environment. They used scales from national norms to compare participants to a larger population. The attitudes inventory (Modified Attitudes Toward Science Scale) was used as a model for the current research.

Results indicated no significant changes in participants' attitudes toward science or the environment. The researchers provided two primary explanations for this finding; (a) because they are motivated to participate, volunteers already had positive attitudes towards these subjects and (b) participants have complex attitudes or ambivalence toward these subjects that cannot be captured effectively with the survey tool (Brossard et al. 2005).

Participants responded to both close-ended and open-ended questions to assess their understanding of science practices. In the close-ended item, participants rated their understanding of scientific investigation, then asked to describe the scientific process in the open-ended item. Participants' self-ratings of understanding were much higher than demonstrated through explanations during pre-tests. More than half of the treatment group could not demonstrate understanding of the scientific process before participation, which did not improve in posttests. However, their knowledge of bird biology improved significantly. This indicates that participants may have been more focused on their interest in the birds rather than in the process of science itself. Participants may show improved understanding of scientific practices if made explicit both in educational materials and throughout project duration (Brossard et al. 2005).

Case studies also indicated that participants may have gained an increased understanding of scientific practices as it relates to a specific study, which may not be captured in a general science inventory. Cronje et al. (2012) Cronje et al. confronted this by developing a new contextual form of assessment to be used in addition to a short general science inventory to assess participants collecting data for an invasive plant study in Madison, WI. The authors hypothesized that a contextual assessment of scientific literacy would be more sensitive than the generalized science and engineering instrument in this situation. The contextual instrument included four open-ended context-based questions and one open-ended general question asking the participant to explain the scientific process. The authors surveyed participants and people who were unable to participate (the latter served as a control group). The treatment group scored 61% and control group 56% on scientific literacy in the pretest. Neither control nor treatment group showed significant improvements on general science posttest. The treatment group scored significantly higher on the contextual items in posttest, indicating an increased understanding of science in the context of their project. While participants demonstrated an increased contextual understanding in science processes specific to this project, it cannot be generalized to any other citizen science project (Cronje et al. 2012). However, these data suggest that participants may have a better understanding of the steps of their projects without connecting it to specific science practices.

Qualitative methods may provide a valuable alternative to assessing scientific practices and the factors that influence scientific literacy. Evans et al. (2005) interviewed participants in the Neighborhood Nestwatch citizen science project to assess scientific literacy and sense of place. Through interviews, 87% of participants reported an increased knowledge of bird biology and research. Interviews also revealed that the participants valued face-to-face interactions with scientists during project, which may have promoted discussions about scientific process. However, this project did not appear to control for threats to internal and external validity, so is difficult to generalize these findings to the larger citizen science field.

Recommendations for assessing scientific knowledge and attitudes. Brossard et al. (2005) recommend interviewing participants in addition to administering surveys to address the complex and ambivalent attitudes not captured in Likert-scale style surveys. Additionally, influence of citizen science projects on scientific knowledge may be understood more fully if similar inventories are used across citizen science field. Both Brossard et al. (2005) and Cronje et al. (2012) did not report changes in participants' understanding of science practices. Explicit connections between project design and protocols and the scientific process may influence participants' understanding of this process (Cronje et al. (2012).

Significant increases in knowledge and attitudes not only bolster the argument for including participants in citizen science program; but also strengthen the potential for citizen science to be influence scientific literacy for entire communities. Additionally, these studies provide evidence that citizen science may be a powerful classroom tool.

Student-teacher-Scientist Partnerships.

One branch of informal science education, student-teacher-scientist partnerships (STSPs), closely resembles citizen science projects involving students and teachers, with similar goals to co-created and collaborative models. STSPs foster inquiry-based learning and bridge the gap between formal education and scientific community through participation in authentic scientific research (Houseal et al. 2014). Understanding the outcomes, challenges, and opportunities of STSPs may help inform scientists and teachers who wish to engage students in citizen science programs.

The "Students, Teachers, and Rangers and Research Scientists" (STARRS) program is one such STSP that demonstrates how students, teachers, scientists, and rangers can collaborate while participating in an inquiry-based investigation of Mammoth Hot Springs, unique hydrothermal features in Yellowstone National Park (Houseal et al. 2014). The authors aimed to understand the impact of this STSP on students' content knowledge and attitudes toward science and scientists and teachers' content knowledge, attitudes, and pedagogical practices participating in the Expedition: Yellowstone! Program.

As is one of the goals of many education-type citizen science projects, a primary objective of the STaRRS curriculum was to engage students and teachers in the entire scientific process, beyond merely collecting data for scientists. Additionally, STSPs promote relationship building between the three groups of collaborators. Teachers play a particularly important role as students in some situations and as educators in others.

STaRRS consisted of three activities for students: photographing hot springs from specific pre-determined locations (called PhotoPoints), collecting physical and chemical data using protocols, and designing and carrying out small group research projects. In the third component, students developed their own questions and presented to their peers in Yellowstone as well as their own communities. Teachers participated in an intensive multiday professional development in Yellowstone and used STaRRS classroom activities to prepare students for and wrap up experience in Expedition: Yellowstone!

Over 220 students and 20 teachers in treatment and comparison groups in this quasi-experimental design study completed similar pre- and post-tests for content knowledge and attitudes toward science and scientists. Additionally, teachers completed a pedagogical inventory, surveys of enacted curriculum (SEC), which measured the time teachers spend on particular content and level of student cognitive demand (expectations for students that included memorizing content, presenting information, communicating understanding to others, and applying concepts). Results indicated that both teachers and students reported significant changes content knowledge and attitudes. Teachers' geoscience content knowledge scores increased only slightly, but they scored higher than average on the pre-test. The most significant changes in teachers attitudes occurred in their attitudes toward leisure of science and seeing scientists as normal people. STaRRS students scored significantly higher in all categories than comparison group. They also reported more significant changes in their attitudes toward scientists than the control group. Finally, teacher SEC surveys revealed significant changes in pedagogical practices in the following areas: (a) measurement, (b) nature of science, (c) ecology, (d) inquiry and technology design, and (e) pH.

According to the authors, this is the first study in this field that demonstrates empirically the impact of an STSP on teachers and students. The "findings indicate that STSPs might serve as a promising context for providing teachers and students with the sort of experiences that enhance their understandings of and about scientific inquiry, and improve their attitudes toward science and scientists" (Houseal et al. p. 84). This study also demonstrates how participating in a well-structured STSP can address students' understanding of science practices, core disciplinary ideas, and potentially cross-cutting concepts as outlined in the Next Generation Science Standards (Houseal et al. 2014; NRC 2012). This study inspired the current research, as I was particularly interested in how participating in a similar project would influence local students, some of which have been exposed to the extraordinary features of Yellowstone for their entire lives.

Citizen Science in the Classroom

Integrating informal science such as citizen science projects and STSPs may significantly benefit students and teachers. According to Adams, Gupta, and DeFelice (1996), the structure of a school, including mandatory attendance, is very important for the progression of learning year after year. However, "…where schools often fail is engaging students. Students express boredom and structured curriculum … feels like a constraint, rather than a programmatic opportunity to develop conceptual understanding" (Adams et al., 1996, p. 409). Additionally, many students struggle with scientific content if it difficult to observe, such as cellular and molecular processes. They cannot construct mental images of such processes and become frustrated and disengaged. Schools that replace traditional direct instruction with humanistic, inquiry-based techniques meet the needs of more diverse learners and make science learning more relevant to students (Jenkins 2011). Hofstein and Rosenfeld (1996) found that students exhibited more positive attitudes toward science in a community youth program than toward classroom science. The authors argue that the "bridge" between formal and informal education limits opportunities for learning, and should be considered a continuum. Citizen science and other informal science experiences can engage diverse learners in science inside and outside the classroom, helping to create the learning continuum (Hofstein & Rosenfeld, 1996).

Examples of classroom-based citizen science. Preceding examples of citizen science projects have focused on participation by the general public. However, many classroom teachers have begun to incorporate long-term citizen science projects into their curriculum. Projects in the classroom have provided both challenges and opportunities to teachers, scientists, and students. For teachers and students, these projects can provide a platform for meaningful interdisciplinary learning. One fifth-grade teacher, Mary Anstey, whose class has participated in Project Budburst, reported that her students view their surroundings in a different way by building and applying precise observation skills of schoolyard trees. In addition to engaging in scientific process, Anstey incorporates the tree study across disciplines by leading reading and writing exercises, studying life cycles, and using technology (Mayer 2010).

Projects have been initiated both by educators and scientists. While a growing number of students have become involved in citizen science projects, previous research suggests mixed results regarding the reliability of student-collected data for professional use (Galloway et al. 2006).

Contributory classroom projects. Galloway, Tudor, Haegen, and Vander (2006) were interested in student collaboration with state natural resource agencies in measuring trees in Oregon. The purpose of this study was to compare scientific data collected by two student age classes and professional scientists to determine if citizen science is a reliable data collection method.

A total of 607 students, grades three to ten, from 13 schools in Yakima School District, Washington state participated in the study. The professional participants were eight professionals from natural resource agencies. Professionals led one-hour training programs in schools before taking students into the field to collect data on a predetermined set of tree transects, where students were learned methods and protocols. Following nine days of data collection, and data from students was compared to that of scientists. For most measurements, there was no significant difference between the data collected by professionals and students. However, the authors found that there were significant differences in reports between students and professionals in identification of oak crown code. They also suggest that there appear to be more discrepancies in data between groups, but the sample sizes were too small to analyze (Galloway et al. 2006). Because of the nature of this project, with its short training periods and small sample sizes, it would be difficult to generalize these results to larger populations of students that may participate in citizen science projects.

Collaborative classroom projects. Patterson (2012) described an initiative in Colorado that connected students at two high schools and Front Range Community College with researchers at the Rocky Mountain Cat Conservancy. Students collected data on the presence of mountain lions at Horsetooth Mountain Park. Data collected included remote-sensor photos of mountain lions and signs of mountain lion prey such as deer tracks and scat. In addition to providing scientific data to be used by the Rocky Mountain Cat Conservancy, students incorporated Science and Engineering Practices (SEPs) of the Next Generation Science Standards into their experience. Honors students from the Front Range Community College high school program developed their own research questions, compiled background information, and analyzed data from the study to answer their question. Students also created scientific posters and articles that they shared with their schools and local communities.

Three major outcomes of this experience for teachers in students were gathered through interviews. First, teachers reported that students gained an appreciation for the wildlife in their own backyards. Second, students applied science practices and experienced scientific investigations outside of the classroom or lab, exploring real career opportunities in the field. Lastly, students contributed and analyzed data that would inform local communities about urban-wildlife interfaces.

Co-created Classroom Projects. Gray et al. (2012) described a yearlong co-created citizen science project in which students in an honors biology class designed and carried out a project that explored public's "willingness to pay" for ecosystem services for a local watershed partnership. The class was given ownership over the design and implementation of study, and even published a peer-reviewed article. In the process of the project, teachers and students designed their own rubrics to critique the quality of sources, which addresses critical thinking and NGSS Science and Engineering Practices (e.g. Obtaining, Evaluating, and Communicating Information), (NRC, 2012).

Challenges in the classroom. With administrative constraints and significant pressure to meet specific content standards and to teach to standardized assessments in schools, classrooms are challenged to incorporate meaningful informal science programs such as citizen science (Jenkins 2011). Additionally, not all schools have sufficient resources or technology to access citizen science projects (Mueller et al. 2012). Gray et al. (2012) argue that citizen science in classrooms can be successful if schools promote epistemology over scientific content. Experiences described from Project BudBurst and Rocky Mountain Cat Conservancy demonstrate how citizen science projects can influence students achievement in multiple disciplines by using the project as a thread to connect between science, social studies, math, English, and art. Additionally, scientists or developers must adopt a collaborative model and allow students to drive scientific investigation. They argue that, “co-constructing science in the classroom is labor and resource intensive, as it requires contributions from myriad actors and a willingness to embrace an uncertain research process in the hopes that scientific knowledge and literacy are outcomes” (Gray et al. 2012, p.5). This challenge may be especially apparent in collaborative or co-created classrooms. One solution proposed by Mayer (2010) would be to start with a more simple project, like Project BudBurst, which provides a simple protocol and training materials for teachers who may not have the time or resources to commit to a collaborative or co-created model. Jenkins (2011) points out that many citizen science projects offer training programs and lesson plans for teachers that are linked to standards. Reducing extra workload may encourage teachers to try to incorporate these into their curriculum.

Opportunities in Promoting Citizen Science

Achieving Projects of Large Scale and Scope. For scientists, the most obvious motivation for engaging the public in citizen science is to collect large amounts of data. In fact, the scale and scope of many large projects would be unattainable without dedicated citizen science volunteers. Rick Bonney of Cornell Lab of Ornithology, interviewed in Cohn (2008) stated, “we can employ citizens to gather data that we cannot get any other way” (p. 193). One of the biggest challenges of large-scale research environmental or ecological projects is paying professionals. According to Donald Owen, a National Park Service specialist with MEGA-Transect Project, “we can’t get enough research assistants to do what we can get volunteers to do. Not even close” (p. 193). Volunteers help save money in projects, but also aid in collecting long-term data on a huge geographic scale (Cohn 2008). However, a large number of volunteers without scientist oversight may create tension between participant and scientist motivations, desired outcomes, and data quality.

Democratizing Science. Citizen science, STSPs, participatory action research, and other public participation in scientific research (PPSR) serve as forms of “democratizing science,” the removal of barriers between the public and scientific process. According to Freitag and Pfeffer (2013), “the benefits of citizen science and democratizing science originate from emphasizing process - specifically by spreading power derived from expertise among more people, creating scientifically educated public for future scientific development, and connecting science to everyday life” (p. 1-2). While empirical data from experts is central to environmental decision-making, citizen science and other PPSRs expand “best available science” to include local knowledge and multiple perspectives.

In classrooms, citizen science can empower students to engage with their communities. “Providing the tools necessary for our students to become informed citizens … is one of many possible benefits of citizen science. In addition to making science a tangible component of our students’ lives, it also provides a framework that they can adopt if the feel their community is being threatened” and feel empowered when facing community challenges with experience in citizen science (Jenkins 2011, p. 507).

Democratizing science can expand citizen science into larger curriculum and include disciplines such as social studies and civics that targets civic engagement and community action. Green and Medina-Jerez (2012) describe the powerful role that citizen science can play in Project Citizen, a large-scale civic and community and engagement curriculum. This curriculum allows students to identify, research, and address local community issues. Environmental issues, namely watershed quality concern, are excellent opportunities for incorporating citizen science as a part of interdisciplinary socio-scientific inquiry. In the case of watershed quality, students first identified the stream quality issue in their community, then researched the issue, and conducted chemical testing in collaboration with local scientists. They analyzed results, but then used results in interviewing community members, collecting stakeholder perspectives, and developing a policy proposal for action. Students used citizen science to engage in socio-scientific inquiry by exploring diverse stakeholder viewpoints and drawing personal conclusions. Finally, students presented their policy portfolios with recommendations and an action plan to the larger community (Green & Medina-Jerez, 2012).

Sense of place. There appears to be a gap in the literature that discusses the relationship between citizen science and developing a sense of place. However, strong connections have been made between sense of place theory and understanding ecological systems. People must understand the places they live in addition to gaining scientific literacy to comprehend humans' influences on ecological systems (Evans et al. 2005). Kudryavtsev, Stedman, and Krasny (2012) synthesized the components of 'sense of place' and connection to environmental education. The role of place has been applied to many other domains including psychology, education and pedagogy, well-being, and environmental behaviors and attitudes (Kudryavtsev et al. 2011; Duerden & Witt 2001). Kudryavtsev et a. (2011) explore sense of place within environmental education, which shares many characteristics with citizen science.

A sense of place (SOP) consists of two concepts: place attachment and place meaning. Place attachment is the bond people develop with place and the degree to which place is important to a person. Place attachment can present in two forms (a) place dependence, or the "potential for a place to satisfy an individual's needs by providing settings for preferred activities" (Kudryavtsev et al. 2011, p. 231) and (b) place identity, or the tendency for place to become part of one’s identity. For example, one’s place attachment for Wyoming might be described in the following way: “Wyoming is very important because I can recreate in the mountains, Wyoming makes me who I am.” Place meaning, the second component of SOP, refers to the tendency to ascribe symbolic meanings to place. For example, one’s place meaning for Wyoming might be states as: “Wyoming is public lands, family, and energy.” People can develop a positive, negative, or ambivalent place meaning. Additionally, place meaning considers not only physical place but also social, cultural, economic, and other aspects of a place (Kudryavtsev et al. 2011).

Some research suggests that developing both place attachment and place meaning can lead to positive environmental behavior, attitudes, and emotions (Kudryavtsev et al. 2011). One who holds strong ‘ecological place meaning’ combined with ‘social place meaning’ may have a stronger impact on attitudes and behaviors (Kudryavtsev et al. 2011). In other words, addition of place attachment will likely increase pro-environmental attitudes, behaviors, and values. The authors recommend that place meaning and place attachment can be developed through both direct experience and indirect learning, but that long-term, frequent, and direct experience with places is likely to have a powerful influence on sense of place (Kudryavtsev et al. 2011).

Although little research has focused on the connection between participation in citizen science and sense of place, citizen science certainly provides direct, long-term experiences with a place. In particular, action, conservation, and education type projects are “strongly rooted in place” (Wiggins & Crowston 2011, p. 5). Evans et al. (2005) explored participant knowledge and sense of place in the Neighborhood Nestwatch backyard bird observation program. The authors identified four potential components of an ecological sense of place: knowledge, skills, awareness, and disposition to care. Researchers interviewed participants after participation in the citizen science project. In addition to increased knowledge about bird biology and behavior, 83% of subjects reported an increase in awareness in the ecological relationships in their backyards. Participants expressed the value of their backyard as a habitat for local organisms. It is likely that other field-based projects analyzed with more specific variables of place would influence the development of place attachment and place meaning for participants.

Challenges and Recommendations

Many of the same opportunities provided by citizen science also act as challenges. The major challenges within the citizen science field include (a) relationships between participants and scientists, (b) limited accessibility to and diversity of participants, (c) pressure from current educational reform efforts, (d) measuring impacts and outcomes of participation, and (e) determining quality of data (Krasney & Bonney, 2005; Mueller et al., 2012; Gray et al., 2012).

Participant-Scientist relationships. The majority of citizen science projects are considered contributory, driven by scientists and supported by participants (Bonney et al., 2009). While this design may be most efficient for enlisting volunteer workforces to collect large amounts of data, it does not necessarily offer participants with collaborative relationships, ownership of project, or understanding of scientific process (Mueller et al., 2012; Krasney & Bonney, 2005; Gray et al., 2012). Participants felt empowered in some interactions in which scientists treated volunteers as partners (Evans et al. 2005). However, the "top-down" structure of contributory projects may inhibit continued participation from some volunteers who seek relationships with scientists (Mueller et al. 2012; Rotman et al. 2012). Part of this issue may stem from the differences in motivations of scientists and participants.

According to Rotman et al. (2012), the dominant motivation of scientists in collaborative citizen science projects was to collect large amounts of data, while volunteers were motivated by personal interest or community concern. However, many volunteers struggled with collaboration and felt intimidated by scientists (Rotman et al., 2012). Additionally, There is a connection between being motivated by local concerns and participating in project long-term, learning comes through collaboration, and more trust can be placed in the data that is collected, even by youth participants. Community-based learning and citizen science can be affected by power dynamics between leaders or professionals and participants and the mission can be compromised.

This issue also extends into classrooms where scientists collaborate with teachers and students. In the co-created watershed project described previously by Gray et al. (2012), students and teachers reported feeling empowered while participating. However, scientists had to intervene to enhance the quality of data collection and investigation several times, resulting in a feeling of loss of ownership over project (Gray et al., 2012).

Data quality. Ensuring the quality of data collected is one of the most critical challenges of citizen science from scientists' perspectives, especially when considering K-12 student participation. As mentioned previously, the primary motivation of scientists engaged in citizen science is capturing data from a large-scale research project (Rotman et al. 2012). However, the nature of large-scale citizen science projects dictates citizens as data collectors without direct supervision or guidance of primary researcher. According to Delaney, Sperling, Adams, and Leung (2007), the "scientific community seems reluctant to accept citizen science due to a current lack of certified audits to assess the validity of using such data in academic research and resource management decisions" (p. 118). Some studies that have measured the reliability of data collected by citizen scientists including students suggest that there may be discrepancies between data collected by volunteers and researchers (Galloway et al. 2006). However, others support that data quality is likely to improve with proper protocol development, data editing and analysis, and thorough participant training (Krasny & Bonney 2005; Delaney et al. 2007; Cohn 2008; Mayer 2010).

Several studies have investigated the reliability and validity of data collected by citizens. Delaney et al. (2007) designed a marine invasive species monitoring pilot study to assess the quality of data collected by citizen scientists, then used the results to determine eligibility criteria for participation. The authors recruited over 1,000 volunteers ranging from ages 3-78 at 52 sites along the east coast from New Jersey to Maine. Volunteers received one-hour training programs from experts in field identification, methods, and using field guides. Volunteers worked in groups of different sizes to identify crab species, gender, and sizes in randomly selected quadrats. The researchers identified variables (participant age, education, group size, and crab size) to predict the reliability of citizen science data.

They assessed data quality by having volunteers collect species, sex, and size data in the field, but also asked volunteers to place crabs in buckets according to each variable at each quadrat for further validation. Citizen science and expert data was compared to investigate citizen scientists' abilities and assign 'eligibility criteria' based on the results. The authors found that grade 3 identified 80% of species accurately and grade 7 students achieved 95% accuracy. They found that sex determination was slightly more difficult for participants, with 80% accuracy for grade 7 and 95% for undergraduate students. The authors used all data from citizen scientists who achieved at least 95% accuracy and established standardized methods and eligibility requirements. The findings indicate that a wide range of participants were able to contribute high quality data and are capable of monitoring less conspicuous invasive organisms

(Delaney et al. 2007). With additional training or intentionally designing groups to contain both novice and experienced citizen monitors, the accuracy could improve for younger participants.

In order to control for data quality, many researchers have focused on improving training, adding steps to validate data, and communicating with participants. Cohn (2008) investigated several citizen science projects to identify protocols and training processes that project scientists use to ensure citizen science data quality. According to a scientist Cohn interviewed, "Nothing we're doing is so difficult that volunteers can't do it if they are properly trained" (p. 194). The most effective training programs involve hands-on trainings presented by project scientists to describe project and demonstrate tools, technology, and methods. (Cohn 2008).

Additionally, scientists need to develop protocols that meet the needs of their research but that also take citizen scientists into account. Protocols that are too complex or detailed for participants are likely to result in lower data quality (Cohn 2008; Couvet et al. 2008). For example, in an invasive plant program, citizen scientists are more likely to accurately measure five or ten important, easily-identifiable plants than identify all species. Some projects are more appropriate for different groups of users. Project BudBurst is a great project for all volunteers including young students as the subjects (plants) are stationary and data can be gathered on same plants each year even though new students participate each year (Mayer 2010). Many citizen science projects also manage data quality by creating checkpoints to remove outliers, and flag and scrutinize questionable data. Other approaches to determine reliability can include collaboration between citizens and scientists in which staff and participants compare data (Cohn 2008). The two parties establish a relationship, and the participant can learn how to improve data collection techniques. As practitioners continue to evolve protocols and share best practices, the reliability and validity of citizen science data is sure to continue improving.

Summary

Citizen science is one of many branches of informal science education that engages the public in scientific research. While volunteers and scientists are motivated by different factors to participate, citizen science provides clear benefits to both groups of people. Scientists can collect large amounts of data over widespread geographic areas, save money with volunteer research assistants, and build relationships with communities. Volunteers can gain new skills, scientific knowledge, and gain new perspectives on science. Challenges to citizen science projects including scientist-participant relationships and data analysis persist in projects, but practitioners constantly look for new ways to enhance these aspects of research. Students can also participate in citizen science projects in the field or in their classrooms. Previous studies indicate that students can participate in the entire scientific process through citizen science projects, from designing questions and hypotheses, collecting and analyzing data, drawing conclusions, and sharing. Participation in partnerships with teachers, scientists, and community members can influence students understanding of science, encourage positive attitudes toward science, and potentially help build students into democratic citizens.

The current study aimed to address challenges and adopt recommendations from previous studies. In order to address challenges to measuring ambivalent or complex attitudes (Brossard et al. 2005), this mixed-methods study included both surveys and interviews to measure attitudes toward science, sense of place, and understanding of science practices. Additionally, context-specific and general questions were designed to measure understanding of science practices. With limited research on the relationship between sense of place in citizen science, this project aimed to explore the influence of a citizen science project on students working in their local national park.

CHAPTER THREE

Methods

Citizen Science Project Description and Background

The Mammoth Hot Springs in the northwest corner of Yellowstone National Park are a unique and dynamic system of hot springs. The water draining from the hot springs precipitates terraces of travertine, a calcium carbonate mineral deposit that can grow as much as 5 millimeters per day (Houseal et al. 2010). Additionally, colorful thermophilic microbial communities occur on travertine and the hot springs. Both the travertine deposits and microbial communities grow incredibly quickly, which result in the dynamic terrace systems. While the hot springs most often provide a short stop for park visitors, observation over time allows one to see the remarkable changes in the hot springs.

The Mammoth Hot Springs PhotoPoints project was developed by Dr. Ana Houseal in 2006 as a component of a student-teacher-scientist partnership (STSP) between park rangers and scientists, university researchers, and teachers and 4^{th}-8^{th} grade students from schools participating in *Expedition: Yellowstone!* Programs (Houseal et al. 2010). The current project has been adapted from the original STaRRS (Students, Teachers, and Rangers & Research Scientists) student-teacher-scientist partnership.

Due to the high volume of visitors to the hot springs and the dynamic nature of the terraces, the PhotoPoints project was re-engaged and extended to the local school, community, and visitors. We were connected by park personnel to a local high school science teacher who was interested in incorporating the project into her Yellowstone Science class.

Participants in the project walked along the Mammoth Hot Springs boardwalk and stopped at several designated “PhotoPoints.” Each photo point was marked on the boardwalk map. At each location, a small “L-shaped” metal bracket was mounted on the outer railing of the boardwalk. Participants used a Nikon P60 camera to photograph the scene from each point. In addition to previously established photo points, the class identified, named, and photographed several new photo points. Photos were compiled, stored on a computer, and analyzed for changes in travertine growth, biofilm color, debris, flow, and facies by students at the end of the semester. Biofilm referred to the colors of microorganism films that develop on travertine. Debris included any object from outside the geothermal system (sticks, rocks, etc.). Flow described the water flow, if any, in the photo. Finally, facies referred to the features of the travertine deposit. Students shared findings to each other in time-lapse PowerPoint presentations. Figures 2, 3, and 4 display three photos taken by students during week 1, week 2, and week 3 of project respectively at one of the PhotoPoints. Students noted changes in several variables in these photos, notably flow and biofilm color.

Figure 2. PhotoPoint “Fudge” at Week 1

Figure 3. PhotoPoint “Fudge” at Week 2

Figure 4. PhotoPoint "Fudge" at Week 3

Subjects

Participants were high school students at a small public school outside of Yellowstone National Park. All students were enrolled in a Yellowstone Science class, a science elective in the last hour of the day. Students in the class elected to enroll in Yellowstone Science for a variety of reasons, including interest in learning more about Yellowstone, enjoyment of teacher, and inability to take another elective. The class consisted of seventeen participants, five female and thirteen male. Not all students in the class received consent to participate in study, and thus were not included in research. Two students were in grade 10, the rest in grades 11 and 12. Many students (n=10) had lived in the area for their entire lives, four for between 5 and 7 years, and three for less than two years. Students traveled to school from the town, Yellowstone National Park, and surrounding rural areas.

Subjects were chosen by using convenience sampling. Students were engaging in the citizen science project as a required part of their Yellowstone Science class. They were informed that participation in questionnaire and interviews were voluntary and would not affect grades prior to assenting to participate in study. Written assent from students and consent from parents or guardians was given before baseline inventories.

Yellowstone Science Course

Course design. Yellowstone Science was developed by the high school science teacher to investigate the geological history and features of Yellowstone National Park. The course was designed to build upon concepts of microbiology, an elective offered during the fall semester, 2013. A small number of students in the class had taken microbiology. Throughout the semester, students learned about the Yellowstone caldera and its influences on the current geological features of Yellowstone. Additionally, students focused specifically on the Mammoth Hot Springs through a series of field trips, speakers, engaging activities, and PhotoPoints citizen science project. They began by reading and responding to two articles from a 2010 publication of *Yellowstone Science, 18*(3), Houseal, Fouke, Sanford, Fuhrmann, & Petrick (2010) and Carr, Jaworowski, & Heasler (2010). Houseal et al. provided background information on the plumbing of hydrothermal features and associated microbial life. They also defined the variables that students would observe during field trips. Bruce Fouke, a geologist studying the hot springs, spoke to students about his research. Additionally, students practiced mapping the PhotoPoints using Google Earth, modeled microbial life using Winogradsky Columns, toured the hot springs with YNP Youth Program Manager Bob Fuhrmann, experimented time-lapse photography techniques, and modeled travertine deposition by precipitating calcium carbonate from solution. Students participated in the PhotoPoints project during April and May as a synthesizing investigation of the change of hydrothermal features over time.

PhotoPoints project. As described above, participants engaged in the PhotoPoints project as one component of their Yellowstone Science class. The current PhotoPoints study was designed as a collaborative citizen science project in which students worked with their teacher to ask investigative questions and form hypotheses. Students traveled to the hot springs to search for existing photo points and identify new ones. Some PhotoPoints were changed because a few previously established springs had stopped flowing, and new active springs interested students. They re-named all photo points based on nearby indicators (PhotoPoint Bush, PhotoPoint Mother Nature, PhotoPoint White, etc.). Next, the class mapped and labeled all existing and new photo point locations using Google Earth. The teacher initially instructed students to create a data collection sheet, but with time pressures, eventually developed the materials herself. The class traveled to Mammoth during their last two periods of the day to collect data. In addition to photographing hot springs at photo points, students observed springs and descriptively measured variables: travertine growth, biofilm colors, flow velocity, presence of debris, and facies classification. Due to administrative challenges and mandatory afternoon school activities, data collection only occurred on three occasions. Nevertheless, the students compiled photos and descriptive data for analysis. In small groups, participants analyzed changes by creating time-lapse presentations of several springs and drew conclusions of the changes. On the final day of class, one student with a special interest in photography created a panorama image of all photo points. Based on their observations over several weeks, the class made hypotheses about the changes expected at photo points using the panorama image. Additionally, students were asked for creative solutions to improve project, collaborate with park, and develop public access to photos. Because of the significant student input in this project, it was considered collaborative in nature.

Next Generation Science Standards. The Next Generation Science Standards (NGSS) are divided into three dimensions: (a) Disciplinary Core Ideas (content), (b) Cross Cutting Concepts (overarching themes), and (c) Scientific and Engineering Practices. Two of these dimensions were tied closely to and used throughout this project. These connections are described more fully below.

Cross-cutting Concepts (CCCs). Cross-cutting concepts demonstrate concepts that can be applied across the sciences and engineering (National Resource Council [NRC], 2012). The most relevant of these to this PhotoPoint project is Stability and Change. According to NGSS,

> Stability means that a small disturbance will fade away—that is, the system will stay in, or return to, the stable condition … a system with steady inflows and outflows (i.e., constant conditions) is said to be in dynamic equilibrium. For example, a dam may be at a constant level with steady quantities of water coming in and out. Increase the inflow, and a new equilibrium level will eventually be reached if the outflow increases as well (NRC, 2012, p. 98).

The water flow and concentration of calcium carbonate in the Mammoth Hot Springs system causes travertine mineral deposits on the hot spring surfaces to grow as much as five millimeters per day. Travertine deposition influences other characteristics of the hot springs to change constantly including biofilm color, spring flow, and debris (Houseal et al., 2010). Changes can be observed in a fraction of the time of other geological processes. These characteristics made the Mammoth Hot Springs an exceptional example of this particular cross-cutting concept. The

Stability and Change concept was determined to align well with this particular project and was addressed during the design of the students' experiences, but was not used in analysis. For example, the classroom activities, readings, and meetings with local geologist connected directly to this concept.

Science and Engineering Practices (SEPs). Science and Engineering Practices (SEPs) represent the skills, or "practices" obtained by students through scientific investigation and knowledge related to investigation. These align with the steps of the scientific process used to measure other citizen science projects, but have language that includes engineering and design principles. The SEPs, in order, are: (a) Asking questions and defining problems, (b) Developing and using models, (c) planning and carrying out investigations, (d) analyzing and interpreting data, (e) using mathematical and computational thinking, (f) constructing explanations and designing solutions, (g) engaging in argument from evidence, and (h) obtaining, evaluating, and communicating information. For the purposes of this project, some were likely more relevant than others in designing the class and project. However, all were considered during analysis.

Instrumentation

A pre-post test method was designed to collect information about student sense of place, attitudes toward science, and understanding of science practices. Pre- and posttests were identical and each consisted of a questionnaire and an interview. Baseline data were collected from ten students on March 14, 2014 in person at school. Because of school schedules and breaks, the remaining seven baseline inventories were collected two weeks later via Skype. Posttests were conducted in person on May 22, 2014 or via Skype on May 29, 2014. Both instruments addressed the three variables (science practices, attitudes, and sense of place). The questionnaire was designed to collect quantitative data and allow for written elaboration and open-ended items. Interviews asked similar questions in a casual conversation form. Because of the small sample size, the qualitative data from questionnaires and interviews was essential.

Surveys. Questionnaires were administered following interviews during pre- and post-testing. The questionnaire asked for basic demographic information (age, gender, years attending school, and previous participation in Expedition: Yellowstone!), and a series of items about understanding of science practices, attitudes toward science, and sense of place. The first ten survey items asked students to rate statements on a 7-point semi-anchored scale (1=strongly disagree, 4=neutral, 7=strongly agree for items 1-9; 1=no understanding, 4=some understanding, 7=full understanding for item 10). Many of these items were followed by a “Please Explain” space for students to elaborate on responses.

The first four items address attitudes toward science, Items 5 and 6 address both attitudes and understanding of science practices, items 7 through 9 address sense of place, and last scaled item addresses understanding of science practices. The last four items were open-ended queries. The first open-ended question asks about views toward science, the second and third address science practices, and last addresses science practices, attitudes, and sense of place. Some questions on survey were influenced by other survey instruments, while others were novel. Several attitudes toward science inventories were evaluated. Items 1-4 are modified from or inspired by the modified attitudes toward organized science scale (MATOSS) (Brossard et al., 2012). See Appendix A for full questionnaire. Questionnaires were filled out on paper, given a subject code number, and filed for later analysis.

Interviews. Structured interviews were conducted prior to the questionnaires. The purpose of the study was explained to students before the interview began, and it was explained that their responses would be anonymous and would in no way affect their grades in class. Baseline interviews were conducted in person or via Skype within a two-week period in March 2014. Interviews lasted between ten and twenty-five minutes. Students were asked a series of questions that generally followed the progression of demographic info, attitudes toward science, understanding of science practices, and sense of place. The conversation was intentionally designed to ask questions that students would likely feel comfortable with first: (How long have you lived here? How do you feel about living here? How often do you visit the park or surrounding public land?) The interviewer then moved to more complex questions (How do you define science? Since beginning the project, have you noticed any changes in understanding of or connection to this place? What is the purpose of citizen science?) A full list of interview questions can be found in Appendix B. Although interviews were structured, students were asked to elaborate on some responses. Interviews ended with invitation for interviewee to ask any questions. The interviews were recorded on Apple GarageBand and saved with subject code. Transcriptions were created from the audio files and saved electronically.

Analysis

Surveys and interviews were conducted in person or over Skype just before and after participation in the study. We received 13 of 17 (76.5%) baseline and final surveys. Some surveys were not collected from students who participated in Skype interviews. Others did not have time to complete the survey due to class conflicts. A small percentage took a survey to complete outside the room but never returned it. We were able to secure a total of 15 of the 17 (88.2%) interviews during initial and final data collection.

Quantitative. Each close-ended survey item was analyzed using two-tailed t-tests ($p<0.05$) for comparison of means at Time 1 and Time 2 ($n=13$) using Microsoft Excel. Open-ended survey items were evaluated using a rubric. Rubrics were designed using emergent themes from qualitative analysis for each variable. Each response was evaluated using rubric, assigned a number from 1-7 that correlated to the value of response, and analyzed using two-tailed t-tests ($p<0.05$) for comparison of means at Time 1 and Time 2.

Qualitative. Interviews were translated into mp3 form and transcribed using InqScribe software. This software allowed for audio to be slowed down for more reliable transcription into word document. Using each variable for study (sense of place, attitudes toward science, and understanding of science practices), interviews were coded for themes within each variable. Additionally, new variables emerged and were coded for themes. Emergent themes were entered into graphic organizer with corresponding supporting quotes at Time 1 and Time 2 for analysis. One random interview was coded by another reviewer and compared for inter-reviewer reliability. Both reviewers identified 14 segments of transcript to code. For 12 out of 14 segments, coding was exactly the same. For two segments, both reviewers coded multiple themes (i.e. Attitudes towards Science/Sense of Place, Attitudes toward Science/Understanding of

Science Practices) with one shared theme. Therefore, with about 93% agreement in coding themes, it was estimated that inter-reviewer reliability was established.

Attitudes Toward Science. Many inventories have been designed to measure students' attitudes toward science. Weinburgh and Steele (2000) designed one such inventory for use in measuring attitudes of urban students called the Modified Attitudes Toward Science Inventory (mATSI). The major attitudes measured in the mATSI inventory were perception of the teacher, anxiety toward science, value of science to society, self-confidence in science, and desire to do science (Weinburgh & Steele, 2000). Because this inventory was found after surveys and interviews were administered, the mATSI was not used in test design. Instead, the mATSI attitudes were aligned with qualitative emergent themes and quantitative items during analysis, and are described in detail in results section.

Methodology Considerations and Limitations

There were many complications in carrying out the methods of this project. Originally, a third testing date was scheduled to occur in the middle of the project. However, several outside factors reduced the span of the project from three months to six weeks, resulting in removal of mid-project testing. One major complication during this time frame was a government shutdown implemented in October 2013, which slowed down the Yellowstone National Park education permitting process and altered early plans. A second challenge in fulfilling the original methodology was a district funding crisis in which funding for most extracurricular activities, including field trips, was lost for several months in the winter and spring of 2014. School breaks and schedule changes also influenced the collection dates of baseline data. Some students were interviewed in person in school, and others two weeks later via Skype. Any outside variables influencing changes in understanding, attitudes, or sense of place in that two-week period could not be controlled for.

Additional steps to increase validity and reliability in this mixed methods research could have been taken as well. It would have been beneficial, if more time was available, to share analyzed interviews with participants to ensure internal validity. Reliability would have also increased if other raters had analyzed all interviews and evaluated open-ended questions. Additionally, more subjects would have increased both the power of quantitative and qualitative methods. However, with the time and resources allotted, qualitative data provided rich insight and results that quantitative data could not provide with the small sample size.

CHAPTER FOUR

Results, Discussion, and Conclusions

In this mixed methods study, a total of 13 of 17 (76.5%) baseline and final surveys were collected and analyzed and a total of 15 of 17 (88.2%) interviews took place during the initial and final data collection. However, only data from students who completed both were used in analysis (n=13).

Quantitative Survey Results

Close-ended scale items. The first 10 items of the survey (see Appendix A) were close-ended Likert scale statements. Of these 10, only item 1, *Science is important in my everyday life,* revealed a significant increase (p=.037) between Time 1 (pretest) and Time 2 (posttest). Table 2 displays the results of close-ended Likert-style scale items. Refer to Appendix A for specific items. This item was designed to measure attitudes toward science, in particular the value of science to self and society. The small sample size (n=13) makes it difficult to generalize these data to a larger population. However, qualitative data collected through interviews supported and expanded on these findings, as described below.

Table 2
Close-ended Likert-scale item results

Item	Dimension	Mean (Time 1)	Mean (Time 2)	p-value (one-tailed)
1	Attitudes toward Science	4.54	5.54	0.037*
2	Attitudes toward Science	4.92	5	0.452
3	Attitudes toward Science	6.23	5.62	0.085
4	Attitudes toward Science	3.84	4.54	0.212
5	Attitudes/Science Practices	3.84	3.77	0.464
6	Science Practices	1.23	1.31	0.410
7	Sense of Place	5.31	4.77	0.223
8	Sense of Place	6.15	5.69	0.128
9	Sense of Place	5.54	5.08	0.246
10	Attitudes/Science Practices	4.23	4.31	0.454

Note: n=13
$*p<0.05$

Open-ended items. Items 11-14 consisted of open-ended questions. In order to analyze these items, a rubric was created for each question that designated a scale number for each of the responses (see Appendix C). Table 3 displays the open-ended Likert-scale items. Items can be found in Appendix A. Of these open-ended questions, item 13, *Describe or draw the components of your class project at Mammoth Hot Springs*, had a significant increase based on the rubrics ($p = 0.01$). This item was designed to demonstrate student understanding of the steps of the PhotoPoints project. This question appeared to result in some confusion from students. Some students drew pictures of the tools used in project, while others described the steps of the project. Therefore it was determined not to use data from this item. Qualitative items provided insight into students' understanding of science practices more clearly than this item.

Table 3
Open-ended Likert-scale item results

Item	*Dimension*	*Mean (Time 1)*	*Mean (Time 2)*	*p*
11	Attitude toward Science	4.85	5.15	0.308
12	Science Practices	3.23	3.46	0.260
13	Science Practices	4.07	4.69	0.010*
14	Unknown	3.38	3.5	0.875

Note: n=13
**p<0.05, one-tailed*

Qualitative Interviews

Interviews were coded and analyzed using grounded theory methodology. Table 4 summarizes the most common themes before participation (Time 1) and after participation (Time 2), which will be discussed in more detail in the following sections.

Table 4
Summary of emergent themes from initial interviews (Time 1) and final interviews (Time 2)

Dimension	Emergent Theme (Time 1)	Emergent Themes (Time 2)
Sense of Place	Recreation Appreciation/respect Learning	Recreation Appreciation/respect Enjoyment
Attitudes Toward Science	Self-concept Beneficial/Important Influence of Teacher	Self-concept Beneficial/Important Personal enjoyment
Understanding of Science Practices*	Asking questions and defining problems Planning and carrying out investigations Obtaining, evaluating, and communicating information	Asking questions and defining problems Planning and carrying out investigations Obtaining, evaluating, and communicating information Analyzing and interpreting data Constructing explanations and designing solutions
Nature of Science	Tools for understanding Discovery Misconceptions	Tools for understanding Discovery Misconceptions
Perceptions of Citizen Science	Learning Public accessibility Contributions	Learning Public accessibility Multiple perspectives

** Science Practices themes as defined by the Next Generation Science Standards Framework (NRC, 2012).*

Sense of place

Several questions in the interview were designed to elicit students' thoughts about their place. A few questions targeted demographic information, such as the amount of time spent living in the Gardiner area. One question was designed to measure the students' understanding of place before and after participation. Another was designed to measure connection to place. One open-ended question, "How do you feel about where you live?" was included to extract the components of place that students identified as meaningful.

Understanding of place. Students were asked questions to specifically measure change in their understanding of place and connection to place. Only two students reported no change in understanding. One of these students stated that this was, "because, before we did this project [our teacher] taught us all about the everything that's up there, then we did the project, so we already knew everything we needed to know before the project, and then we did it."

All other students reported at least some increase in understanding about place after participating in the project. One student, who was reflecting on his observations of the hot springs, stated, "I didn't think that things grew that fast, and now I can see that Yellowstone changes really quick[ly] and it's good to go there once in awhile and inspect your surroundings a little bit." This student's response reflects acknowledgement of the rate of travertine growth and biological changes in the hot springs. Additionally, through this experience some students recognized the processes that shape Mammoth Hot Springs, in other words, the "why" behind the unique hydrothermal feature.

> I've gone up to Mammoth so many times, and I've always just thought of it as beautiful and incredible but it was cool to see why everything happens because I never really thought about what makes it the way it does or why it changes... I

knew the basics already, but I had never really thought about it on a smaller scale, the specifics of anything, so it definitely made me think more how complicated it is here (N010S).

Another student used the rate of change at the hot springs as an example of the many things people have to learn about Yellowstone:

> I had no idea how fast things change up in Yellowstone. It was really interesting and cool to see and hear about how all these people want to live here. It's humbling knowing that people are coming here, and they hardly know anything about the park, but neither do we, we can still learn things about the place we live and that's just … humbling to know that we do not fully understand how things work in an area that's in our backyard (W012W).

The students (n=10) who described an increase in understanding after the project were all influenced by the experiential nature of their project, seeing the change from week to week through observation. This was contrasted by those (n=2) whose understanding did not increase, who demonstrated this by mentioning only content that was presented in class.

Connection to place. Participants were asked during interviews if their connection to place changed since they first learned about the project. Five students described no change in connection to place. However, two of these students claimed to have a deeper connection to place. One stated, “I’ve always had that feeling of wanting to appreciate where I am because it’s so amazing, so I think in that sense I have felt connected already.” Six other participants felt an increased connection to where they live after the project was over. One student felt that,

> … [I] never give enough credit to the area. I've been kind of taking it for granted. We're so lucky living here and I felt ignorant about it but I feel this class has

> helped me get a grasp on the reason why it's important to understand how Yellowstone works and why it's so nice to live here (W012W).

Another explained his awareness of place has grown and he is “more interested in the landscape and what is around.” Many students in this group were also influenced by landscape and topography of their home. When asked how he felt about transitioning to a new town after graduation, one student said, “I know about everything around here mountain-wise, and where everything is, and I will be kind of disoriented for awhile probably, but I'll get used to it.”

In reflecting on understanding of and connection to place, interviews revealed that observing change of hot springs over time increased many students’ awareness to natural phenomena and surroundings that they may have overlooked before. This awareness of natural systems manifested in both understanding of the geological features of Yellowstone and their appreciation and respect for these features.

Sense of place: emergent themes. Students answered several interview questions that targeted the most meaningful components of place. They were asked (a) how they felt about their place, (b) how often they visited public lands, and (c) for what purpose they visited public lands. Table 5 displays emergent themes and quotes from students. Students revealed value in recreation and appreciation of place during both initial and final interviews. Students placed highest value in learning about place during initial interviews, but enjoyment of place during final interviews.

Table 5

Sense of place emergent themes with supporting quotes

Emergent Theme	Time 1	Time 2
Appreciation and Respect	"I've always thought that we were the lucky ones or special ones. My mom always told me all the time to appreciate where you are, so few people get to live here. So I've always thought it was cool. Sometimes I feel I sometimes forget how interesting it is that I live here, so I have to remind myself. I think we are very lucky."	“I feel like there's a lot of people who don't get to have the kind of life that I've had growing up where I live.”
Recreation	"The only reason I go [to YNP] anymore is to go snowmobiling in Cooke City.” "I hunt and stuff. In the winter a lot, in the summers a lot, I'm always outside."	" I do sometimes go on hikes with friends in the park, but I spend a ton of time in the mountains outside horn [antler] hunting and hunting and riding horses and all that stuff, like 90% of my time. I like seeing mountains, some definition to the landscape."
Learning	"My whole life I've lived here, and you pick up on stuff, but I felt like living here you do kind of want to know more about it, because I am asked a lot of questions.”	
Enjoyment of Place		“Well, this is the first national park, it's really nice, it's a really touristy area, but it's really nice, mountainous, and I could not live in a flat area.”

During initial interviews, the most common themes of place that emerged, in order of frequency, were (a) desire to learn about place, (b) connection through recreation, and (c) appreciation and respect of place. Most students reported that their major influence in taking Yellowstone Science class was to learn more about the geological and ecological features of their local park. In final interviews, enjoyment of place emerged most frequently, followed by recreation and appreciation and respect. Students' responses revealed that while many enjoyed recreating outside, some sought out the park for recreation, while others actively avoided it. For example, as shown in Table 3, one student's "only reason to go to YNP anymore is to go snowmobiling in Cooke City," while another stated, " I do sometimes go on hikes with friends in the park." Overall, these responses reveal that students had a deeper connection to natural components of place rather than cultural components of place, likely related to their use of public lands for recreation during free time.

Sense of Place Discussion: Attachment, Dependence, Identity. Student interviews suggested that many students have a strong sense of place. It was more challenging, however, to identify specific components of place in students' responses. The components of sense of place as described by Kudryavtsev et al. 2011 include place meaning and place attachment. This study provides several examples of place attachment. Three of the four emergent themes reflect place attachment: enjoyment of place, appreciation and respect, and recreation. Place dependence, an element of place attachment, was reflected most strongly in recreation. Many students referred to how mountains and climate provide opportunities to recreate in all seasons, from snowmobiling in winter to hiking in spring and summer to horn hunting in fall. Many students in this group spend a significant amount of time outside. One student explained how he understood local topography and would be disoriented if he moved to another place, which may be a form of place identity or place meaning. It is important to note that individuals can hold a positive, negative, or ambivalent sense of place (Kudryavtsev et al. 2011). No negative themes emerged about place, however a few students expressed their dislike of Yellowstone crowds, small community, and spending time outside.

The increase in understanding of place but not connection to place may support the idea that learning is one way to develop a sense of place. Kudryavtsev et al. (2011) discussed how although both direct and indirect experiences can influence a sense of place, long-term, frequent direct experiences with places will likely have a more powerful impact. Active engagement with place can further drive place attachment. Considering the short-term of this project, long-term community monitoring projects or stewardship would likely lend more direct experience and indirect learning to form a sense of place.

Attitudes toward science

Students were asked several questions during interview to target attitudes toward science. These included:

- Why did you decide to take Yellowstone Science?
- What do you think of science?
- When you first learned about the project, how did you expect to feel about it, and how do you feel about it now?

Attitudes toward science: emergent themes. Students' responses to these first two questions revealed several attitudes toward science and their projects. The initial emergent interviews themes were (a) science self-concept, (b) science is beneficial and important, and (c) the influence of their teacher. Themes that appeared after participation included (a) science self-concept, (b) science is beneficial and important, and (c) enjoyment of science. Table 6 displays the attitudes that emerged before and after participation.

Many students stated that they believe science benefits humans in some way. However, some of their responses were vague. For example, one student stated, “I think [science is] the future of all of people and we definitely need to invest in it and focus on it, whatever it is.” This suggests a lack of understanding of nature of science, which will be described below.

During the final interviews, common themes included (a) science self-concept, (b) science benefits humans, and (c) personal enjoyment of science. Students’ descriptions of the benefits and importance of science as well as self-concept were similar to their responses from Time 1. However, the most common theme that emerged after participation was a personal enjoyment of science, which was not mentioned before participation.

Table 6

Attitudes toward science emergent themes with supporting quotes

Emergent Theme	Time 1	Time 2
Self-concept**	"I had some troubles in other classes but science has always been a strong suit to me. I've always liked it, so I take as much science as I can." "It's hard, complicated."	"Science has never been something I've been very good at, but I thought it would be more helpful than what I was taking, so I wanted to learn more about stuff I could apply myself a little more." "It's confusing. I just know it's everywhere."
Beneficial/ Important	"I believe it helps us advance and learn more about the world we live in." "I think it's an important thing that people should be researching more to further people's ideas and stuff like that."	"I think science is the greatest tool created by mankind, it helps us understand how things work, what we need in order to progress our civilization and to evolve our minds."
Influence of Teacher	"A lot of people are taking it because it's supposed to be an easy class, which it is if you like it, if you don't like it, it's not." "I learned more from [my teacher] than any other teachers I've had. She's helped me understand science a lot better."	
Personal Enjoyment of Science		"I like it a lot. It's super cool and how everything kind of comes together in science." "I like it because it's the study of the world basically."

*** Self-concept was a theme that represented students' impressions of personal abilities in science. Self-concept responses spanned*

When the students were asked how they felt about the project before they began and after their participation ended, four students reported no change in their attitudes toward the project. All others' attitudes changed regarding their project. For some, this was one of their major outcomes of the experience. One student described how the project influenced his personal attitudes by saying,

> I really do enjoy getting out, … into Yellowstone, it brings back memories …and not only does this project enlighten us and allow us to gain knowledge about Yellowstone but it also brings us together in a natural place. … my attitude … has changed, from then to now (W012W).

The student's statement about convening together in a natural place also displays a link between sense of place and attitudes toward science.

Attitudes Toward Science Discussion: Motivations and Attitudes. Results suggest that students felt that they personally enjoyed science more after participating in the project. As described in Chapter 3, attitudes were aligned with the measures from the mATSI inventory. The emergent attitudes are followed in parentheses by the mATSI attitudes to which they aligned. The most common attitudes that emerged from interviews fell into self-concept (self-confidence in science), science is beneficial (value of science to society), science is important to humans (value of science to society), personal enjoyment of science (desire to do science), and influence of teacher (perception of the teacher).

Additionally, quantitative survey items 1, 3, and 4 correlated to the mATSI variable Values of Science to Society. Item 2 correlated to the Desire to do Science variable. The rubric used for item 11 was developed with the themes that emerged from qualitative data, including self-concept, importance to self and society, personal enjoyment, and influence of teacher which again correlate to the mATSI variables as described above.

A primary interest in the current study was to understand how student attitudes might change, as they did not choose to volunteer for this project in the same way as traditional citizen scientists. Some motivations for taking Yellowstone Science class did not align with the motivations of volunteers in previous studies. The initial motivations of volunteers identified by Rotman et al. (2012) was personal interest in material but influenced long-term by feedback and recognition from researchers and community involvement. Before participating, several students reported registering for Yellowstone Science because they learned more from this science teacher or believed her class would not be challenging. This initial attitude suggested a lack of personal interest or personal choice in participating in the project. However, a shift in motivational attitudes emerged from beginning to end of the study. After participating, a personal enjoyment of science was the primary attitude presented by students. Although this study was short and contained a small sample size, it would be interesting to see how attitudes and motivations toward citizen science and science in general change in a classroom setting in larger, longer-term classroom citizen science projects.

Lastly, interviews provided a deeper insight into the complexities of attitudes toward science, including ambivalence. Ambivalence, or “mixed-feelings” attitude, has been a challenging variable for scientists to measure using quantitative methods (Brossard et al. 2005).Brossard et al. (2005) suggested that standardized attitude instruments might not fully capture the complex attitudes toward science such as ambivalence, and recommended that interviews supplement quantitative surveys. The current study addressed the shortcomings of quantitative studies by coupling interview questions that matched some of the quantitative questions regarding student attitudes. In interviews, students revealed some of their complex attitudes that allude to feelings of ambivalence. Although ambivalence was not one of the common emergent themes, a few students presented this attitude.

Understanding of Science and Engineering Practices

A Framework for K-12 Science Education (NRC, 2012) outlines the following Science and Engineering Practices used in the NGSS (NGSS Lead States, Appendix F, 2013, p. 1):

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

These practices were used in this study to analyze student responses and evaluate students' understanding of science practices. During interviews, students' understanding of science practices was measured through several questions, including:

- Please describe the PhotoPoints project that your class is participating in.
- What is your role in the project?
- What are some outcomes that you expect for the end of the semester?
- How would you design and carry out a scientific investigation?

Of the eight SEPs, students mentioned to three during initial interviews and five during final interviews. Before participation, students described the following three SEPs: (a) Asking questions and defining problems, (b) Planning and carrying out investigations, and (c) Obtaining, evaluating, and communicating information. After participation, students described the following five SEPs: (a) Asking questions and defining problems, (b) Planning and carrying out investigations, (c) Analyzing and interpreting data, (d) Constructing explanations and designing solutions, and (e) Obtaining, evaluating, and communicating information. See Table 7 for examples of student responses containing descriptions of SEPs during the initial interview (Time 1) and during the final interview (Time 2). Below the significance of recognizing and understanding SEPs in a citizen science project are discussed.

Table 7

Emergent Science and Engineering Practices (SEPs) with supporting quotes

SEP	Time 1	Time 2
Asking questions and defining problems	"I expect to be able to see the time-lapse some pretty good growth on the travertine" "I would probably do a lot of research first before to see what other people did before I go out here and look at what I'm trying to discover"	"First I'd probably ask what the relevance to going to understand what I'm trying to find out. Trying to find out benefits starting this would have on me and other people it would benefit. The whole process as why this should be understood."
Planning and carrying out investigations	"First you look at your topic, and hypothesize, take an idea, come up with a process by which to investigate your idea, and repeat that process several times to validate yourself, then record your results."	"Then I would set up an experiment with the control and with something else, with the varying factor, change it, and would observe those two differences and I would repeat the experiment several times and then I would record my results each time and share at the end."
Obtaining, evaluating, and communicating information	"And people will be able to look at that and learn from it, like other people will be able to from our research and expand from it." "Help other people that want to look at the research."	"We had a presentation that showed all of the weeks, what the pictures were, how they changed, and how much they changed in characteristics"
Analyzing and interpreting data		"When I made my power point, I went from week one to week three to show the different levels of biodiversity that changed."

Constructing explanations and designing solutions	"Well we went out today and made our predictions [for next year], and for the majority we predicted [the travertine deposits] would expand, there was one or two thought that I thought would decrease, would drain out. That was interesting because at first I thought they would all get bigger, but I started to change my mind… because, … it's been two weeks since we went the last time and there was one in particular that had started getting bigger over the weeks and we came back and it was a lot smaller and I was shocked at how drastically it had changed the other way, than what it had previously been doing. "

Using scientific language. At first glance, it seemed that many students did not us scientific language to describe their experience. For example, one student stated: "First I'd probably ask what the relevance to … find out benefits starting this would have on me an people it would benefit. The whole process as why this should be understood." The studen referring to defining the problem and purpose of the study, but does not use the language. occurs throughout students' interviews.

However, several interviews demonstrated that from the beginning to end, some st language and vocabulary evolved from vague explanations to specific descriptions. Studer descriptions of variables exemplify this outcome. Table 8 contains three examples of stud descriptions of the PhotoPoints project before and after their participation. At the beginnir the study, most students described the study using vague terminology and less descriptive After their participation, students were able to provide specific variables being measured, example, they specifically mentioned water flow, biofilm color, debris, and facies.

Table 8
Students' abilities to describe specific variables during project

	Time 1	Time 2
Student A	"To see how the growth of the hot springs over the year by taking a picture at a still place where it is an exact location so you can get a good perspective of how much growth there is."	"We looked at the coloration, the flov what kind of debris was laying there. day we might get a tree limb and mig be there the next day and stuff like th and it was just to see how quickly the terraces are growing."
Student B	"There are brackets around the terraces and you take pictures along the terrace, and just see the photos points and views of the park there."	"We go up to Mammoth, walk the boardwalk up by the hot springs, and pictures where the brackets are by the boardwalk and record how much flov biofilm, something else, and facies ar there."

Student C	"We are able to go up there once a week and have little brackets that we take pictures of it like eight different photo points. And we are making a time lapse of it so we will be able to go back and see the growth of it over time."	"We walked around Mammoth to these photo points at these brackets where you put your camera so the pictures look the same every time. We had a sheet of paper we filled out like the name of the photo point, a description of it, like if there's any debris or anything around, how much water is flowing, just filled that out every Thursday for three weeks."

Understanding of Science Practices Discussion. Both quantitative and qualitative data supports that students' understanding of science practices increased during participation in the project. Participants identified or referred to only three SEPs before participation, but five during their final interviews. Additionally, many were able to describe the specific variables measured after participating in the project. These results support the significant increase in student understanding of science practices from the survey (Item 13: Describe the components of the PhotoPoints project, p=0.01). However, in interpreting interviews for SEPs, students' understandings of science practices were revealed mostly through context-specific responses. For example, students were able to describe how to carry out this particular study, but only a few described the steps of the scientific process when asked, "What steps would you take to carry out a scientific investigation?" Survey results also suggest this relationship, as Item 12 showed no significant change (Item 12: In your own words, describe what it means to do scientific research, p=0.26).

Appendix F of the Next Generation Science Standards outlines the rationale, guiding principles, and performance expectations for each of the eight SEPs (NGSS Lead States, 2013). By high school, students are expected to understand and perform all eight practices. Most students were unable to describe the core meaning in these practices, such as asking questions, making hypotheses, and drawing conclusions using the scientific language. However, some students were able to describe these steps in context as they related to the PhotoPoints project without using the general terms. Some informal science projects have found a significant increase in scientific knowledge using general science inventories, such as the STaRRS STSP presented in Houseal et al. (2014). However, few citizen science projects have been able to accomplish this finding using general inventories. Cronje et al. (2012) found that scientific knowledge increased when participants were assessed with a context-specific instrument, but not with general scientific knowledge instrument. It is possible that citizen science projects, such as the current project, promote field of study or science content rather than understanding of science practices, or that participants think about practices in a contextual way.

Additionally, interviews revealed that students used minimal scientific language when describing the PhotoPoints project. Several students' scientific language advanced from Time 1 to Time 2, which indicates they may feel more comfortable using scientific language by describing variables, materials, and methods more fully. A guiding principle from NGSS Appendix F states, "engagement in practices is language intensive and requires students to participate in classroom science discourse" (NGSS Lead States, Appendix F, 2013, p. 2). Communicating with peers and community during a citizen science project would be an excellent approach for practicing scientific language.

Challenges in measuring Understanding of Science Practices. There were many challenges in measuring students' Understanding of Science Practices (USP). During the first round of interviews, questions were designed to measure this variable in several forms. All students were asked to describe the PhotoPoints project, but this question did not target specific SEPs, so more pointed questions were added to elicit responses. First, students were asked to describe all of the steps of this project. Additionally, some were asked to describe all of the steps they would take in carrying out their own scientific investigation. Some were then asked to describe the scientific method. Several students appeared anxious when asked questions about the scientific process rather than in the context of the project. Some were unable to answer when asked what steps they would take to carry out their own investigation. These students may have felt as if they were being tested with these questions. In searching for the appropriate question to measure students' USPs without eliciting anxiety, it was difficult to reliably identify science practices that emerged in interviews at Time 1. During final interviews, there were more questions asked about USPs for some students based on responses to questions. Therefore, it is not surprising that qualitative data revealed more SEPs during final interviews.

In addition, some SEPs emerged in response to specific questions. All students were asked how they hypothesized the hot springs would change over time, both before and after participation in the project. However, responses to this question were not applied to any SEPs unless students used evidence or background information to support their hypotheses, which would align with the "Constructing Explanations and Designing Solutions" SEP.

Nature of science

In each interview, students were asked to define science. Their responses fell across a large spectrum from no response to extensive explanations. Table 9 organizes the major themes that emerged at Time 1 and Time 2: (a) science is a tool for understanding how the world works and (b) science is a process of discovery and learning.

Several misconceptions about the nature of science also emerged during the interviews. Here misconceptions was used as an umbrella term for definitions in which students either could not verbalize a definition or demonstrated misconceptions about the nature of science. Students had misconceptions both before and after participating in the project. Some responses defined science contextually "the science of all life and living things," in this case referring specifically to biology. Others described science in a very vague way, or as "the study of everything."

Table 9
Nature of Science emergent themes and misconceptions

Emergent Themes	Time 1	Time 2
Tools for Understanding	"A way of reasoning through natural phenomena … it's an informative tool"	"Fundamental tool used to understand the surroundings and how things work."
Discovery and Learning	"The pursuit of learning and knowledge having to do with math and technical based things rather than history and philosophy." "The discovery of new things, the exploration of different fields of stuff."	"Studying nature and other things that have never been studied or discovered before, people learning about it." "It's the constant discovery of new things, always learning more and exploring more."
Misconceptions of Science	"A whole bunch of small things" "I don't know, like everything that exists pretty much." "The study of everything I guess."	"Particles and mixed up organisms." "I would define science as pretty much everything, I don't know, everything has to do with science."

Nature of Science Discussion. Nature of Science dimension was not measured intentionally, however, the interview question, "How do you define science?" produced a fascinating spectrum of responses from students. In fact, improving understanding of the nature of science has been identified as a critical component of education reform and is highlighted in the Next Generation Science Standards (NRC, 2012). The nature of science themes that emerged from interviews were science is (a) tool for understanding and (b) discovery and learning. Some student definitions do align with Nature of Science principles. For example, "the pursuit of learning and knowledge having to do with math and technical based things rather than history and philosophy" aligns to the NGSS principle "Science is a way of Knowing," and science is "a way of reasoning through natural phenomena … it's an informative tool" aligns to the principle "science models, laws, mechanisms, and theories explain natural phenomena" (NGSS Lead States, Appendix H, 2013).

The results of this study also indicate that there are widespread misconceptions among high school students about the nature of science. A significant portion of participants displayed misconceptions about science. Many studies have explored avenues in which students best learn the nature of science. Khishfe and Abd-El-Khalick (2002) compared middle school students' understanding of the nature of science through implicit involvement in science inquiry and explicit, reflective inquiry. Students in implicit inquiry group showed no informed conception of the nature of science, while students exposed to an explicit and reflective approach showed significant increases in understanding. Because it was not an initial focus of this project, explicitly presenting the nature of science were not promoted in methods. It is likely that if nature of science principles were made explicit, there would be fewer misconceptions of science and more emergent themes that aligned with nature of science principles outlined in NGSS Appendix H. Additionally, these misconceptions may reflect a general focus on science content knowledge in high school and not on the nature of science.

Perceptions of citizen science

The final question of all interviews aimed to understand students' impressions of the purpose of citizen science. Students were given a few examples of citizen science projects, including their own, and asked what they believed was the purpose of these projects. Although this dimension was not anticipated at the beginning of this study, students provided interesting responses that fell into several themes. Table 10 displays students' responses as themes that emerged during initial and final interviews.

Table 10

Students' impressions of citizen science emergent themes

	Time 1	Time 2
Learning	"They can teach other people and have other people be informed about the park and see how often it changes."	"When citizens get into [science], it makes us more knowledgeable about where we live and what's happening, so I think it's helping ordinary people, expand knowledge and everything, and when more people know about it, more people have ideas about it."
Public accessibility	"People like me that are just students or people that are not really scientists get to be involved in a research project like this" "To prove that the general populous can help us with scientific studies."	"I guess it's trying so you don't have to be a big shot scientist, trying to involve everyone, everyone can be a part of doing these different projects. There's so many aspects to it, so everyone will be able to find something they are interested in or they are good at."
Contribution to large-scale project	"You can get a lot more people involved in it, and the more people that care, the bigger impact on what you're researching." "Not only to help further our understanding, but to help the geologists and scientists of the Yellowstone area to keep track of data of how much these are growing."	
Multiple Perspectives		I think the purpose is not just to get the scientists' views but everyone's view, so you can get a better range of ideas and people's observations. It's not all going to be in one area, it could be in different parts of the country, you will get a wider variety of hypotheses and observations and stuff." "It can show scientists who are used to trying something if they are stuck on something, but if they had citizenship science, people giving their opinions whatever they think, look at whatever they're trying to do with a different point of view or perspective could

Table 10 only describes the most common themes that emerged. There was significantly more consensus about the purpose of citizen science projects at the end of the project. During the first interview, about 12 total themes were discussed, while the second interview responses fit into four themes. The most common themes identified during initial interviews were learning about science, contributing to large-scale project, and public accessibility to science. During final interviews, the most common themes that emerged were learning about science, public accessibility to science, and citizens providing multiple perspectives. Students also provided longer, well-articulated responses after participating in the project.

Perceptions of Citizen Science Discussion: Citizen Science and Democratizing Science. During final interviews, several students described the purpose of citizen science as a way for citizens to provide alternative perspectives by asking questions, making observations that may differ from scientists, and giving feedback to improve projects. This feedback may reflect changes in students' impressions of citizen science from the beginning to the end of the project, and supports citizen science as an avenue for democratizing science. This supports previous findings that there are social and scientific benefits to citizen science, in which citizens' local knowledge and perspectives can lend to creative solutions or applications of scientific knowledge (Freitag et al., 2013).

Additionally, students' shifted one perception of citizen science from Contributing to Science (Time 1) to Multiple Perspectives (Time 2). The shift in perception alludes to the collaborative nature of this project, in which students participated with teacher in the design process. Students had more ownership over development and sharing of project. Although there was no scientist using their data, their responses suggest that they see learning value in citizen science.

Summary

Although I had only anticipated measuring the three variables above, the design of interviews and surveys provided insight into two additional dimensions of students’ experiences: understanding of nature of science, and perception of citizen science projects. Quantitative data did not yield results of any power, as the sample size was very small. However, qualitative data revealed important insight into students’ knowledge and attitudes.

Students reported an increase in understanding of place, but not connection to place, after participating in the PhotoPoints study. Emergent themes indicated that some students exhibit place attachment, particularly place dependence, through recreation, enjoyment of place, and appreciation and respect for place. Student attitudes toward science in the class revealed that students initially did not exhibit many of the same attitudes toward science and citizen science projects as volunteers from other studies. A major motivator for many students to take the Yellowstone Science class was their attitudes toward their science teacher. After participation, the major attitude that emerged was a personal enjoyment of science, suggesting students may not have been initially motivated by this attitude, but enjoyed their experience participating in a citizen science project.

There was a significant increase in understanding science practices from survey and interviews, however students were only able to identify five of eight of the scientific practices after participation and did not use scientific language. The nature of science dimension that emerged from interviews revealed that there are significant misconceptions about science, and that explicitly connecting these to scientific inquiry can inform student conceptions. These findings suggest that participating in citizen science may not be able to increase scientific literacy by itself, but coupled with explicit lessons about the scientific process. Lastly, students identified the major goals of citizen science. Several highlighted the democratic benefits of citizen science, in which citizens can offer multiple perspectives to scientific research. Student impressions of citizen science suggest students value their own contributions and role in this project.

Conclusions

This project was a mixed methods study to investigate the influence of participating in a citizen science project in Yellowstone National Park on local high school students' understanding of science practices, attitudes toward science, and sense of place. Several studies have measured the impacts of citizen science on volunteer attitudes and scientific knowledge, but few have investigated the same influence on students in a classroom setting. Previous research on student-teacher-scientist partnerships, similar to citizen science projects, demonstrated that participatory research between students, teachers, and scientists could yield significant increases in scientific literacy and shift attitudes toward science (Houseal et al. 2014). Therefore, it was hypothesized that incorporating the PhotoPoints citizen science project into a high school course would increase student understanding of scientific practices and support development of positive attitudes toward science. Additionally, due to the place-based nature of this project, in which students lived only a few miles from the study site in iconic Yellowstone National Park, it was hypothesized that engaging in a citizen science project would elicit an increased sense of place in students.

Findings from this study support the hypothesis that citizen science projects can influence scientific knowledge, attitudes, and sense of place. However, the degree to which this project influenced each of these outcomes varied. The high percentage (85%) of students that reported an increased understanding of place during interviews (n=11) suggests sense of place was influenced significantly. Students reported substantial changes in their understanding of place, citing specific examples of what they learned about their local National Park.

It was impossible to determine whether project participation itself impacted these variables, if these were a result of teacher-delivered content, or a combination of both. Based on the significant amount of classroom time dedicated to learning about these hydrothermal features and preparing for field project, one could assume that content had at least some influence on these outcomes. Although this was the only section of Yellowstone Science offered during this semester, a control group from another science class would help to shed some light on these relationships. Similarly, changes in sense of place and attitudes toward science likely were not caused directly by experience. However, certain student responses indicated that the project directly influenced their understanding of place or connection to place by providing examples. For example, one student stated, “I didn’t think that things grew that fast, and now I can see that Yellowstone and everything like that changes really quickly and it’s kind of good to go there once in awhile and inspect your surroundings a little bit” (PJ017T). This student referred to both specific content knowledge (rate of growth and change in Yellowstone) and value of understanding place (it is good to inspect surroundings).

One of the most important outcomes of this study was its exposure of misconceptions about the scientific process and the nature of science. For over a decade, young students have performed well in standardized tests compared to counterparts in other countries. However, performance decreases as students get older (Falk & Dierkling 2010). Adults in the U.S. consistently outperform adults in other countries in science, which Falk & Dierkling (2010) attribute to exposure to informal science experiences such as museums or scientific television programs. This argument is bolstered by studies in which volunteers' scientific content knowledge improved after participating in citizen science projects (Brossard et al. 2005). Houseal et al. (2014) also indicates that student-teacher-scientist partnerships resulted in significant increases in scientific knowledge for both students and teachers. With these successful outcomes for adults and young students, and with the addition of the current study's findings to this body of knowledge, there is certainly a strong correlation between scientific knowledge and citizen science. If teachers and researchers intentionally design projects to highlight the steps of the scientific process and the elements of the nature of science during the project, perhaps students can confront these misconceptions through participation.

Students' perceptions of citizen science presented further evidence of the benefits of citizen science in classrooms. The "multiple perspectives" emergent theme highlights the students' values in their role as participants. It provides support for the power of collaborative projects in democratizing science. Additionally, this perception suggests students may have a stronger understanding of another important element of the nature of science: "science is a human endeavor." Therefore, when all of the dimensions measured in this project are considered together, they piece together, one can see that dimensions are related. In other words, findings illustrated that students' sense of place and scientific knowledge are likely interconnected. Students' impressions of citizen science and ability to describe their project both reflect on their conception of the nature of science. Additionally, students' attitudes toward science may be related to their understanding of science practices. Instead of considering the influence of citizen science on individual dimensions, this study suggests that citizen science can be used as holistic, place-based tool to connect these dimensions and develop the whole learner.

Limitations

Fulfilling the parameters of citizen science. As discussed in chapter three, many compounding factors reduced the length and scale of the PhotoPoints project. In developing this project, I was very focused on the details of setting a project timeline of pre-tests, student data collection, and post-test. While many components of the Yellowstone Science class and PhotoPoints project provided students with an enriching experience, I question whether or not I can define this as a full-scale citizen science project. The Yellowstone Science teacher and I did not set in place a plan for the future nor establish a long-term collaboration with any scientists who would be interested in using the data. We did have a few informal conversations with Yellowstone personnel about potential extensions of the project, but I did not follow-up during the next school year (2014-2015). I believe there is a great deal of potential in this project as a long-term student-driven citizen science project in collaboration with the park, and believe that the outcomes of this project would help inform the preparation, process, and outcomes of a successful citizen science project.

Potential sources of error. It was difficult to run any statistical analysis on data of such low power (n=13). It is likely that a larger sample size would produce different results, and certainly results that would be a more valid representation of the population.

Potential bias. Qualitative data provided rich insight into the experiences of participants of this study. However, the nature of qualitative data collection and analysis leaves the potential for research bias or misinterpretation of information. If more time and resources were available, I would have verified my transcripts of interviews with students to ensure that my analysis accurately represented their attitudes and understandings. Additionally, although students were informed that their responses during interviews would not be shared with teachers or reflect on their academic performances, it is possible that students' responses were influenced by the presence of an outside researcher.

Recommendations for Classroom-based Citizen Science Projects

The outcomes from students' experiences and impressions of the PhotoPoints study presented both successes and challenges of implementing citizen science projects in a high school classroom. Considering the goals of citizen science projects, the types of projects (contributory, collaborative, co-created), and the abilities of diverse classrooms, the following recommendations may help guide teachers and researchers in developing successful projects.

1. Connecting context-specific understandings to Understanding of Science Practices: Because these data support previous research that context-specific assessment reveals increase in knowledge of natural processes and understanding of science practices, it is essential that Science and Engineering Practices are explicitly discussed in relation to the project. In doing this, students will understand that all scientific investigations, citizen science or otherwise, utilize SEPs.
2. Directly/Explicitly confront misconceptions about science: From this study, it is apparent that there is a broad spectrum of misconceptions of the nature of science, as illustrated in students' efforts to define science. However, citizen science is a promising pathway to confront misconceptions about the nature of science. Through scientific investigation, including citizen science, students should be introduced to the principles of the nature of science that apply, as outlined in the Next Generation Science Standards (NRC, 2012).
3. Determine project goals and objectives, then choose the type of citizen science project that will best meet objectives for students (contributory, collaborative, co-created). For example, if the teacher's goal is to connect students to an issue in their community, a co-

created project would be appropriate. Consider time, resources, and access to professional researchers.

4. Motivations and attitudes: Voluntary participation is essential to the nature of citizen science. Integrating citizen science into a classroom with mandatory attendance and participation may lead to challenges motivating students in the same way as traditional citizen science volunteers. Recognizing the different motivations of participants will lead to continued collaboration and participation (Rotman et al., 2012). Teachers should consider differentiating participation in classroom citizen science by harnessing students' individual interests in planning and carrying out project.

Future Research

Future projects could expand on the findings of this project to investigate the outcomes of citizen science projects. Interviews from this project provided a vast amount of qualitative data that was coded specifically for the dimensions that were measured. This data could be analyzed using other variables to provide insight into different aspects of students' experiences. In addition to the two dimensions of NGSS that were analyzed in this study (Science and Engineering Practices and Nature of Science) responses could be analyzed for understanding of Cross-Cutting Concepts. This project was designed to align with the "Stability and Change" cross-cutting concept, and it would be interesting to measure students understanding and awareness of this concept.

Due to the significant misconceptions of the nature of science exposed in this project, it is recommended that future research investigate the influence of a citizen science project in developing an understanding of the nature of science. In addition to this, researchers could consider coupling a project with intentionally designed classroom activities to target nature of science principles and science and engineering practices explicitly.

Lastly, it would be interesting to follow changes in student attitudes, scientific knowledge, and sense of place over time. A longitudinal study measuring these variables on students participating in a long-term, established project would provide insight into how citizen science can influence students as they develop into informed, democratic citizens.

As the field of citizen science continues to evolve, it will be exciting to follow the progress of incorporating citizen science into formal classrooms. As illustrated in this and other participatory science research studies, citizen science has the capacity to be a powerful, holistic tool to promote place-based values, positive attitudes toward science and scientists, scientific literacy, and democratic classrooms.

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Appendix A

PhotoPoints Project Questionnaire

Student Code: ____________________

Birth month/year: ____________/_______

Gender: M F

How many years have you lived in Gardiner? ______________

Have you ever participated in Expedition: Yellowstone! Yes / No / I'm not sure

Please rate the following on a scale of 1 (strongly disagree) to 7 (strongly agree):

1. Science is important in my everyday life.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

Please explain:

2. I believe that I will use scientific knowledge and skills throughout my life.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

Please explain:

3. I believe science can be beneficial.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

Please explain:

4. I believe science can be harmful.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

Please explain:

5. Only certain people are able to do science.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

6. Every question in science has been answered.

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

Please explain:

7. I feel connected to the **cultural heritage** of the place I live:
****Cultural heritage:** legacy of physical artifacts (structures, etc.) and intangible attributes (history, stories)

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

8. I feel connected to the **natural surroundings** in the place that I live:

1	2	3	4	5	6	7
Strongly			Neutral			Strongly

Disagree Agree

9. I feel that the place I live has influenced my interests in life:

1	2	3	4	5	6	7
Strongly Disagree			Neutral			Strongly Agree

Please rate on a scale of 1 (no understanding) to 7 (full understanding):

10. When you read the phrase "scientific research," how much do you feel you understand it?

1	2	3	4	5	6	7
No Understanding			Some Understanding			Full Understanding

Please Explain:

Please answer the following questions:

11. In a few sentences describe your views about science:

12. In your own words, describe what it means to do scientific research:

13. Describe or draw the components of the your class project at Mammoth Hot Springs.

14. Use the space below to answer the following prompt about **Mammoth Hot Springs**:

I used to know:

Now I know:

Appendix B

Sample Interview Questions

The following are sample questions that were asked in interviews. Not all questions were asked in each interview, and in some cases students were asked to elaborate more about their responses with additional questions:

- How long have you lived in the area?
- How often do you visit the park, national forest, and other surrounding public lands?
- How do you feel about the place where you live?
- Why did you decide to take the Yellowstone Science class?
- What do you think of science?
- Can you define science?
- Please describe the PhotoPoints project that your class is participating in.
- What is your role in the project?
- What are some outcomes that you expect for the end of the semester?
- Since beginning your participation in this project, have you noticed any difference in your understanding of the place where you live? Have you noticed a difference in your connection to the place where you live?
- When you first learned about the project, how did you expect to feel about the project? How do you feel about it now?
- What do you think the purpose of citizen science projects is?

Appendix C

Open-ended Evaluation Rubrics

Table 1
Item 11: In a few sentences, describe your views toward science.

Dimension measured	Rating
Self-Concept: How does the student rate his or her performance in science? Low self-concept demonstrated through "Science is hard" or "I'm not good at science." High self-concept is demonstrated through: "I've always been good at science"	1= low 4= average 7= high
Importance to self: How important is science to student personally?	1= not important 4=somewhat important 7=very important
Benefits to Society: How does science benefit society?	1=harmful to society 4=no benefit 7=very beneficial
Personal Enjoyment: Does the student personally enjoy science?	1= strongly dislikes science 4=ambivalent 7= strongly enjoys science
Influence of Teacher: How does teacher influence student's attitudes toward science?	1= Negative influence 4= no influence [illegible]

Table 2

Item 12: In your own words, describe what it means to do scientific research.

Dimension measured	Rating
Understanding of Science Practices (General)	1= No understanding of scientific research The Student was unable to describe science practices.
	2-3= Poor understanding of scientific research The student provided a definition without any mention of SEPs or steps of scientific process.
	4= Some understanding of scientific research The student provided vague or incomplete response that includes at least one SEP or step of the scientific process.
	5-6= Proficient understanding of scientific research The student provides several SEPs or many steps of the scientific process.
	7=Full understanding of scientific research The student demonstrates understanding through SEPs and/or description of all steps of the scientific process.

Table 3
Item 13: Describe or draw the components of the your class project at Mammoth Hot Springs.

Dimension measured	Rating
Understanding of Science Practices (Contextual)	1= No Understanding of the project. Student was unable to describe any part of the project. 2-3= Poor understanding of the project The student provided a vague description of the project. 4= Some understanding of the project The student provided a description of one component of the project. 5-6= Proficient understanding of scientific research The student provides several components of the project or description of project. 7=Full understanding of scientific research The student demonstrates understanding through detailed description of the project.

Table 4

Item 14: Use the space below to answer the following prompt about Mammoth Hot Springs

Dimension measured	Rating
Sense of Place (Connection to place, understanding of place)	1= No change in sense of place. The student provided a response similar to "I don't know."
	2-3= Little change in sense of place. The student provided a vague response.
	4= Some change in sense of place The student provided at least one specific gain in content or connection to place.
	5-6= Considerable change in sense of place The student provides at least two gains in understanding and/or connection to place.
	7= Significant change in sense of place The student provides more that two changes in understanding and/or connection.
Understanding of Science Practices	1= No change in understanding of science practices
	2-3= Little change in understanding of science practices The student provides vague or incomplete response alluding to SEPs or nature of science.
	4= Some change in understanding of science practices The student describes at least one change in understanding of SEPs or nature of science.

	5-6=Considerable change in understanding of science practices. The student describes at least two changes in understanding of SEPs or nature of science. 7= Significant change in understanding of science practices The student provides at least three changes in understanding of SEPs or nature of science.