STUDENT AS SCIENTIST: MEASURING OUTCOMES OF

CONTRIBUTORY AND COLLABORATIVE CITIZEN SCIENCE

by

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ABSTRACT

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and Collaborative Citizen Science

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Citizen science offers a possible avenue for scientific inquiry in K-12 science education. Citizen science projects are growing in number and are being recognized as a powerful tool for teaching science that is relevant, meaningful, and place-based. A citizen scientist is someone who contributes voluntarily to scientific research. Most citizen science projects follow a contributory model in which participants collect data for scientist-driven research. In contrast, participants in a collaborative citizen science model work with scientists to develop and conduct research. In an effort to understand the differences in educational impact between these models, I assessed outcomes relating to scientific content knowledge, skills involved in the nature of science, and attitudes towards science. I exposed 76 middle school students to two versions of a curriculum based on a citizen science project called Bugs in Our Backyard and measured differences between pre and post test scores. Students across both treatment groups showed improvement in understanding of scientific content knowledge. Differences between treatment groups were not statistically significant. This research contributes to methods for assessing scientific inquiry, illuminates challenges of implementing contributory citizen science in a school setting, and provides suggestions for how to facilitate citizen science for the purpose of science education.

This thesis is dedicated to Super Snake, the 7-yr-old who taught me how to be a Salamaster. And to Kit-Kat, fellow Salamaster.

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Ch. 1 – Introduction

1.1 Background

Citizen science projects, in which amateurs engage in scientific research, have been growing in popularity over the past decade. A conglomerating website for citizen science projects lists over 1600 projects and events ("SciStarter," n.d.). Many projects are being integrated into K-12 public school programs as a way to raise interest in the sciences, bring authentic experiences into the classroom, and build skills related to scientific inquiry. Science educators are finding citizen science to be especially useful in the latter as science education standards in the United States shift from a focus on content to a 'three-dimensional' approach to learning about science, emphasizing process and patterns in context to specific content. The challenge for both educators and citizen science project developers is to maintain rigor of data collection and relevance to the scientific community while also allowing students to take meaningful part in the entire scientific process (research question formation, method design, data collection, communication of findings, etc).

Citizen science projects range in their level of participant involvement in the research process and have been grouped into three categories by Bonney et al. (2009): a) Contributory: projects are designed by scientists but utilize citizens for data collection, b) Collaborative: projects are structured by scientists (especially in terms of research question), but citizens have the freedom to refine, edit, analyze, and communicate findings, and c) Co-created: projects that are jointly designed, carried out, and communicated by both scientists and citizens with the scientist acting as a guiding expert (Table 1). Most projects are considered contributory, with the participants collecting data

that is given to the scientists orchestrating the project. This type of citizen science is useful for collecting large amounts of data over great geographic distances and long periods of time. The tradeoff, however, is a de-emphasis of participant education, especially in terms of building skills in scientific inquiry. Though participant education is not a main goal for many projects, those being utilized in the realm of public education may be more effective at meeting learning targets if they are of a collaborative or co-created nature.

Step in Scientific Process	Steps included in Contributory Projects	Steps included in Collaborative Projects	Steps included in Co-created Projects
Choose or define question(s) for study			X
Gather information and resources			X
Develop explanations (hypotheses)			X
Design data collection methodologies		(X)	X
Collect samples and/or record data	X	X	X
Analyze samples		X	X
Analyze data	(X)	X	X
Interpret data and draw conclusions		(X)	X
Disseminate conclusions/ translate results into action	(X)	(X)	X
Discuss results and ask new questions			X

X = public included in step; (X) = public sometimes included in step

Table 1. Models for Public Participation in Scientific Research. (Bonney et al., 2009).

The curriculum designed for this thesis research was based on a citizen science project called Bugs in Our Backyard (BioB) and differentiated to represent both the contributory model and a crossover form of collaborative and co-created, which I will refer to in this paper as "collaborative." Participants experiencing the contributory curriculum received background on the BioB project before collecting data in the form of a field monitoring survey. In what I term the *collaborative* curriculum, participants develop a research question and possible methods before conducting the field survey. This is different than Bonney et al.'s collaborative model in that participants are experiencing more of scientific research *preparation* steps versus analyzing or communicating findings in addition to data collection.

1.2 Research Problem

Despite the growing popularity in the use of citizen science projects by science educators, there is minimal peer-reviewed research of educational outcomes for these projects, especially regarding K-12 participants. Discussed below are some initial studies in citizen science research, however more research of learning impacts —in regard to content knowledge, scientific reasoning, and skills in science— is needed. Research of environmental education tends to focus on attitude and behavior changes with less emphasis on knowledge gain outcomes. In some scenarios, citizen science fits into the environmental education category, and emphasis on behavior outcomes is appropriate. However, many educators are now utilizing citizen science as a way to meet science education standards. Science education research methods have the potential to increase our understanding of the educational impact of projects used in K-12 settings.

Research into citizen science would benefit from utilizing manipulative study designs to compare experimental and control treatments. Much of the current research consists of case studies regarding a single citizen science project. These studies often use qualitative surveys alone to assess impacts on participants. In some cases, knowledge gain is measured retroactively via a Likert-type scale (e.g. "After the completion of this project, I rate my understanding of the topic as …"). While such studies are valuable to building our understanding of citizen science and its impacts, projects utilized for K-12 science education would benefit from the addition of quantitative, direct, and comparative research methodology. My research will be illuminating for those considering citizen science for educational purposes by assessing learning gains of specific disciplinary content, general science process skills (e.g. developing a hypothesis, experimental design, interpreting a graph), as well as measuring changes in student attitudes. Outcomes are assessed via a quantitative pre and posttest that compares two treatment groups.

My research hopes to address challenges in science education by assessing a citizen science project that allows students to take on the role of scientist by creating their own scientific research that is place-based, relevant, and contributes to a larger body of understanding. I do this by exposing middle school students to a citizen science project in which the level of participation in the scientific process varies. One student group is exposed to a traditional "contributory" project where they are involved with data collection only; the other group follows the "collaborative" model and has a greater role in developing research questions and methods in addition to data collection.

1.3 Research Questions

How can participation in scientific research affect learning outcomes relating to content knowledge, science process skills, and attitudes towards science of middle school students? How do different models of citizen science –collaborative and contributory— affect these learning outcomes?

1.4 Research Plan

My research seeks to evaluate the educational effectiveness of citizen science programs in relation to specific content and scientific inquiry skills, as well as improving attitudes toward science in general within a public middle school setting. My goal is to understand the effects of different models of citizen science projects (contributory and collaborative) on student learning and attitude outcomes. I exposed groups of students to two versions of a citizen science curriculum. I assess student learning outcomes and attitude changes via a 30-question pre- and postevaluation with 10 multiple-choice questions regarding science content knowledge, 10 multiple-choice questions for science process skills, and 10 Likert-type questions regarding attitudes toward science.

All science teachers in the Olympia School District were invited to participate in this project via a mass email sent in September 2016 (Appendix D). Teachers that were both interested and had available class times for the project were chosen for this research. Two middle school teachers participated in this project. The contributory citizen science curriculum was delivered to one group of students (group: Capybara) while the second group received a modified collaborative curriculum (group: Liger). The curricula for both groups was based on Bugs in Our Backyard, which asks participants to complete

field surveys to monitor for four bugs of interest and their host plants via species-specific surveys or to monitor for any insect species via an 'open-ended' survey.

1.5 Bugs in Our Backyard (BioB)

Bugs in Our Backyard (BioB) is a citizen science project founded by researchers at Colby College in Waterville, Maine and funded in part by the National Science Foundation (NSF). Their goal is to "engage students in biology by making them citizen scientists" (Bugs In Our Backyard n.d.). This goal aligns with the curriculum created for the collaborative experimental group (e.g. Ligers), which was based on the Headwaters Science Institute's "Student Driven Research" model. In this teaching model, the students takes on the *role* of scientist by creating their own field research based on their questions for a given topic, (Headwaters Science Institute n.d.). Bugs in Our Backyard has five field survey options including: Goldenrain Tree/Soapberry Bug Survey, Boxelder Survey, Milkweed Survey, Halomorpha Survey, and an Open-ended Survey. For my research, I chose the open-ended survey option due to our location on the West coast of the United States since most of the "bugs of interest" are limited to the Eastern United States. I did, however, emphasize the western boxelder bug (*Bosia rubrolineata*) and the brown marmorated stink bug (*Halomorpha halys*) during the curriculum delivery since these bugs have a possibility of being found in our location.

Bugs in Our Backyard publishes all survey data on their site with an interactive map of the United States showing survey locations for each of the five survey types along with public access to the data in a spreadsheet form. They also offer a BioB Field Guide for teachers that provides background information on insects, true bugs, life cycles,

specifics about each of the bugs of interest and their host plants, and details on how to complete the field survey. There is one Teaching Module published on the website – for the Goldenrain Tree/Soapberry Bug Survey—with a promise to publish more modules in the future. The Colby College researchers also publish a blog on the site that contains interesting information about their research and bugs in general.

I chose BioB for this research for several reasons. It could be adapted into both a contributory and collaborative curriculum that could be compared. BioB offered an open-ended survey in addition to the four species-specific surveys (two of which are not present in Western Washington and two of which are rare in the Olympia, Washington area). The data collection could take place in the late fall, winter, and early spring when my own research needed to take place. BioB also offered the ability to connect directly with the lead researcher, Dave Angelini, an associate professor at Colby College in Maine.

1.6 Significance of Research

This thesis is significant at the intersection of several fields of study: Citizen Science, Science Education, and Environmental Education (Figure 1). Specifically my research addresses literature gaps within general assessment of citizen science outcomes, scientific literacy, and scientific content knowledge by utilizing quantitative pre/posttests to measure citizen science outcomes. My research measures outcomes for youth participants of citizen science while much of the literature focuses on adult participants. My research is one of few studies with a manipulative design in which the same citizen science program is assessed using two different modes of participation curricula.
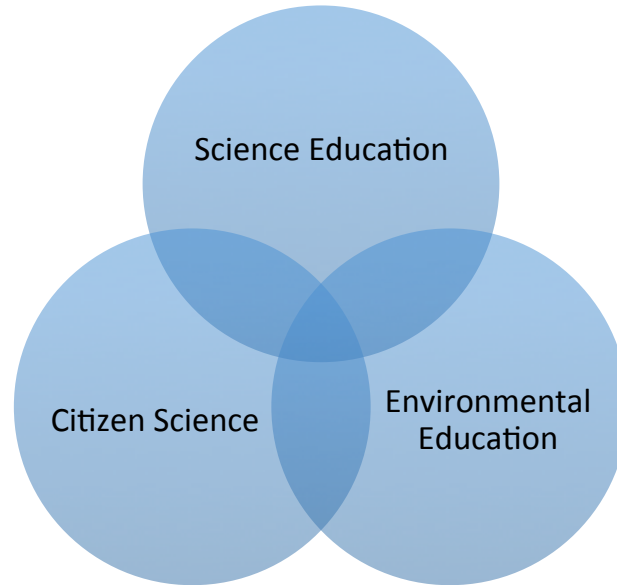
Fig. 1. The overlap of Science Education, Environmental Education, and Citizen Science.

Science educators, both formal and informal, are faced with the challenge of developing students' scientific inquiry skills, a term whose meaning has been debated for decades. This large and fairly elusive task involves teaching critical thinking skills, responsible risk-taking, focused curiosity, accurate data collection and analysis, fairness of experimental design, collaboration with peers, and effective communication. When tackling this responsibility, many educators feel restrained by textbooks and outdated curriculum –often leading to surface-level understanding of content by students and rote memorization but little deep understanding of concepts. This has long been recognized as an issue in science education, with literature and philosophy on the subject misaligning with classroom practices. In an effort to redirect science education in the United States, there have been various reforms such as the NSF's 'Citizens for Science' program in 1978 (National Science Foundation, 1978), and the recent Next Generation Science Standards (NGSS). The NGSS were developed by the National Research Council, the

National Science Teachers Association (NSTA), and the American Association for the Advancement of Science and published in April 2013 and seek to focus on both science and engineering as a three dimensional process that involves content knowledge, scientific and engineering practices, and common concepts that underlie all science (e.g. patterns, cause and effect, and structure and function).

Though these standards are in place, how effective will teachers be at teaching science as a process (skills and ways of thinking) as well as a product (knowledge accumulated by the work of previous scientists)? This has been a struggle arguably for the whole of science education in the United States, with teachers advocating for inquiry-based pedagogy in word but unable to meet the demands of such teaching in practice. Teaching via a discovery model (in which the teacher acts as a guide or a facilitator while the student creates their own meaning based on experiences) takes significant time, provides classroom management problems, requires more individualized attention to students, and can be less effective at conveying knowledge or concepts in an efficient manner. The desire to teach science via inquiry is clear, yet there is a need for practical tools that teachers can utilize in their classrooms. Citizen science, if implemented with intentions of meeting goals relating to scientific process, may be one such tool.

Even the teaching of science as a process is a challenge. How do students perceive what it means to be a scientist? Do they see scientific research as a rigidly defined set of steps as reflected by posters on the walls of their classroom? Do they see science as the process of meticulously collecting and recording data? Or do they see science as a recursive process that utilizes available tools to answer questions about the natural world? This research addresses such challenges in science education by

analyzing a citizen science project that allows students to take on the role of scientist; creating their own scientific research that is place-based and relevant. Through quantitative analysis, I am able to compare directly the impact of collaborative and contributory citizen science projects on student learning outcomes.

1.7 Thesis Overview

The following chapter begins with an account of the history of science education in the United States before continuing on to a review of literature representing significant and/or recent research in the fields of citizen science, science education, and environmental education. This review provides important background, acknowledges gaps in the literature that this research addresses, and assesses foundational methodologies used for this research. I then present my own methodology for this study (Ch. 3). In tandem to presenting results, I interpret the significance and meaning of research findings followed by a discussion of limitations and suggestions for future study (Ch. 4). I end with a personal narrative relating to the topic of Student Driven Research, a review of how this study fits into existing research, and the potential for Citizen Science to be used as a tool for inquiry-based science education.

Ch. 2 - Literature Review

2.1 Introduction

Citizen science projects in K-12 education may prove to be a strong tool for achieving scientific education goals by engaging students in meaningful and authentic scientific research that impacts their local communities. Though citizen science has been around –formally—since the early 1900s, it has begun to surge in popularity with projects now ranging from astronomy, biochemistry to ecology and even psychology. Most people with a smart phone and an interest can now meaningfully contribute to data collection on huge spatial and temporal scales. As educators turn to citizen science as an aid for providing *real* experiences in science for students, we need to evaluate the effectiveness of various modes of these projects – that offer participants different levels of participation in the scientific research – on education-related outcomes.

In the following review of the literature on science education and citizen science, I first provide a brief history of science education in the United States. I then describe how citizen science fits into that history. Next I define and give historical context for citizen science in general. In the third section, I will provide examples of citizen science projects, their goals and outcomes, and participants of such projects. I then discuss citizen science in the realm of K-12 public education, as this study will focus on effectiveness of citizen science projects in that setting. Though there are few studies of the educational effectiveness of citizen science projects, I will provide several examples from the literature as well as research of education outcomes for other types of informal science education. Throughout this chapter, I also include research into other outcomes of citizen science relating to attitude or behavior change. I conclude this review with a

discussion on how citizen science can be used in schools to address the goals of science education.

2.2 Science Education in the United States

Science education in the United States has generally focused on two goals: 1) creating a scientifically literate population capable of making informed democratic decisions and 2) preparing a small number of the population to pursue careers in science and technology. The extent of attention and funding for these two goals and how they are met has fluctuated in focus throughout the country's history. Even today, we are experiencing education reform that seems to echo reforms of the past. This section will serve as a background for science education in the United States. I begin with science education's starting point in the early 1800's and trace its undulating path –back and forth from a focus on rigorous content to a focus on social relevance—through the history of the United States. The following account borrows heavily from the work of George E. DeBoer's *A History of Ideas in Science Education: Implications for Practice* (1991) in which the story of American science education is eloquently explored from a historical perspective.

Though hard to imagine, science was not always a staple subject in American education. Formal education in the United States during the early 1800s was for the aristocratic few and was of a classical European nature, consisting of language studies in Greek and Latin, learning the great works of poetry, drama, and philosophy, and obtaining skills in logic through studies of rhetoric and arithmetic. With advancements in technology brought on by the Industrial Revolution and an increased understanding of the physical properties of the natural world through scientific research, people started to

advocate for teaching science in school. Critics of science education saw it as an

indulgence; taking away from the pursuit of knowledge for its own sake by endeavoring

to learn something for its practical application. Science education also offered a contrast

to the formalized, rote-memorization, authority-driven pedagogy that marked classical

education. Advocates for science education argued that it could still accomplish goals of

increasing mental capacity but in a more practical and useful way. In science, one must

still exercise memorization skills, but the content being memorized pertains to the natural

world and everyday life instead of to ancient works of art or linguistic rules for dead

languages. Advocates of science education also argued that it helped pupils to practice

their inductive reasoning skills, which are required in day-to-day decision-making. This

was opposed to the deductive reasoning learned in arithmetic in which pupils are given an

outcome and asked to prove it, a type of reasoning rarely encountered in every day life

(DeBoer, 1991).

Science eventually made its way into curriculum. By the mid 19th century in the

United States, teaching academies such as the Benjamin Franklin's Philadelphia

Academy had become popular and taught a more practical curriculum that included many

science topics as well as vocational subjects like surveying. The idea behind the

academy was to provide a more utilitarian education in contrast to the elitist classical

schools. The academies had many problems, however, such as their short course

rotations of roughly 6 weeks and a lack of highly skilled teachers. Nearing the end of the

19th century, most of these academies had been replaced by public schools (DeBoer,

1991).

Drawing from philosophies of European pedagogues like Swiss educator Johann Heinrich Pestalozzi, who advocated the education of the 'whole person' through direct sensory experiences, American public schools of the late 19th century embraced science as an important subject for teaching through observation and experience of the real world to make inferences and conclusions in a methodical way. Educators in America often failed to truly implement these philosophies leading to the ineffective Object lesson fad of the 1850s and 1860s. During these object lessons, teachers would rely on the old style of rote memorization and regurgitation of facts, perhaps passing around an object –such as a saltshaker while lecturing on its molecular and geological properties. A truly Pestalozzian style of teaching requires that the teacher become more engaged with the individual student rather than controlling the entire classroom from a teacher-centered position. It also requires teachers to allow students to explore natural phenomenon on their own and to help them turn their observations into meaning (DeBoer, 1991).

Herbartian pedagogy arrived in the United States through translator and popularizer, Charles DeGarmo in the 1890s (several decades after being popularized in Europe). Johann Friedrich Herbart believed that the purpose of education was to guide individuals' experiences to build a complex and interconnected mind theoretically without bounds for acquiring new knowledge. To Herbart and his followers, conceptual knowledge was more important than the content used to build those concepts. Education's purpose was to provide individuals with a conceptual framework for which to live a well-rounded and socially moral life and to build more knowledge on existing frameworks provided by their education. For Herbart, the pupil's emotional engagement was a key aspect to learning (DeBoer, 1991).

Beyond philosophical quandaries for schools in the United States, secondary schools in the late 1800s were struggling to meet ever-changing college entrance requirements while also serving the academic needs of non college-bound students (which were the majority). Schools were offering an enormous array of subjects, ranging greatly in time allocated for certain topics, and constantly changing course offerings. Enrollment in secondary schools was increasing, going from 6.7% of the population of 14-17 year olds in 1890 to 32.3% of that age range in 1920. For these reasons, the Committee of Ten was commissioned in 1892 by the National Education Association to standardize the curriculum of secondary schools in the United States. The committee recommended that the high school curriculum be 25% science. They also emphasized the use of the laboratory as a place for hands-on experimentation in order to learn via direct experience and manipulation as well as to gain proficiency in expected laboratory procedures (DeBoer, 1991).

By the early 1900s, science education was firmly established in the United States. Its importance was seen beyond the understanding of established scientific knowledge – important for democratic decision-making as well as for those entering a field in science or technology—but also as a tool for increasing mental capacity, inductive reasoning skills, and as a scaffolding of concepts for life-long learning. Science as a topic had a unique capacity for learners to directly observe natural phenomenon rather than learning more abstract concepts in the classical liberal arts subjects (DeBoer, 1991).

There was a philosophical shift in the 1920s from science education as being a tool for increasing mental capacity and critical thinking skills to it being a way of producing happy and contributing members of society. Goals of 1920s science education

were socially motivated and criticized for only teaching students things that they might find appealing or useful instead of teaching all topics in an effort to expand the horizons of pupils. Science education was seen as being practically important for increasing understanding of health and human physiology which could lead to better life decisions and stem rampant drug use or illicit sex. Science education could increase an appreciation for and enjoyment of nature. It could also give youth practical technical skills for around the house such as understanding how electrical circuits work (DeBoer, 1991).

This student-centered pedagogy focused on social applications and real-world importance marked United States education in the Progressive Era. There was a call to make schools more enjoyable and meaningful for students and to emphasize understanding of concepts over content. American philosopher and pedagogue John Dewey wrote about the need to incorporate experience-based teaching into the traditional education of the United States. Despite this desire, however, teaching via rote-memorization continued through the progressive era. Standardized testing –developed in this era— continued dependence on text books, and the misapplication of the laboratory setting in which teachers relied on step-by-step lab instructions versus setting up problem-based student inquires, may have all played a role in limiting the shift of science education to align with progressive philosophies (DeBoer, 1991).

World War II effected drastic change to the United States education system, as it did arguably for every facet of American life. The war brought to light many issues faced by science education and the education system in general. Through testing of recruits, it was revealed that many citizens lacked the literacy and quantitative reasoning

skills needed for armed conflict. The war highlighted the need for improved technical and vocational skills necessary for producing industrial and agricultural products. The war created a shortage of and need for more people to pursue careers in the science, technology, engineering and math (STEM) fields. It also revitalized the desire for education to promote the ideals of democracy and the importance of a universal education (DeBoer, 1991).

There were many conflicting opinions among educators for how these problems should be addressed. Should science education be socially relevant, pragmatic, and emotional engaging or should curriculum focus on the technical skills and knowledge needed to pursue a STEM career? Should education as a whole be for the masses or serve to elevate the elite few capable of entering a scientific or technical field? Should science education be generalized for wide application in every day life or should curriculum be focused on a selected few specific topics? Most arguments boiled down to education addressing either social issues or promoting intellectual thinking. These debates were nothing new, as we have seen, but the war definitely amplified the need to make critical decisions via education reform (DeBoer, 1991).

By the late 1950s and the launching of Sputnik by the Russians, the progressive era of education was dead –at least for the moment. There was a national cry for a reversion to content-focused science curriculum that could prepare youth to compete on a national scale (Hurd, 1958). American education was seen as 'soft' and too focused on social problems. In 1958, the National Defense Education Act (NDEA) was passed and marked the beginning of federal aid and oversight of American education (Zhao, 2009).

Physics was the first subject of focus, especially due to the steady and long-standing decline in enrollment of students in physics courses (and science courses in general) in secondary schools. Across science disciplines, there was a pedagological shift to teaching the process of science as a human endeavor. Most of this reform came through the commission and publishing of textbooks in which unifying principals for a specific discipline (e.g. structure and function of living organisms for biology) were woven into the technical aspects. During this shift toward disciplinary focus and textbook modification of the 1950's and 60's, much of the social aspect of science education was lost (DeBoer, 1991).

With any aspect of human endeavors –politics, economics, literature—when the pendulum swings far to one side, it will inevitably swing back. By the mid 1960's, the disciplinary focus of science education was seen as a detriment to societal issues such as equality and democracy. Science education in the 50's served the elite few and led them into sought-after careers in STEM fields. But at what cost? Like many social institutions of the time, education was called on to address issues of inequality and as a means for creating an enlightened population sensitive to human and environmental needs. The individual student was once again the focus of reform with an emphasis to increase scientific literacy – a term that had begun to appear in academic journals of education (DeBoer, 1991).

The new progressivism of the 60's and 70's yet again shifted science education towards socially motivated goals. The kind of humanistic education from this era was designed to encourage people to have empathy for their environment as well as the humans that occupy it. It was during these decades that the Science-Technology-Society

(STS) initiative was started by the NSF as a way to emotionally engage young people in the sciences in a relevant and meaningful way (DeBoer, 1991).

It was also during this time period that the field of Environmental Education built its foundation. It was defined and described in the first issue of the *Environmental Education Journal* in 1969 by William Stapp and his graduate students at the University of Michigan. By 1977, Environmental Education became formally recognized at an international level during a conference held in Russia known as the Tbilisi Conference. Environmental education offers a clear example of the socially oriented goals for the new progressive era reforms to education as evidenced by Stapp's (1969) original definition: "Environmental education is aimed at producing a citizenry that is knowledgeable concerning the biophysical environment and its associated problems, aware of how to help solve these problems, and motivated to work toward their solution," (p. 34).

During the 1960's, 70's and into the 80's—there was a larger discussion concerning the psychology of human learning and how an understanding of child development could influence teaching practices. Jean Piaget and other constructivist theorists had a great influence over American education. Science educators were challenged to develop students' scientific cognition (using logic, rational thought, evidence, being open-minded, etc.), their inductive reasoning abilities, and also their ability to understand and retain knowledge within scientific disciplines. Most teachers, education philosophers and policy-makers through these three decades considered inquiry learning to be the best way to accomplish these goals (DeBoer, 1991).

These experiments with discovery learning would not last. In 1983, a report titled "A Nation at Risk" was published by the National Commission on Excellence in

Education during (but not necessarily supported by) the Reagan administration (National Commission on Excellence in Education, 1983). The report inspired Sputnik-esque panic that the United States was failing to educate its citizens to compete in a highly globalized world. International comparisons of the United States with other countries did not look good. The Trends in Mathematical and Science Study (TIMSS) conducted in 1995 showed the United States in 18th place out of the 21 countries tested in math and science literacy for students in their final year of secondary school, a score of 471 out of an international average of 500, (Martin & Kelly, 1998).

The fear the United States was falling behind the international competition lead to an era full of government oversight, curriculum standardization, and strengthened accountability measures. Most people in the U.S. today are familiar with President George W. Bush's No Child Left Behind (NCLB) Act signed in 2001. Its goal was to "close the achievement gap with accountability, flexibility, and choice, so that no child is left behind," (U.S. Department of Education, 2010). While challenging to summarize the impacts of NCLB due to its fairly recent history, it seems to have gone beyond the typically short-lived education reform to fundamentally altering the national philosophy regarding the role of assessment and accountability in education (Zhao, 2009).

We are now seeing the effects of standardized education and high-stakes testing. Across the country, and even from voices such as the NEA and NSTA, people are admonishing high stakes testing and its impact to the American education system, (Zhao, 2009). Elementary teachers are feeling pressured to prepare students in math and reading and have little time to devote to meaningful science education. Even taking students out of doors for natural exploration and observation is limited due to pressures of time. I

work with an elementary school that can no longer give teachers a weekly 'free' time to use for subjects seen as curriculum extras such as art, music, or gardening because of pressures to ensure students pass exams in math and reading.

Science education in the United States holds many traces of its relatively recent history. There are still cries that content and memorization of a wide range of facts receive too much focus at the detriment of learning –perhaps fewer—concepts at a deeper and more transferable level. Teachers feel bound by textbooks and pressed for time in their efforts to cover the whole of humanity's scientific discoveries. Standardized testing has played a role in these problems, despite efforts to make test questions more integrated across science topics and to assess conceptual understanding as well as content knowledge. Even this discussion of citizen science is an argument to make science education more relevant and meaningful to the individual student; a desire that has been held since the early 1900s.

The advent of Informal Science Education (ISE) in 1984 by the NSF helped develop tools and programs for engaging students in real life science outside the classroom context (Dickinson & Bonney, 2012). The motivation for real and meaningful science education has continued to inform various state and federal teaching standards (National Research Council, 2012), and yet these philosophies have not been fully integrated as practices in schools with many classroom teachers continuing to employ textbook-driven, teacher-centered, lecture-style pedagogy where science is taught more as history or collection of facts (Mueller, Tippins, & Bryan, 2012). Teachers, parents, employers, and universities disparage that young people lack critical thinking skills, and yet the United States public education system continues to facilitate content focused

curriculum through high stakes standardized testing and fails to adequately provide experiences or resources that might build high-level thinking skills. A core motivation of current science education reform –such as the Next Generation Science Standards (NGSS)—is to shift from content-focused to process-focused pedagogy in which students are the drivers of scientific inquiry, preferably in socially relevant contexts (National Research Council, 2012).

2.3 Scientific Literacy

Rhetoric and jargon in the field of public education often morphs throughout the years, but retains essentially similar meanings. Lederman, Lederman, and Antik (2013) argue that the main goal of science education has not changed in over 100 years and remains to help students "develop adequate conceptions of the nature of science (NOS) and scientific inquiry (SI)," (p. 139). It is the methods for implementation of this goal that has changed over time. In recent years, with the dawning of federal educational standards, how science is taught has been made more explicit. There is an emphasis on unifying concepts that span various scientific disciplines like chemistry, physics, and biology meant to create a holistic understanding of how the world works and how science helps shape that understanding. Science education has gone beyond teaching exhaustive vocabulary-based content and serving only a select few members of the population –those destined to become leading scientists and engineers. The role of current science education is much more inclusive, seeking to promote general scientific literacy to be utilized in making societal decisions –a necessary component especially for a democratic

country. Inquiry-based and constructive styles of pedagogy seek to enhance critical thinking and problem solving skills.

Prolific educational philosopher, John Dewey, articulated the democratization of schooling. Dewey argued that the function of public education was to facilitate experiences for youth that would lead to their development as an informed, critically thinking and civically engaged adult (Dewey, 1916). The hierarchical top-down model historically common in citizen science has been called into question, as it does not serve to facilitate the democratization of science (Calabrese Barton, 2012).

It is advantageous to define what is meant by 'scientific literacy' in the era of educational buzzwords and policy reform. Citizen science researchers, Dickinson and Bonney (2012) describe scientific literacy as "the development of habits of mind that foster systematic reasoning about scientific problems and issues," (p. 175). The National Academy of Sciences compiled a list 21 definitions and their origins from the year 1958 to 2016 in a report titled Scientific Literacy: Concepts, Context, and Consequences (Snow & Dibner, 2016). Scientific Literacy is now seen as more of an umbrella term as definitions have gotten more complex over time. The original coining of the term, made independently by P. Hurd and R. McCurdy in 1958, was meant to indicate the ability to use science as a tool for understanding, and while it does also include a person's knowledge, it is more about people's "disposition and knowledge to engage with science" both to produce more knowledge and to apply it to understanding in social and political contexts (Snow & Dibner, 2016). What most of the definitions seem to have in common is that scientific literacy involves a person's actual knowledge of science and issues related to it, skills to engage in or understanding of the scientific process, attitudes toward

science, and the ability to apply this knowledge/skill/interest to social or political contexts.

If hard to define, scientific literacy is even more difficult to measure. It has been argued that scientific literacy *cannot* be measured, especially since it a clear definition has not been agreed upon. Despite this, many studies have attempted to capture changes in scientific literacy of participants of all ages engaging with many types of formal and informal science education. Some studies focus on a wide range of outcomes: emotional, behavioral, and knowledge gains to capture participants' scientific literacy while others point to just one or a few examples of participant changes to make claims of improved literacy.

Cooper et al. (2009) suggest using the following as ways to measure scientific literacy outcomes of citizen science: duration of involvement with a project, numbers of participant visits to a project website, improved content understanding, improved attitudes toward science, improved skills for conducting science, and increased interest in science-related careers. Others suggest measuring scientific literacy using detailed questionnaires, such as the Student Understanding of Science an Scientific Inquiry (SUSSI) and the Test of Scientific Literacy Skills (TOSLS), (Gormally, Brickman, & Lutz, 2012; Liang et al., 2006). Both of these questionnaires will be discussed in further detail in the methods chapter.

2.4 Citizen Science History and Definitions

Citizen science is not immune to etymological confusion either and has its formal education roots in what used to be called Science, Technology, and Society (STS)

education, an outreach project funded by the National Science Foundation. It has been referred to as: Street Science, Public Participation in Scientific Research, a type of Free-Choice Learning, Community-action Science, and Participatory Action Research, (Cooper, 2012). In this section, I will first explore the etymology of Citizen Science, discussing its various definitions and aliases. Once defined, I distinguish between types of citizen science projects and their associated goals, discussing trade-offs between education, research, and stewardship. I end with an overview of current trends in the realm of Citizen Science, including the impact of technological accessibility.

Citizen science is the engagement of non-scientists in scientific research with the guidance of experts. The Audubon Society's Christmas Bird Count is considered one of the oldest examples of what has been formally thought of as 'citizen science,' (Dickinson & Bonney, 2012). Starting in 1905, this project utilizes avid bird watchers who submit their sightings in order to gather spatially and temporally varied data concerning species occurrences, migration patterns, and breeding habits that has been used in over 200 peer-reviewed scientific studies and by government agencies in decision-making regarding birds, ("Christmas Bird Count Bibliography," 2015). In 2002, Audubon launched eBird in a partnership with the Cornell Lab of Ornithology –leaders in the citizen science realm—as a way for bird enthusiasts and professional ornithologists alike to submit detailed bird sighting data all year round (Strycker, 2015). The site claims that over 9.5 million observations were recorded through eBird in May 2015, (Sullivan et al., 2009).

Influential researchers in citizen science, Dickinson and Bonney (2012), describe citizen scientists as "people who have chosen to use their free time to engage in the scientific process," (p. 1). They can be considered non-scientists, amateurs, hobbyists,

volunteers, participants, community members and citizens. These people can be motivated by a number of different factors: environmental stewardship, social interaction, scientific contribution, knowledge gain, physical activity, career advancement, and more. In a survey of 271 participants in 8 different water quality oriented citizen science projects, Alender (2016) discovered the following as top motivators for participants: helping the environment (1), helping the community (2), connecting with nature, and contributing to scientific knowledge (3). Because of the variety of topics, locations, accessibility, and levels of involvement, people are increasingly able to find projects that meet their individual needs and desires.

Much citizen science is of an ecological nature, consisting of participants that have an existing interest in a certain topic: plant identification, invasive species, animal behavior, or amphibian monitoring to name a few. These projects appeal to the amateur naturalist and give them a way to meaningfully contribute and potentially help to preserve something they value.

I distinguish two main branches of citizen science: 1) projects that focus mostly on the collection of data to inform the scientific community and 2) projects motivated by engagement of participants in the scientific process and environmental stewardship. This literature review deals mostly with the latter and thus the literature examined has been selected based on relevance to education and public engagement in science. In both forms of citizen science, however, the participant is often limited to the 'data collection' portion of what is commonly viewed as the scientific method, even when the project's focus is on education. The scientist, expert, or directors of the organization generally make decisions about the questions guiding the research, methods, data analysis, forming

conclusions, and publishing the research (Cooper, 2012). This 'top-down' model is useful for ease in project management, but may limit the educational value for participants.

Today, the citizen scientist can be found almost everywhere. The ubiquity of citizen science applications (apps) for smart phones has made citizen science extremely accessible and also fun. Some utilize a game format to entice people to download and use their apps, others target peoples' desire to contribute via crowd-sourced information, and still others highlight educational value to users. In following sections, I discuss examples of many of these technology-based citizen science projects such as: GLOBE Observer, Fold-It, I-naturalist, Face Topo and more. While there are some projects that struggle with consistent usage, data entry, or publicity, many well-designed citizen science projects are helping scientists to reach challenging data-collection goals while engaging the public in free-choice science learning.

2.5 Citizen Science Goals and Outcomes

It can be a challenge for citizen science projects to balance goals relating to quality of scientific research, participant engagement in science and/or environmental stewardship, and increasing participants' knowledge in specific content areas. Dickinson & Bonney (2012) surveyed 80 citizen science project developers and found that a trade-off does exist between these three main goals: research, education, and stewardship (e.g. environmental attitudes).   They found a negative relationship between research and education goals, indicating that as projects focus more on data collection, their efforts to educate participants weakens and vice versa.

For programs that focus on educational outcomes for participants, the scientific rigor of the research tends to suffer. The scientific community may not utilize data collected by participants in these education-oriented projects due to inconsistencies in collection methods, data entry, and lack of oversight or quality control. A lack of resources in time, staffing or budget can also result in data being collected but never communicated to interested stakeholders. Dickinson and Bonney (2012) would consider such projects a 'failure' in that they do not contribute to peer-reviewed literature.

Even when data is collected consistently and with proper quality control, scientists may not consider the data valuable, reliable, or from sufficiently randomized samples. There has been criticism that data collected by non-scientists may not meet rigorous standards for use in scientific research (Catlin-Groves, 2012). However, several studies that analyze reliability of citizen-collected data show that data collected by non-scientists can be rigorous enough for scientific research, especially when citizens are collecting objective data after receiving appropriate training.

In a study of citizen science-collected data on condensation trails for a project called OPAL (Open Air Laboratories), it was found that about 70% of the citizen observations were plausible given the presence of aircraft and atmospheric conditions (Fowler, Whyatt, Davies, & Ellis, 2013). This percentage agrees with similar studies of citizen science and contrail data collection by non-scientists –even school children in one study. The study showed strong agreement between citizen collected photographs and expert analysis of these photographs; however, only a small portion of the data collected included photographs. These findings are promising for utilizing citizen collected data

for research, especially if it includes photographs that can be verified by experts or if error is factored into data analysis.

In a case study of Oregon white oak stand surveys, researchers compared data collected by trained students' (grades 3-10) with professionally collected data and found consistency ($p = 0.05$) for objective measurements of diameter at breast height and tree counts. However, there were differences between the student surveys and professional surveys for more subjective measurements such as crown assessment and live or dead status (Galloway, Tudor, & Vander Haegen, 2006). In Sussex, London, volunteers were subjected to three different training methods and tested for their ability to correctly identify insects on ivy flowers. Researchers found that training method had a significant impact ($p=0.008$) on volunteers' ability to correctly identify insects with direct training (versus pamphlet alone or pamphlet + slideshow) yielding 94.3% accuracy (Ratnieks et al., 2016). These examples in addition to expert verification of data and the ability to account for error and bias via analytical modeling approaches suggest that citizen-collected data can be used appropriately in scientific research (Bird et al., 2014).

Projects that focus intently on the rigorous collection of data tend to fall short when assessed for outcomes of participant growth in environmental stewardship, attitudes and/or knowledge gain. One reason for this limited participant growth may be that such data-focused projects tend to attract volunteers that already have familiarity or interest in the research topic. Though the Cornell Lab of Ornithology is conducting significant outreach, participants for the long-running Christmas Bird Count tend to be avid bird watchers or hobbyist ornithologists. Outcome assessments for these projects are unlikely to see much improvement in participants because of their already high level of content

knowledge and existing interest in the subject and/or environment. A study assessing the impacts of The Birdhouse Network on participants' knowledge, attitudes, and scientific inquiry skills showed no significant change in attitudes toward science/environment or understanding of the scientific process, but did show slight improvement in content knowledge of birds (Brossard, Lewenstein, & Bonney, 2005).

Spotting the Weedy Invasive is a citizen science project with a research question pertaining to the proximity of invasive plant species to human-used trails. Project leaders developed three specific educational goals for their participants (hikers with little to no botanical experience): 1) to gain concept knowledge relating to invasive species, 2) to increase science process skills especially relating to large-scale quantitative research techniques, and 3) to gain an appreciation for scientific ways of thinking or what the authors called 'habits of mind used by scientists.' Behavior change of participants was also documented as a part of this study (Jordan et al. in Dickinson and Bonney, 2009).

Hikers began their participation in the study with a daylong workshop that consisted of an invasive plant lecture; practice identifying 11 target species, and training in the data-collection protocol. Following the lecture, participants were given tools for data collection –a pedometer and plant press, engaged in an in-depth conversation regarding data collection, and practiced making inferences from example data models.

Researchers found that participants did increase their content understanding of invasive plants and environmental issues concerning them and that this understanding was lasting at least up to six months following their experience. However, participants did not increase their knowledge of either the nature of or the process of science. Results

also showed little indication that participants' behavior was modified following their experience.

A unique feature of this native plant study is that their findings led the project organizers to alter their volunteer training methods to better meet their goals for participants. Protocols were developed in relation to each goal. For example, to increase appreciation for the nature of science, Jordan et al. (in Dickinson and Bonney, 2009) suggest, "allow[ing] time for discussion, practice, and mistakes related to conducting an investigation … [including] involvement and growing autonomy with data collection, analysis, and interpretation," (p. 171).

A citizen science project called Fold-It utilizes a computer game, which asks participants to properly fold a protein molecule. Developed by researchers at the University of Washington, Fold-It is able to harness the pattern-seeking behavior of the human brain to solve complex computational problems, resulting in useful algorithms for predicting protein structure . Fold-It does not explicitly attempt to educate participants about the larger impacts of understanding protein folding or the scientific process involved, with participant motivators being contribution to scientific research and an interest in science (Curtis, 2015).

The trade-off between project outcomes of scientific rigor, environmental stewardship and knowledge gain are necessary given various constraints such as time, physical, financial, and structural limitations. Teachers and educational groups may lack the time, resources, and skill to design scientifically rigorous citizen science curricula. It can also be a challenge for the scientific expert involved in the project to find time to commit to communication with the educators. Enough physical materials must be

acquired for student use for data collection. Logistics such as access to a nearby study site, transportation to further sites if necessary, obtaining guardian permission, and gaining primary source literature access for students can all be barriers to conducting 'usable' citizen science in a school setting. Despite these barriers, educators are increasingly looking to citizen science projects to bring relevancy to science learning.

As citizen science projects become more prolific in schools, there is need to assess specific goals such as the educational benefits of these projects. The Center for Advancement of Informal Science Education (CAISE), an entity supported by grants from the NSF, released a report in which they indicate through case studies that gains in understanding the scientific process is achieved during projects that involve participants in a greater number of steps related to scientific research (Bonney et al., 2009). This makes intuitive sense, as participants gain skills related to scientific inquiry and not just the single step of collecting data. The authors distinguish three categories of citizen science projects: 1) Contributory –or top-down model in which scientists guide the research and citizens collect data, 2) Collaborative –in which the research is designed by scientists but citizens are involved in adapting, analyzing, and disseminating research, and 3) Co-created –a participatory research model in which citizens are engaged in almost all steps of the scientific process (Bonney et al., 2009). According to the authors, projects falling into the co-created category yield the strongest educational benefits in terms of scientific inquiry.

Cooper et al. (2009) suggest an evaluation model for measuring Scientific Literacy Outcomes that includes: 1) The length of time participants are involved in the project, 2) the number of visits to the project's website, 3) improvement in science

content understanding, 4) improvement in attitudes toward science, 5) improved skills in conducting science, and 6) increased interest in science-related careers. In a survey study of 23 adult volunteers, statistically significant results showed that science vocabulary knowledge and the understanding of scientific process increased after participation in informal outdoor adult education via what was termed a 'renewed citizen science paradigm,' (Cronin & Messemer, 2013). In a pre- and post-survey study of 57 participants who underwent a 2-day training event to learn invasive species monitoring techniques, Cronje et al. (2011) measured scientific literacy using the Science and Engineering Indicator and found no significant difference, however did find significantly higher test scores when evaluating pre- and posttests using their 'multi-item context-sensitive instrument' and thus offer this measurement tool for use in evaluating scientific literacy outcomes of citizen science programs.

In contrast, a study by Druschke and Seltzer (2012) found that their goals for behavior, attitude, and knowledge were not met. When analyzing the results of a pre- and post-survey of volunteers in the Chicago Area Pollinator Study program, they found no significant difference in scores. The authors reflected that they had "failed to effectively engage our citizen scientists and bring them into the collaborative research effort" (p. 179). This is a point that I will return to in this research as I propose a more engaging participatory model for citizen science projects in K-12 educational settings.

One possible limitation that I discovered after extensive review of the literature is that many studies rely on participants either self-reporting their gains in knowledge, attitude, etc. or self-reports on a pre- and postquiz (e.g. "To what extent are you knowledgeable about environmental science" (Jordan, Gray, Howe, Brooks, & Ehrenfeld,

2011)). For example, Evans, et al. conducted a survey of participants in the

Neighborhood Nestwatch Program, in which 90% of participants *reported* learning from

the project (2005). This study also found that 44% of participants did not know how the

data they collected could be used and were not familiar with project goals. This example

presents a possible flaw in the evaluation of citizen science learning outcomes in that

participants may be misrepresenting their actual knowledge gain by only reporting their

perceived knowledge gain. It also indicates a structural flaw in these programs, as

participants are only engaged in a small portion of the scientific process and are unaware

of how their work fits into a larger context.

As mentioned earlier, the use of online databases is allowing for broader

participation in citizen data collection projects. While conducting this research, I

discovered a conglomerating site called SciStarter.com that allows users to search for

specific projects based on topic (e.g. astronomy, ecology, psychology), locations, cost,

and participant age level (http://scistarter.com/).   Along with greater access to projects

for participants, scientists now have the ability to analyze larger collections of data over

greater geographical areas. Though some researchers and publishers may be skeptical of

data collected by 'average citizens,' a number of studies have assessed the validity of

using such research and statistical methods that can be employed to deal with data

collection error or bias (Bird et al., 2014; Bricker, Sachs, & Binkley, 2010; Fowler,

Whyatt, Davies, & Ellis, 2013).

Access to technology has also increased citizen participation in scientific

research. A smart phone application called iNaturalist utilizes phones' GPS, cameras,

and internet connection to allow users to take pictures of any organism found in nature.

Each observation is then uploaded by the user to a shared database and map. An observation can be considered of 'research grade' if the identification of an organism's taxon is agreed upon by 2 out of 3 other users, it is georeferenced, has a date, has a photo or sound, and is not of a human ("Help · iNaturalist.org," n.d.). That data is then freely available to researchers. This is just one example of many citizen science programs that utilize public data and smart phone technology.
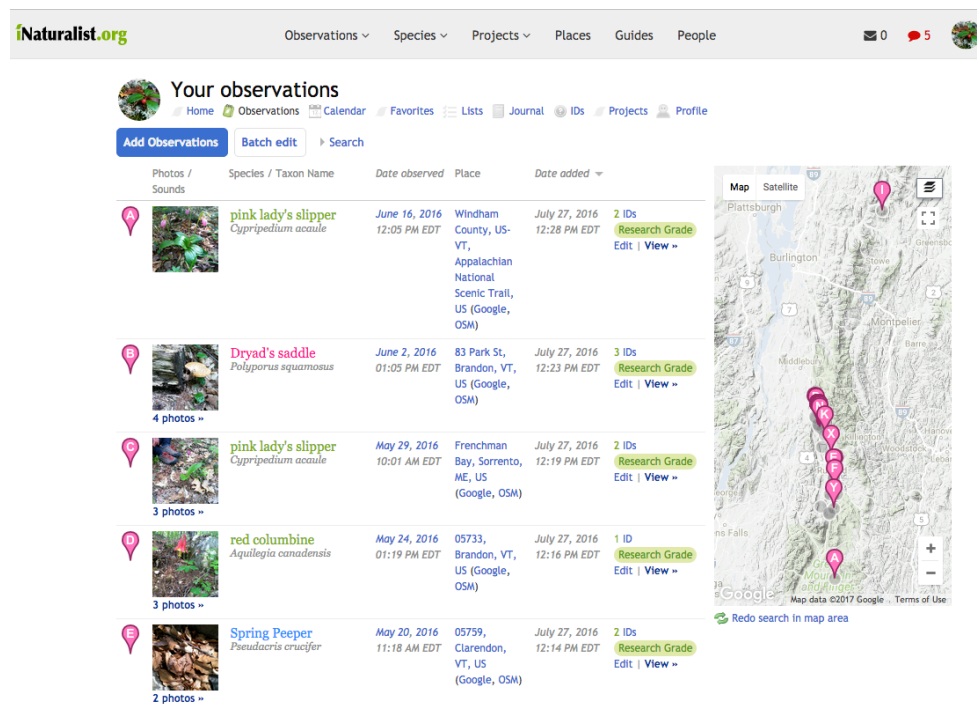

Fig. 2 Website interface for user account on iNaturalist.org showing user observations A-E with accompanying map. 'Research Grade' indicates positive identification of the organism's taxon by at least 2 other iNaturalist users.

2.6 Examples of Citizen Science: Contributory / VGI, Collaborative, Co-Created

As previously mentioned, the term citizen science encompasses a wide spectrum of projects ranging in topic, location, geographic distribution, modes of participation, usage of technology, and goals. In the following section, I choose several specific projects to serve as examples for different types of citizen science. Foldit is an example

of game-based citizen science and illustrates how collective intelligence can compete with computer-generated algorithms. Three examples of Volunteered Geographic Information (VGI) – type projects are then briefly described, as VGI is a large subcategory of citizen science. I then describe an international water quality monitoring project (GREEN) as one example of many watershed education citizen science projects. In an effort to convey what is meant by a co-created project, I next describe the Headwaters Science Institute's Student Driven-Research model. Though not truly a citizen science project, this model may serve as a foundation for education-focused research that seeks to place students in the scientist role. I end this section with an example of true co-created citizen science –a rare occurrence in the literature.

Foldit

In this contributory citizen science project, participants use a computer game (using the protein-folding Rosetta software) to help researchers uncover protein-folding possibilities. Participants get a score for each protein they work on based on their ability to make a smaller, more tightly-packed protein that avoids empty spaces, ability to 'hide the hydrophobic' sidechains and expose hydrophilics, and to 'clear the clashes,' by avoiding steric interaction between atoms in sidechains. One study describes Foldit as 'tetris-from-hell puzzles,' (Kelly & Maddalena, 2015). Researchers at the University of Washington are able to use the protein-folding predictions made by human participants to 'teach' computer folding programs more efficient algorithms for predicting how proteins might fold.

Foldit is an example of a computer-based citizen science project that utilizes a game-like interface to attract and engage non-scientist (or maybe even just non-biochemist) participants to crowdsource data. Their model is effective and has even attracted media attention from *Scientific American* ("Foldit Online Protein Puzzle," n.d.). Beyond this, Foldit has been the focus of 12 peer-reviewed research publications – according to their website—several of which are articles using participant folding data in biochemistry research regarding proteins (Eiben et al., 2012; Gilski et al., 2011; Khatib et al., 2011). Researchers hope to one day attract enough attention to get funding for players of Foldit to solve actual protein crystal structures (as opposed to just predicting possible proteins).

Though a contributory project, participants engage in a community forum, learning from each other as well as the protein researchers. The game increases in difficulty, and can become fairly technical. The Foldit website boasts many other resources for participants such as a 'Let's Foldit' podcast, a regularly updated blog, and even its own Wiki page on Wikia.com. Players are in teams or groups (some of which are school classrooms). In a research study of their work, Foldit scientists found that two of the most commonly used folding 'recipes' made and used by participants matched a newly developed protein-folding computer algorithm, (Kelly & Maddalena, 2015). Though participants are not developing their own research questions for the data they collect, nor are they analyzing that data or communicating findings, Foldit has created a community that seems to engage beyond the mere crowdsourcing of data.

Volunteer Geographic Information (VGI) Projects

Even before the advent of GIS-capable devices in the hands of the masses, non-scientists have been helping to collect geographic information for scientists, especially in the realm of ecology. Now, many of these projects are based in smart phone software applications; easy to use highly accessible leading to a huge expansion of volunteered geographic information (VGI) (Jones, Mount, & Weber, 2012). Through Esri's online map-making and app-making program, ArcGIS, virtually anyone can create a downloadable application to utilize VGI. For example, a featured story on the ArcGIS Online website describes how the drugstore chain Walgreens has created a Flu Index in order to provide the general public with timely and relevant health information ("ArcGIS Online," n.d.).

VGI offers benefits to many researchers that cannot obtain their needed data via satellite imagery but instead need more tedious, site-specific observations. For example, a project called GLOBE Observer utilizes avid cloud watches –which do, in fact, exist— to document observations on the underside of clouds, which cannot be captured with satellite imagery, ("GLOBE Observer," n.d.). Such volunteer-collected data recently aided in the classification of a new cloud type, asperitas, by the World Meteorological Organization, (WMO, n.d.). According to Cloud Appreciation Society's founder Gavin Preator-Pinney, a new cloud type has not been added to the International Cloud Atlas since its last edition over 40 years, ("The Asperitas Cloud and World Meteorological Day," 2017).

Another example of a GIS-based crowd sourcing citizen science project is Biodiversity PEEK. Similar to i-Naturalist –discussed earlier, PEEK seeks to engage all people by photographing 'overlooked species in underserved places' to help 'facilitate

informed management decisions by people, governments, and land preservation organizations,' in an effort to preserve species biodiversity. Another similar project in structure, Marine Debris Tracker, allows the public to log debris found in coastal areas for use in cleanup actions and also to build awareness of marine debris.

GREEN -- Global Rivers Environmental Education Network

Watershed education has vast potential as a platform for both contributory and collaborative citizen science. Water is a fundamental human need, pollution to water can be highly visible, there are a number of water quality tests that can be done ranging from biological to physical to chemical, and most homes and schools are within walking distance of some body of water. Water quality education has also been a staple of environmental education for a long time resulting in a large number of available resources and curriculum models.

The Global Rivers Environmental Education Network (GREEN) was established by professors at the University of Michigan's School of Natural Resources and Environment in 1989 including a well-known figure in environmental education, William Stapp. In their manual for Water Quality Monitoring, Stapp and Mitchell express that, "rivers were chosen as the central focus of GREEN primarily because they are a reliable and informative index of the environmental quality of biology, and for relating the physical sciences to the social sciences and humanities," (p. 9). Water is a necessary component to life, with the majority of the world's population living near a river making it a relatable part of everyone's life. The impacts of pollution to rivers are highly visible and elicit emotional responses. Today, studying the health of rivers is fairly accessible

for the typical classroom, with scientific tests ranging from chemical (pH and nutrient levels), biological (macroinvertebrate analysis), and physical (sediment and current).

Non-scientists can participate in recurrent monitoring events that provide useful data for stakeholders (city planners, politicians, scientists), while also answering specific questions of those that monitor (such as how a riparian zone revegetation affects water quality). This is precisely what GREEN —one of the first large scale watershed education projects— and many other citizen science programs attempts to accomplish. In Olympia, Washington South Sound GREEN (a local branch of the international program), engages public schools year after year in monitoring events, educational workshops, side projects, and an annual student-led congress.

The Headwaters Science Institute

The Headwaters Science Institute (HSI) in Soda Springs, CA is an environmental education nonprofit that utilizes their 'Student Driven Research' (SDR) model to engage youth in the entire scientific process for field investigations ("Headwaters Science Institute," n.d.). I am categorizing this project as 'co-created' although it is technically not a citizen science project. There is no overseeing scientist beyond the project directors and it is not clear if student-collected data is communicated beyond the classroom. HSI's Student Driven Research could be a valuable model for developing co-created citizen science project for educational settings.

In the HSI program, the project leaders (themselves both scientists and educators) visit a classroom or group of students over the course of several days. Students are first exposed to a specific, localized, and narrow topic to learn about. In one of their projects,

students learned about the effects of mistletoe on spruce trees from one page of text and the examination of physical examples. Once familiarized with the focus topic, students work in groups of 3-4 to brainstorm everything they learned about the topic (including any information they had beforehand). They then create a list of 25 open-ended questions without the direction of project facilitators —though facilitators will encourage students to go further with an idea or turn one question into several new ones. Groups then narrow down their list into their 'Top 3 Questions', which they will choose one of to answer with their field research. Though turning their top question into a hypothesis is a goal, it is not pushed by facilitators to be worded in the proper 'If, then, because' format. Instead, facilitators focus on getting students to understand the interaction of their chosen independent variable with their dependent one. If possible, the facilitators then show students various tools of measurement that they will have access to for their project (though students are not limited by these tools and are encouraged to be creative in how they answer their research question). With assistance from facilitators, the student groups then design their own research methods. It is emphasized that they just need to have an *idea* of how they want to collect their data in the field and that these methods might change due to site variability and their changing understanding of the project. Facilitators also emphasize that some form of data must be collected and diligently recorded on their observation charts (pre-made).

Learning about the topic, forming a list of questions, and designing the study might take 2 or 3 days of work with students. The groups then conduct their field investigations in an outdoor setting, being sure to collect data as they work. This can take one or two days of work in the field. The HSI project then culminates with students

analyzing their data and presenting their findings to the rest of the students. This can be the most challenging and rewarding part of the Student-Driven Research process. Once students start to see patterns in their data, they become attached to their project and take on a sense of pride. However, if a group was unsuccessful at collecting data in the field, it can be challenging for them to create a conclusion that is still meaningful and details what they have learned from the process or what they could do differently. If given the chance, it is worth it for these students to try their project again before presenting. Though the HSI presentation template is fairly simple, the act of communicating findings to the group is powerful for students. It is here that they take on the role of scientists and start to contribute to that vast 'body of knowledge' aspect of science.

In my work with students as a formal educator, I have adopted the HSI student-driven research model. I have used this model with students in both lab (yeast-based experiments) and field settings (ranging from beaver dams to invasive species to water quality). If enough time can be dedicated to the project and students are allowed to make vital mistakes —even if this means having to re-do their data collection—the student-driven research model can be a powerful motivator in science education.

Salal Sustainability Study

Labeled a 'Participatory Action Research (PAR) project, the Salal Sustainability Study (or just Salal Study), was developed from a partnership between local salal (*Gaultheria shallon)* harvesters, the Washington State Department of Natural Resources, the USDA Forest Service, and private industrial and non-industrial forest land owners in Mason County, Washington under the direction of California-based education researcher,

Heidi Ballard, whose interests lie in "how people learn through public participation in scientific research (PPSR) as a form of informal science education," (Ballard & Belsky, 2010; "Heidi Ballard," n.d.). The Salal Study is being cited here as an example of co-created citizen science, although not labeled as such at the time the research was published. It also fits into the category mentioned earlier titled Public Participation in Scientific Research (PPSR).

Ballard measured learning impacts of the 3-year PAR study in areas of ecological literacy, civics literacy, values awareness, and self-efficacy via semi-structured interviews with 30 salal harvesters and 10 land managers (Forest Service, DNR, landowners). The study was unique in that learning outcomes for both the 'professionals' as well as the participants were assessed. An outside interviewer also conducted interviews with the harvesters in order to obtain open reflection from the participants about their experience with the PAR Salal Study. Findings of the study indicated an increase in ecological knowledge for both groups: harvesters and professionals. The salal harvesters showed most gain —as self-reported through interviews— in ecological literacy (e.g. understanding of how and why science is conducted, quantitative impacts of varying harvest intensities) and civics literacy (e.g. improved relationship with forest managers, understanding of government and NGO structure that impact their harvesting). The agency personnel also indicated an increase in ecological knowledge especially relating to optimal forest conditions for salal growth and impacts of harvesting methods as well as an increase in value awareness with regard to how they perceive and value the 'local' knowledge of the salal harvesters.

The Salal Study represents a prime example of how co-created citizen science can positively impact the participants, scientists / professionals, and even the research itself. One of the many outcomes of collaboration with the salal harvesters was that the original research question developed by Ballard and the Norwest Research and Harvester Association was altered after communication with participants to become, "What are the impacts of differing harvest intensities on salal regrowth and commercial and biological productivity on the Olympia Peninsula, Washington, USA?" (Ballard & Belsky, 2010). Some of the harvesters that had a larger leadership role in the study indicated that they felt their contribution made a larger impact regarding permitting policies and government land management practices.   Likewise, some of the agency personnel began seeking harvester input regarding permitting policies after the Salal Study was completed.

2.7 Citizen Science in Education

Educators that seek out more interactive and relevant learning experiences for their students are drawn to citizen science projects in hopes of engaging students in real-world scientific research. Many of these projects are funded by informal science education (ISE) groups —such as museums, conservation districts, and nonprofit organizations— and have dedicated personnel that conduct trainings for teachers, provide equipment for data collection, and offer classroom visits to supplement their provided curriculum. Participation in such programs is often a result of individual teachers who wish to expand the typical classroom experience in an effort to reach mandated goals of increasing students' scientific literacy. In this section, I will give specific examples of how citizen science projects have been used in formal and informal education, how its

impacts are being assessed, and results regarding educational outcomes for youth participants.

In a quasi-experimental mixed-methods study of the affects of participation in horseshoe crab citizen science on 8th graders, Hiller (2012) found significant increases in knowledge, science self-efficacy, and citizen science self-efficacy. The experiment compared 86 students aged 13-14 in neighboring public schools with almost identical demographics. The treatment group of students (n = 46) engaged with professional scientists in the field to document horseshoe crab characteristics for a speciation study, as well as interactions with naturalists during field visits. The comparison group (n = 41), learned about horseshoe crabs within a classroom setting. The results of this experiment —grounded in social cognitive career theory—show the complex interaction of knowledge, self-efficacy, career goals, and interests and how participation in citizen science can positively impact students on a variety of academic goals.

Although extremely rare, I came across one article that describes a co-created citizen science project in a K-12 setting —specifically with a high school classroom. In a response to Mueller, Tippins, and Bryan (2012) article, "The Future of Citizen Science," authors Gray, Nicosia, and Jordan (2012) offer their first-hand experience with co-created citizen science in a case-study format. From their account, it is clear that such projects require a significant amount of time, effort, and resources from all stakeholders involved –teachers, scientists, students, and project coordinators. In a yearlong study, 9th grade honors biology students exercised a great deal of autonomy to answer a research question regarding the public's "willingness to pay" for ecosystem services of a watershed. Scientists visited the classroom monthly with ongoing email communication to provide

support and feedback during the research process. Students engaged in a number of high-level scientific processes included but not limited to: an extensive review of scientific literature using a collaboratively developed rubric, the development of a specific research question, survey-design methodology development and data collection, and communication of findings to important community stakeholders (e.g. environmental agencies). After a peer-review from the collaborating scientists, students submitted their research to a scientific journal for publication.

Authors of the article argue that students gain valuable skills relating to scientific and civic literacy when allowed to engage in a meaningful level in a recursive scientific research that is relevant to their local community, (Gray et al., 2012). They also highlight the challenges to goals of the democratization of science and creating more equal power dynamics between scientists and citizens, especially in the classroom. Authors also mention the limitations in their study in that teachers still felt a lack of confidence in their skill to 'create' science and that scientists —although they enjoyed their involvement— felt the pressure of time devotion to the project. Another limitation to this study —as with any case study— is the difficulty to make broader claims about the impact of citizen science; especially as the group of students involved were enrolled in an honors level course, presumably with selection criteria of some kind.

The previous study is an extreme example of collaboration between scientists and teachers; one that is rarely found in the literature concerning citizen science. However, there are a number of studies that point to the educational impacts of citizen science as more typical contributory or even collaborative modes of participation. One collaborative project at the University of Minnesota called Driven to Discover is an

enrichment program for middle school students. Researchers studying this program

showed via a retroactive post-survey —in which students ranked their level of

understanding or skills both before and after their experience— that participants'

significantly increased their understanding of science content and scientific investigation

skills (Meyer et al., 2014).

In their discussion of a model for inquiry-based science education through student

and scientist collaboration, authors Feldman et al. describe their 10-year long process to

develop a model they called Multiple Outcome Interdisciplinary Research and Learning

(MOIRL) (Feldman, Chapman, Vernaza-Hernandez, Ozalp, & Alshehri, 2012). Authors

highlight the interaction between and learning of all stakeholders in their project,

including students, teachers and education researchers, scientists, engineers, graduate

students, and community members. As an example of a MOIRL projects, the authors

describe a climate change education experience called the Camuy caves project between

a speleologist (specializing in cave research) and K-12 students in Puerto Rico. Students

first learned about cave formations in class, visited a cave, spoke with the speleologist

about his research, analyzed data on humidity and temperature given to them by the

scientist, and then made posters for a local interpretive center of their findings. The

researcher found significantly improved understanding of science content (climate

change, caves, and their relationship) as well as skills relating to scientific process

(Vernaza-Hernández et al. in Feldman et al., 2012).

Ch. 3 – Methods

3.1 Introduction

In this section, I will give an overview of methodology for this research, explain the BioB-based curricula —both the contributory and collaborative versions, describe the pre/post-assessment, and summarize the statistical analysis used for this dataset. This research was approved by the Institutional Review Board at The Evergreen State College, Olympia, Washington.

For this research, I chose a manipulative study design in which I assessed the outcomes of two different types of citizen science curricula on middle school students in the Olympia School District. I chose a manipulative study design so that I could directly test the impact of a contributory versus collaborative model for citizen science in public education. I used two sample sites for the trials in this study: Washington Middle School and Marshall Middle School. At each site, I conducted both the contributory and collaborative curricula with two different classrooms over a time span of two hours (two classroom visits).

I designed two versions of curricula based on the Bugs in Our Backyard (BioB) Open-Ended Survey and associated education materials found on their website. For the contributory version, I followed the education guide for teachers from the BioB website. In this version, students learned background information from a PowerPoint lecture during the first visit and then conducted the survey in the field for the second visit after a brief reminder of what was covered. If there was time, students also had the opportunity to enter the data into the online survey format in the classroom.

For the collaborative version, I utilized a model called Student Driven Research, which I adapted from a non-profit organization called The Headwaters Science Institute. Students in this group received the same background information from the same PowerPoint lecture during the first visit. For the second visit, students were asked to brainstorm a list of questions about bugs in small groups of 3-4. A discussion then took place as a whole group about how we could collect data to answer some of those questions. Students then conducted the same field survey, but were asked to let their questions guide their choice in host plant, survey methods, and what their findings could mean.

To determine the difference in outcomes from the two versions of citizen science curricula, I designed a pre/post-quiz and survey that assessed: scientific content knowledge (pertaining to insects), scientific skills/literacy, and attitudes towards science. Prior to my visits, students were given a permission slip to inform their legal guardians of my research and ask for their consent for their child to participate in the research (Appendix A). Each group of students took the pre-quiz and survey immediately prior to their exposure to the curriculum and then the identical post-quiz and survey 1-2 weeks following my last visit. This procedure was replicated at two sites in the Olympia School District: Washington Middle School and Thurgood Marshall Middle School.

3.2 Curriculum Design

For both sets of curricula, students receive a 30-minute lecture via a PowerPoint presentation, an explanation of the BioB Survey procedure, and then conduct the field survey outdoors. The lecture includes an introduction to the BioB citizen science project,

general background information on insects (anatomy, metamorphosis, ecology), and more detailed information on two true bugs of interest (the Western boxelder bug and the brown marmorated stink bug) that we may encounter in our area. Students are then given a break-down of the survey data sheet: how to characterize the field site, how to find longitude and latitude, what a 'host plant' means and how to identify it using field guides, how to measure the circumference and height of the host plant, how to collect an insect, how to photograph an insect, and an explanation of what a 'good' photograph is in order for the BioB researchers to identify the host plant and insect. Students are shown what tools they may use during the survey: tape measurers, magnifiers, petri dishes, and identification guides. We discuss areas around the school that would provide a variety of host plants to survey. Students are then broken up into groups of 3, instructed to come up with a group name, and retrieve their needed tools and survey sheet. Once outside, students proceed to a chosen host plant at the survey site. The teacher and I rotate through the groups to troubleshoot any questions that arise during the survey and to ensure teams are working together. Students have around 30 minutes to complete the field survey.

3.3 Pre/Post Quiz and Survey Design

The pre/post-quiz and survey contains 30 questions total: 10 science content questions, 10 nature of science questions, and 10 attitudes towards science questions. The science content and nature of science questions are multiple-choice with 5 possible choices including an "I don't know" response for every question. The 10 'attitudes towards science' questions ask students to rate how they feel using a numbered scale

where 1 is 'Strongly Disagree' and 5 is 'Strongly Agree.' The quiz/survey was made

using Google Forms for ease of data collection —every classroom had access to Google

Chromebooks and students in the Olympia School District are familiar with Google.

Before answering any questions, students 'agree' or 'disagree' that they have read

and understood a statement concerning the nature of my research and a brief description

of the assessment. It is emphasized to students that the quiz is not graded and that their

name will not appear in any of the final research. The quiz/survey takes students 10-15

minutes to complete. The entire quiz/survey can be found in Appendix B. I administered

the pre quiz at the very beginning of my first visit —after introducing myself—and the

participating teacher administered to posttest at some point 1-2 weeks following my

second visit.

3.4 Science Content Questions

The first ten questions of the survey –following 5 basic questions about the

student— are designed to ascertain student knowledge related to insects. For the online

survey, this section is titled "Questions About Bugs" in the Google Form. Since this

research is aimed toward the middle school level, questions were designed to be

appropriate for this age-level. All questions are multiple choice and have an "I don't

know" response option. Questions were modeled on research into learning outcomes of

citizen science conducted by Vitone et al. (2016). Their research used two citizen science

projects: School of Ants and Backyard Bark Beetles and was conducted in a college

entomology course. Some of their pre/post-assessment questions were used for this

research, other questions were modified to fit the middle school level, and others were

left out due to lack of relevance to the Bugs in Our Backyard project. Appropriate and believable distracters were chosen for each question, helping to ensure that students needed to know the content to get an answer correct –minimizing the chances of correct guessing.

3.5 Nature of Science Questions

The next section of the quiz/survey asks students 10 questions relating to the nature of science (NOS): the purpose of science, how to find an average, what is a valid source of information, if one should accept/reject a hypothesis, etc. These questions were designed to assess students' skills relating to scientific methods, their understanding of what science is and their understanding of what it is for. Measuring these skills, knowledge, and beliefs is intended to assess a participant's level of 'Scientific Literacy.' Since there is still no established evaluation for measuring scientific literacy that has been agreed upon by the research community, I designed this section of the pre/postquiz using the Test of Scientific Literacy Skills (TOSLS) as a model (Gormally et al., 2012).

The TOSLS consists of 28 multiple-choice questions that assess 9 categories of scientific literacy skills. The assessment was created after an extensive literature review of scientific literacy measurements, faculty surveys; a pilot test followed by student and faculty interviews to further refine the TOSLS. When constructing the multiple-choice questions for this research, I consulted the TOSLS to ensure that each of the 9 scientific literacy categories were covered by the 10 NOS questions. Since the TOSLS was developed for general education science courses at a university level, the 28 multiple-choice questions were used as guidelines and examples, and not utilized directly.

3.6 Attitudes Toward Science Questions

The final section of the quiz/survey asks students to rate their agreement to 10 statements on a 1-5 Likert-type scale. These 10 questions were designed to assess students' attitudes towards science (e.g. "I want to take more science classes at school"). Responses are on a numbered scale 1-5 with 1 being "Strongly Disagree" and 5 being "Strongly Agree." This section was modeled in part from a non-published pre/post-analysis utilized by three local watershed education networks. Having interviewed the developer and statistician behind the pre/post-analysis, I found that it was originally based on the work of Zint, Kraemer, & Kolenic (2014) conducting environmental education research into the stewardship behaviors of participants in Meaningful Watershed Environmental Education (MWEE) programs.

3.7 Data Analysis Methods

In order to assess the impact of level of participation in citizen science programs, comparison of means between groups' learning gain scores were analyzed. Gain score (D) = posttest score (Y_2) – pretest score (Y_1). Mean gain scores were calculated for each question category: content, nature of science, and attitudes and then compared using an analysis of variance (ANOVA) and student t-tests in the statistical software JMP when data met parametric assumptions of normalcy. When data did not meet normal distribution assumptions, I conducted re-sampling comparisons in Excel to compare mean gain scores between treatments for each question categories. In some cases,

statistical analysis was not needed, and I instead made comparisons via simple pie graphs and tables to look for subtle changes in response rates by individual questions.

Gain scores for each section were calculated by taking the sum of the score for each section divided by the number of questions (10), resulting in a decimal ranging from -1.0 (a diminished score of 100%) to 1.0 (an increased score of 100%). Responses were coded with a score of "1' if correct and a score of '0' if incorrect (including a response of "I don't know."). For the attitudes section, the final score was divided by 50 in order to compare gain scores between the three categories of questions on a scale of -1.0 to +1.0.

Some researchers question the use of an ANOVA test when analyzing differences between pre and posttest gain scores (Weber, 2009). Because of the nature of most college courses, the sample populations are not randomized —students self-select into courses based on interest, major, etc. In this non-randomized setting, it is recommended that an analysis of covariance (ANCOVA) is performed, using the pretest as a covariate (Dimitrov & Rumrill, 2003). However, since the participants in this study are required to take the middle school science courses utilized for this research and because both schools in the study are public institutions with no selection or application process, an ANOVA was seen as an appropriate way to compare group means.

Dichotomous coding was used to quantitatively analyze quiz responses for two of the three sections. All answers for the two objective sections —science content and nature of science questions—were coded with either a 1 (correct response) or a 0 (not a correct response). A response of "I don't know" was considered an incorrect response and given a score of 0 (except when intentionally comparing correct, incorrect and "I don't know" response rates by question). A pre and posttest score for each participant

was calculated for both quantitative sections using total points for correct responses divided by ten (10 questions per section). These average scores were a decimal figure ranging from 0 to 1. Gain scores for both sections were then calculated by subtracting posttest scores from pre-test scores resulting in a positive (improved) or negative (diminished) score.

There is discussion in the literature concerning the use of normalized gain scores to account for the relatively small gains possible based on high pre-test scores (Weber, 2009). Normalized gain scores are calculated by dividing actual learning gains (post – pre score) by possible learning gains (100% - pre score). When measuring changes in behavior or understanding based on raw score differences, it is possible that easy test questions will yield a falsely high gain score for a low-ability participant while more difficult questions may falsely show higher gain scores for a participant with higher ability.

3.8 Participants

76 student responses were analyzed for this research after redacting responses where students answered 'disagree' to participating in the study, did not have a permission slip from their legal guardian and/or did not have a corresponding pre- or posttest. The 76 students were from two separate classes taught by the same teacher in two separate middle schools, totaling 4 middle school science classes. Thurgood Marshall Middle School and Washington Middle School are both in the Olympia School District in Olympia, Washington. 49 of the students were in 6th grade –all from Washington Middle School. 10 of the Thurgood Marshall Middle School students were

in 7th grade, and 17 were in 8th grade. Specific student demographics, such as gender or

ethnicity, were not collected as a part of this research, though I will outline demographic

data (Appendix C) for the two middle schools as a whole. All science teachers of grades

6-12 in the Olympia School District were invited to participate in this study via several

emails (Appendix D). Out of four interested teachers, the two schools chosen were those

able to schedule 2 classroom visits within the time frame of this study. One other school

—Capital High School— was initially part of this study but was removed due to

inconsistent pre- and posttest results, a low level of participants, because the specific

group was an alternative program not representative of the general population, and

because of a failure to submit permission slips.

Ch. 4 – Results and Discussion

4.1 Overview

In the following sections, I break down the pre- and postquiz results based on the three question categories —science content, nature of science, and attitudes towards science—and by treatment group. For ease of communication, the contributory treatment group will be called 'Capybara' and the collaborative treatment group will be called 'Liger.' This designation was used during classroom visits in order for students to designate their group on the pre- and postquiz but not know the functional difference between these groups. To address the two-pronged research question, I will show pre- and posttest results at two levels: 1) comparisons of scores from pre- and posttests for *all* students in the study and 2) comparisons of scores *between* the Contributory (Capybara) and Collaborative (Liger) treatments. I will follow this two-pronged structure for each of the three question categories: content, nature of science, and attitudes. An interpretation of the results in terms of significance and meaning will be presented at the end of each section, following the presentation of data.

Over the course of this study, students improved most in their understanding of science content, with significant difference in understanding of more BioB-specific content for Group Liger (collaborative) (Fig. 3) Students' nature of science skills and attitudes were relatively unaffected by their experience with the project (Fig. 3). There was no significant difference *between* the treatment groups for either of the three question categories (content, process, or attitudes) (Fig. 4). However, when looking at all students, there was a significant increase in science content understanding as indicated by difference in mean score for pre- to postquiz (Fig. 5). In the following sections, I will

elaborate on results and interpretations for each question category, adding notes about specific questions.
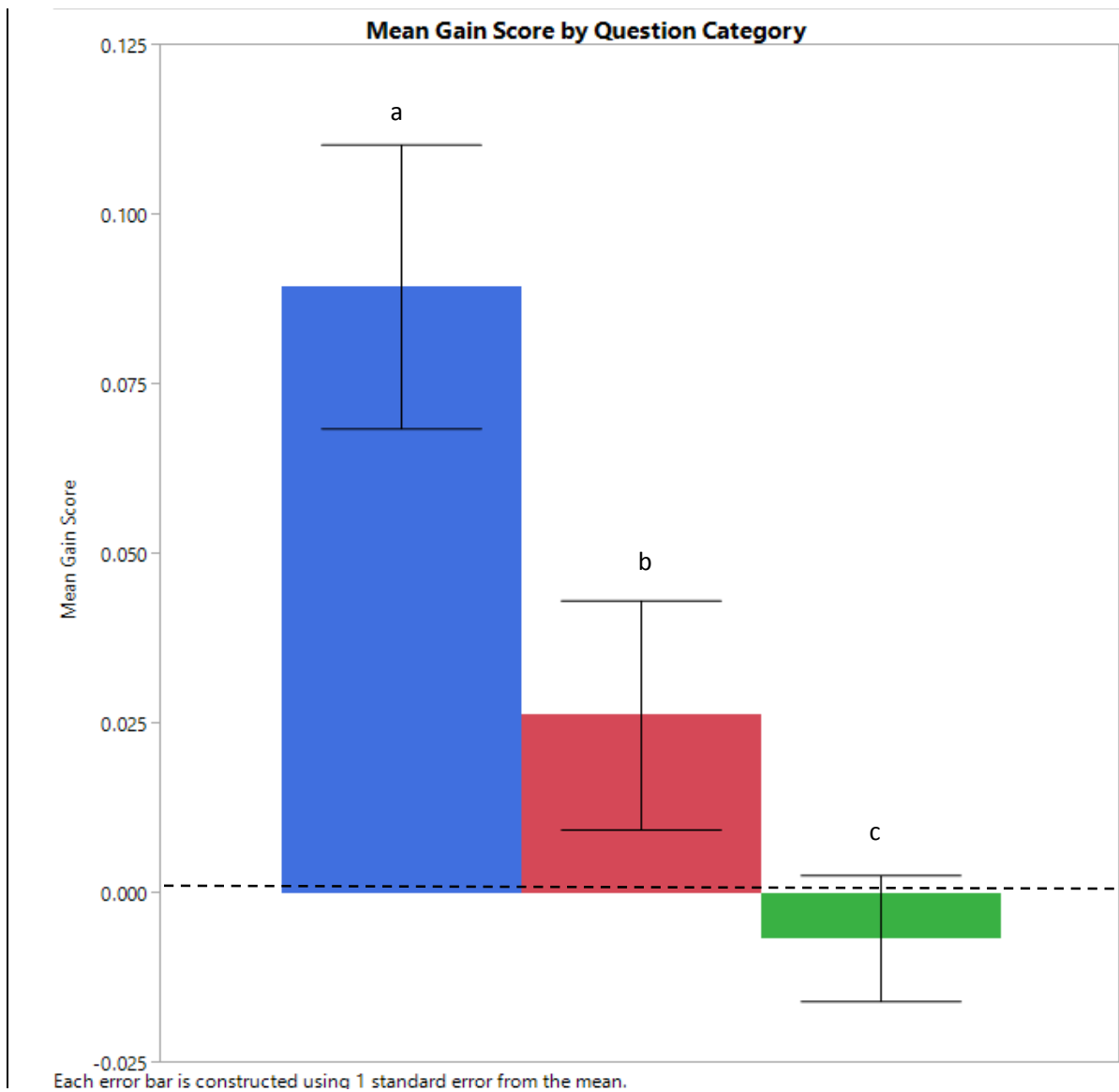

Fig. 3 Mean student gain scores for (a) science content, (b) nature of science, and (c) attitudes across all treatments. Gain score of 0 = no change from pre- to postquiz.
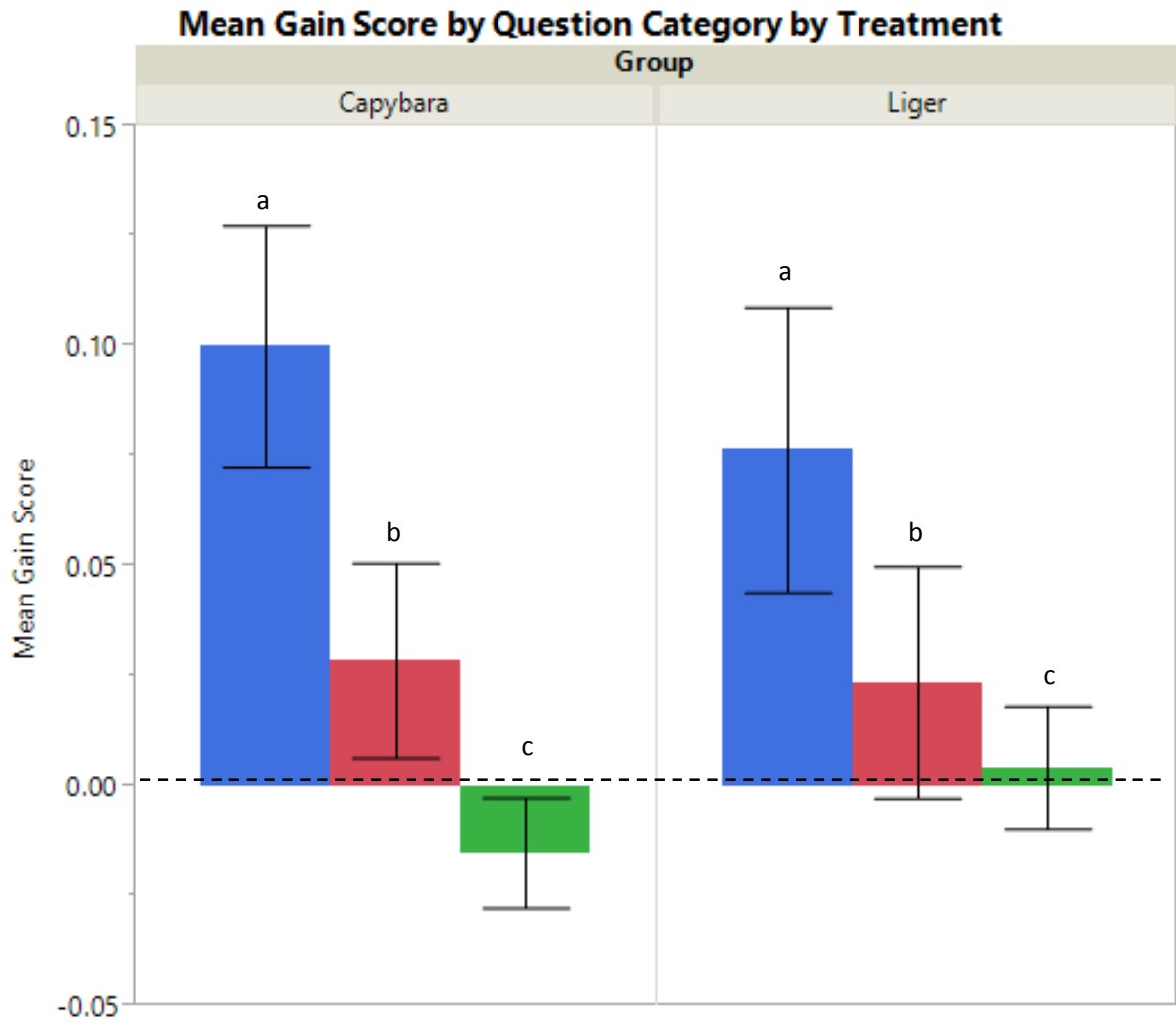
Fig. 4 Mean student gain scores for (a) science content, (b) nature of science, and (c) attitudes for each treatment (Capybara = contributory, Liger = collaborative). Standard error shown. Gain score of 0 = no change from pre- to postquiz.
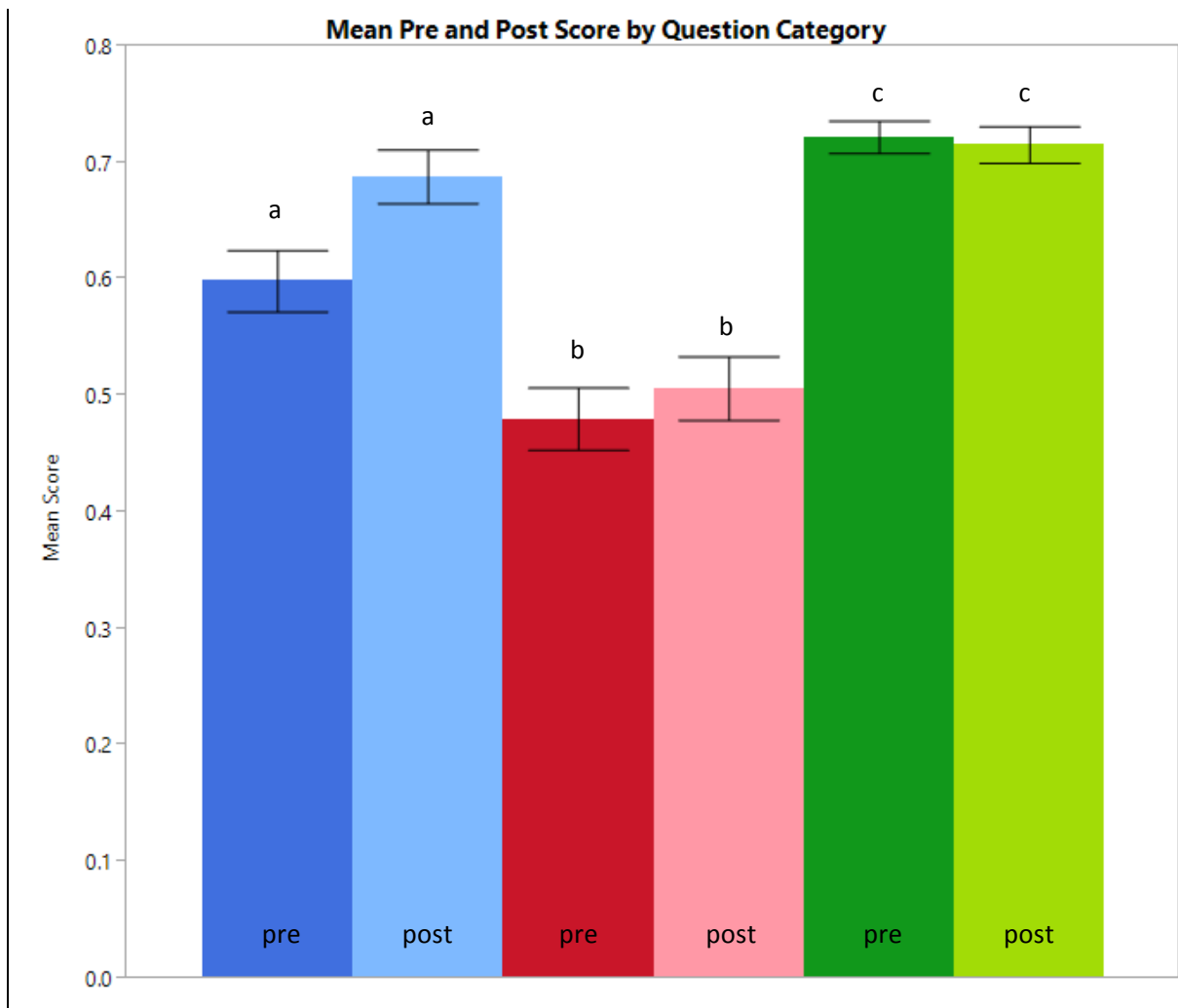
Fig. 5 Mean score for all students for pre- and postquiz for (a) science content, (b) nature of science, and (c) attitudes. A score of 1.0 is equivalent to 100%. Standard error shown.

4.2 Science Content

Results

As mentioned above, as a whole, students increased their understanding of scientific content as seen by the positive mean gain score for all students in Figure 3. Capybara's faired slightly better with a mean gain score than the collaborative group (Fig. 4). A greater increase in knowledge can be seen for content more closely related to the BioB project and field survey. For example content question 7 ("Which of the

following IS an insect") and content question 10 ("Which of the following is an example of a 'true' bug") show greater improvement than other questions in this category (Fig. 6).

When comparing content understanding between students in each treatment group, it can be seen that group Capybara fairs slightly better than Liger in overall increase of content knowledge (Fig. 4), however this is not statistically significant. When looking into response rates by specific multiple-choice option, it can be seen that there was a shift in response rates from "All of the above" to 'Agriculture' and 'Invasive Species,' (Fig. 7). Both of these responses were topics covered in more detail during the presentation.

CQ7. Which of the following IS an insect?
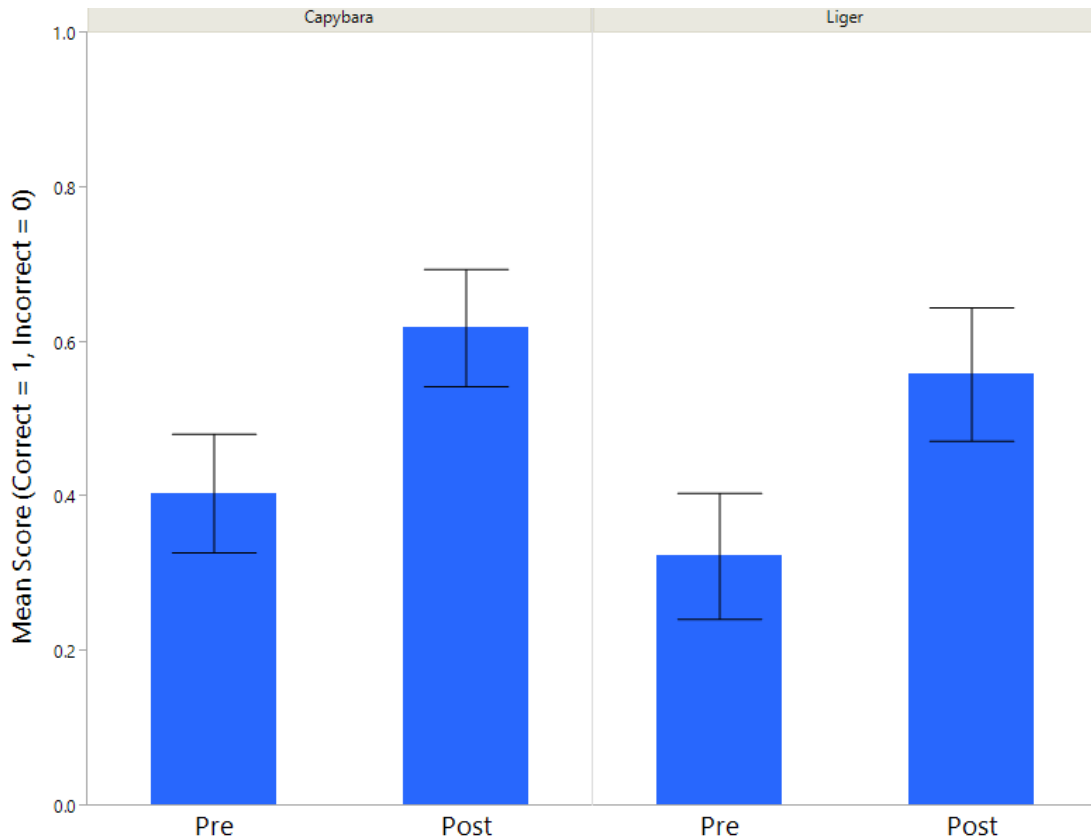
a.

CQ10. Which of the following is an example of a 'true' bug?

b.
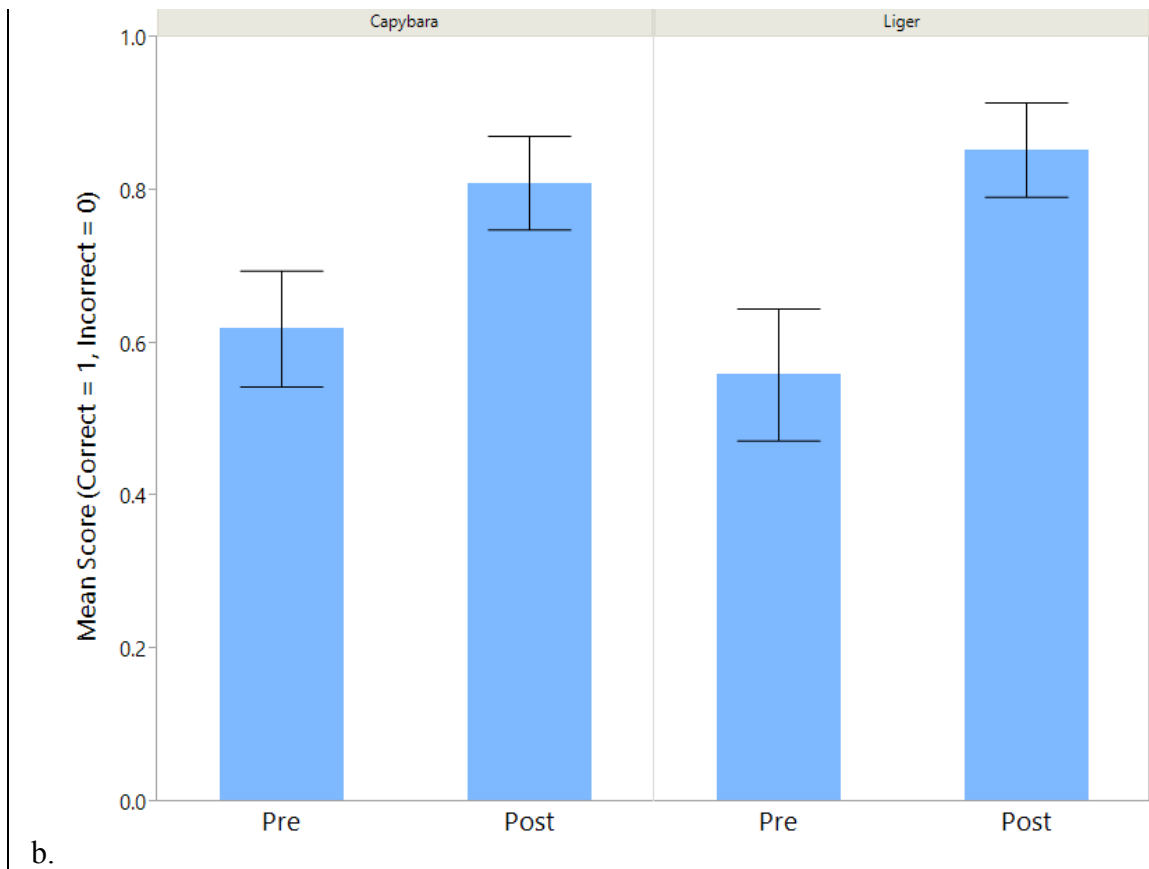
Fig. 6 Pre- and postquiz mean scores by treatment group for a. content question #7 (CQ7. Which of the following IS an insect) and b. content question #10 (CQ10. Which of the following is an example of a 'true' bug belonging to the order Hemiptera).
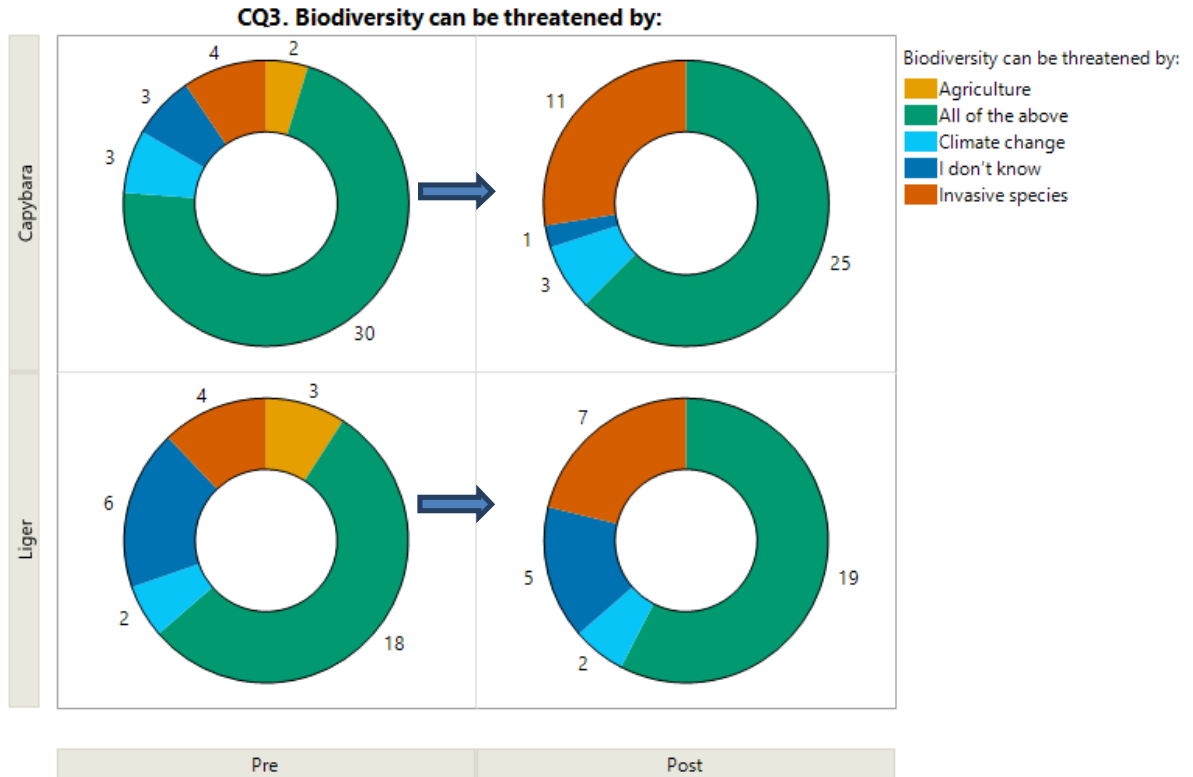
Fig. 7 Comparison of the change in response rates by response option from pre- to postquiz for Content Question 3 (CQ3) between treatment groups (Capybara and Liger).

Discussion

Despite engaging with the BioB curriculum for only two hours, students showed notable —and in some cases significant—increase in their level of science knowledge as related to the project. This finding is in line with similar studies that often show participant increases in knowledge during interactions with citizen science at all modes of participation (contributory, collaborative, co-created).

It is worth noting that for the only question that posed an "All of the above" response option, students in one of the treatment groups (Capybara) actually shifted their response rates and answered with more specific options on the postquiz. While these options were not considered 'best,' they were still technically correct. When looking at a

breakdown in responses by response option (Fig. 7), it can be seen that the Capybara response rate shifted from the correct answer to an increase in the 'Invasive species' response option. The topic of invasive species was covered in more detail than the other response options during the presentation with a discussion of the brown marmorated stink bug as an invasive and biocontrol methods. This is a bug that most of the students had a personal interaction with at some point. It is possible that students were thinking about the question with more nuance during the posttest and therefore chose a more specific response than 'All of the above.' The 'Invasive species' response also increased by three for Group Liger. It could also be a natural factor of the passage of time or a result of their experiences in class outside of the project.

Interestingly, the contributory group (Capybaras) fared better in many of their learning gains for science content and nature of science questions. Possibly, these students had more time to engage in the field research and develop a more innate interest in the project itself. These students were able to explore in more authentic and personally meaningful ways while the collaborative group (Ligers) were exposed to what must have seemed like an irrelevant trip into the tedious task of formulating a specific research question without first exploring the topic and developing their own personal interest in it. When speaking of creating "educative" experiences, John Dewey (1938) states, "The planning must be flexible enough to permit free play for individuality of experience and yet firm enough to give direction towards continuous development of power," (p. 58) which is "a much more intelligent, and consequently more difficult, kind of planning," (p. 58).

That students improved in their understanding of content relating specifically to their experience with the BioB presentation and field survey makes logical sense. "Every experience is a moving force," says Dewey. Whether or not that experience is effective in the reaching the established goals is another question. It seems that the scaffolding of the BioB experience was sufficient to cause students to retain information at least by the time the posttest was administered. It would be interesting to see if these knowledge effects are lasting via a retention posttest, a common tool for assessing educational outcomes.

4.3 Nature of Science

Results

Ten of the pre/postquiz questions assess student understanding of skills, practices and ways of thinking about science such as: how to set up a controlled experiment, what a reliable source of information looks like, and whether to accept or reject a hypothesis based on evidence. Students, as a whole, did not improve their understanding of or skills regarding the nature of science during their experience with this project (Fig. 3). There was also no significant difference in mean gain scores between the treatment groups for the nature of science question category (Fig. 4).

Even when using a finer grain question-level analysis, there is very little change in student knowledge or skill regarding the nature of science. Slight increases can be seen across both treatment groups for questions #4, 5, and 10 (Table 2). One question (#3) yielded a decrease of 1 correct response for both treatment groups. Question #8 showed an increase of 4 correct responses only for the Liger group. Question #1 ("Science is _____.") shows an increase of correct responses by 5 for the Capybara group,

while a decrease in correct responses by 4 from the Liger group; the only question to

show this pattern on increase for one group and decrease for another (Table 2). When

looking at question #1 responses by multiple-choice option, it can be seen that the Liger

group shifted their response of "All of the Above" (the correct response for this

question), to either "I don't know" or "A way of thinking about and exploring the world

around us," (Fig. 8). Capybara's on the other hand, shifted their responses from "A

collection of facts that explain the world around us" to "Both a collection of facts and a

way of thinking about the world," (Fig. 8).

Question #	Capybara		Liger	
	Increase	Decrease	Increase	Decrease
1. Science is:	5	---	---	4
2. What is the mean (average) of the following numbers: 2, 6. 1	---	---	---	2
3. Why do researchers use statistics (averages, probability, percentages) to interpret data?	---	1	---	1
4. Which of the following would be the *best* resource for background research on bugs	1	---	1	---
5. The variable being changed (or manipulated) in this experiment is:	1	---	3	---
6. The variable being recorded/measured (the 'responding' variable in this experiment is:	---	---	1	---
7. An important variable to control (keep the same) in this experiment is:	2	---	---	---
8. One conclusion from this experiment could be:	---	---	4	---
9. Based on results of this experiment, the researchers' hypothesis should be:	---	---	2	---
10. The conclusions of this experiment could be used to make decisions about:	2	---	4	---

Table 2. Difference of correct response rates between pre- and posttest for Nature of Science Questions. Shows increase or decrease in the number of correct responses from pre- to posttest for each question in the nature of science category for both treatment groups.
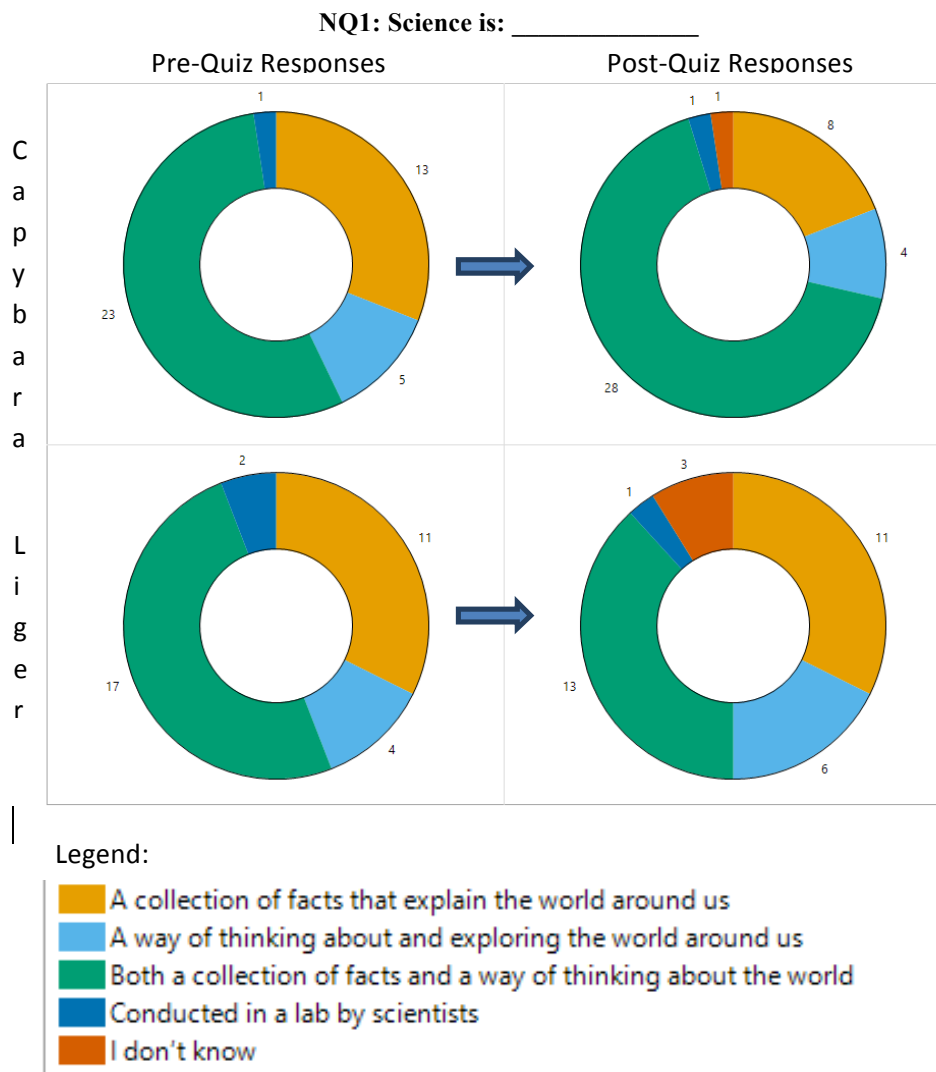
NQ1: Science is: _____

Fig. 8 NQ1. (Science is: _____) response rate by multiple-choice option for both treatment groups from pre- to postquiz.

Discussion

This section did not see much change in student's level of skills or knowledge relating to the way science is thought about and conducted. This is likely due to a lack of emphasis on the scientific process during this project and possibly because the questions on the pre/postquiz were not in the context of the BioB project. Due to the 2-hour time limitation of this study, students did not have the opportunity to analyze their collected

data, nor did they get to upload their data onto the BioB website (due to restrictions in how the data could be entered and the need to upload pictures from a desktop computer).

"I don't know" responses did decrease from pre- to posttest for over half of the nature of science questions for both groups (Appendix E). Perhaps this was due to an increase in students' confidence when taking the posttest. The decrease in "I don't know" response rate may also have been a factor of test facilitation. When I conducted the pre-test, I emphasized that students could chose "I don't know" at any time without penalty. The two participating teachers conducted the posttest and may not have emphasized the "I don't know" response in the same way. But, as can be seen by the relatively unchanged pre/postquiz scores, the changes of student responses did not result in more correct answers for this category.

The nature of science questions asked students to assess validity of information sources, how to set up a controlled experiment with independent and dependent variables, why the use of statistics is important to analyzing data, how to take an average of a set of numbers, how to read a graph, and how to interpret results into a sound conclusion. These questions, being modeled from the TOSLS questionnaire, may begin to assess the scientific literacy of middle school students, but it is difficult to determine their effectiveness in this particular study. If students had time to engage in the entire Student Driven Research (SDR) project (described earlier as the curriculum model developed by the Headwaters Science Institute), perhaps scores for this section would have reflected a deeper understanding of what science is and how to use it for understanding a research question.

I would caution against drawing any strong conclusions for the Nature of Science questions for this research due to the lack of participation in SDR by students in the Liger group. There has also been discussion regarding how effective 'science process' questions are if they are not in some way directly related to student experience. For example, future studies could compare science process questions as relating to general examples versus utilizing specific examples and details from the experience under study.

4.4 Attitudes toward Science

Results

The final ten questions were Likert-type questions that asked students to gauge their level of agreement to various statements related to science such as "I would like to take more science classes in school" on a scale of 1-5. When taken as a whole, students showed no significant changes in their attitudes toward science (Fig. 3). Though slight difference between means of gain scores between treatment groups was observed, this difference was not of statistical significance (Fig. 4). Several students had strong opinion shifts following their BioB experience, resulting in outlier data as depicted by the standard error shown in Figure's 3 and 4.

For this section, very little change can be seen at the question level. However, student responses shifted slightly from pre- to posttest for several questions. For example, question #1 ("I like doing science") showed a decrease in positive response rates (Fig. 10). The capybara group shifted from 18 responses for "Strongly Agree" (5 on the Liker-type scale) on the pretest to 14 on the post. Likewise, the Liger group shifted from 14 "Strongly Agree" responses to 12. Students appeared to strengthen their

agreement or disagreement to question #9 ("I would like a job that involves science")

following their experience with BioB for both treatment groups. This can be seen by an

increase in "Strongly Agree" responses for both treatments and an increase in "Strongly
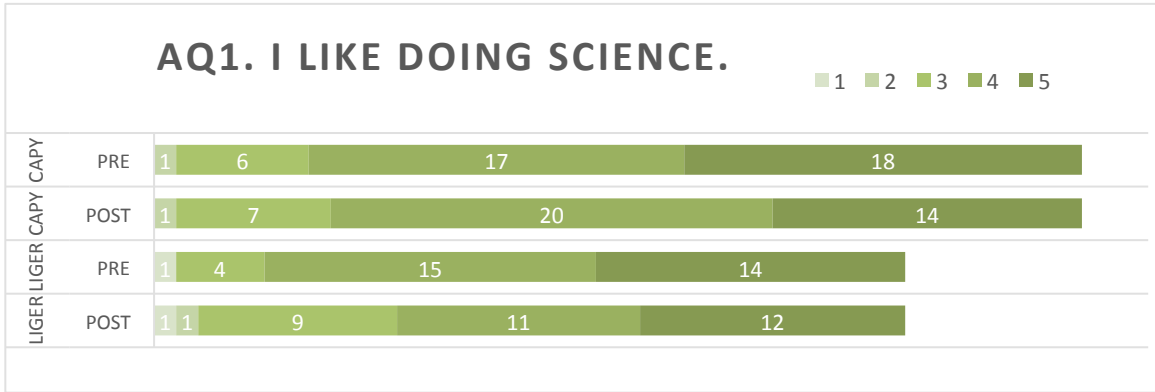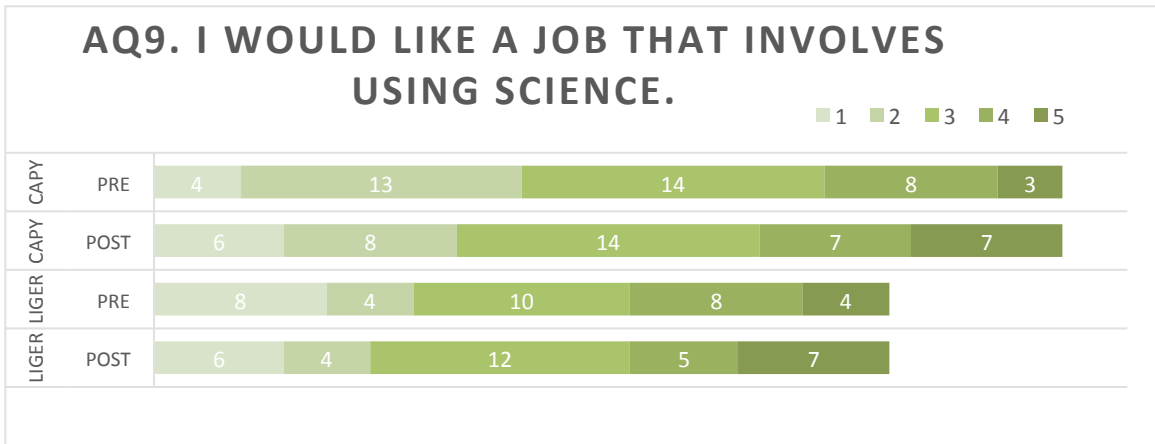
Disagree" for the Capybara group (Fig. 11).

Fig. 9 Change in response rates for attitude question #1 ("I like doing science") for both treatment groups from pre- to post-test on a Likert-type scale with 1 = Strongly Disagree and 5 = Strongly Agree.

Fig. 10 Change in response rates for attitude question #9 ("I would like a job that involves using science") for both treatment groups from pre- to post-test on a Likert-type scale with 1 = Strongly Disagree and 5 = Strongly Agree.

Discussion

The attitudes question category yielded a few interesting results, again at the question level, as the mean gain scores for this category were relatively unchanged for both treatment groups. For question AQ9 ("I would like a job that involves using science."), there was a shift toward both extreme options (1: Strongly Disagree and 5: Strongly Agree) for both treatment groups (Fig. 10). This could suggest that students with a previous interest in science-related careers had a reinforcing experience through the BioB curriculum, while those students at the opposite end of the spectrum were pushed further away from an interest in science-related careers by their experience. For question AQ1 ("I like doing science"), students seemed to have decreased their interest in science following their BioB experience (Fig. 9). This was not expected as a result of this experiment, and may be indicative of the rushed nature of the curriculum delivery, given the two-hour time frame.

4.5 Further Considerations

Changes in content, scientific inquiry, and attitudes may have occurred based on exposure to different modes of citizen science. However, these changes may also have been a result of differences between school-wide factors (such as school culture and climate), pedagogical differences of teachers, differences in timing of curriculum delivery (late winter versus early spring), or other confounding variables.

For Marshall Middle School, students were enrolled in a Natural Resources course at the time of this research study and so were covering very similar topics relating

to nature identification, field measurements such as tree height, the effects of invasive species on biodiversity, and biocontrol methods for dealing with invasive species problems. Though the cooperating teacher did not interfere during the time of the curriculum delivery, there may have been assignments and lessons delivered during the time between pre- and postquiz that could have affected their results. Another difference for Marshall Middle School is that this research was conducted during January and February which resulted in finding very few bugs during the field survey.

For Washington Middle School, the curriculum was slightly modified to fit the teacher's classroom management requirements and the higher number of students per class (30-31 students per class vs. only 15-20 at Marshall Middle School). These modifications included giving students a brief tutorial in the field for identifying three specific plants –red alder (*Alnus rubra*), bigleaf maple (*Acer macrophyllum*) and Indian plum (*Oemleria cerasiformis*). Students were instructed to find one of these three plants during their field survey to use as host plants. Their field survey was conducted in March yielding a higher number of bugs found during the study.

Finally, time was a significant limiting factor in applying the Student Driven Research model in the classroom. In the original vision for this study, students were to engage in all aspects of scientific research —coming up with their own research question, methods for data collection, data analysis, and communication of findings. Because I was only able to visit the classrooms two times for around an hour each time, students only engaged in the very first part of the Student Driven Research model in which they brainstormed a list of possible research questions after the background information lecture. Though we did discuss the possibilities for answering these questions using

study methods that varied from the field survey, this was done as a whole group and not by individual students or student groups.

4.6 Recommendations for Future Research

From the lessons learned while conducting this research, there are a few recommendations that I would advise for researchers interested in assessing educational outcomes of collaborative citizen science projects: increasing the number of replicates / sample sites, increasing the amount of time spent with students on the Student Driven Research model, modifying the curriculum design for both groups, and modifying the pre- and postquiz methods.

This study utilizes data from only two sample sites. This is a severe limitation when attempting to seek trends in the data to generalize to larger populations. The study was conducted within the Olympia School District (OSD), and so may not represent low-income populations or school districts with different ethnic demographics (OSD being 69.5% white). It is recommended that future studies, if time and funding allow, incorporate data from a larger number of sample sites from across school districts. Even including a middle school from the nearby Shelton School District —a more rural, low-income district—and the Tacoma School District –an urban setting—would have allowed for more generalization of results to greater populations.

As mentioned before, the Student Driven Research model requires extensive time to implement effectively in a classroom setting. In previous experiences, I have used SDR with students over the course of several weeks and even several months (amongst other projects and curricula). In one study mentioned in Chapter 2 of co-created citizen

science with a high school group, the researchers spent an entire school year working closely with a scientist to develop an environmental behaviors survey conducted in their local community (Gray et al., 2012). An important aspect of SDR is that students have time to make vital mistakes and even to fail in order to make the scientific process authentic and personal. It can be difficult for a facilitator to watch as students fail to recognize errors in field survey methods, but students are quick to understand their own mistakes once they start collecting data. I have seen student groups want to tackle extremely complicated questions only to realize once in the field that collecting 100 rough skinned newts in association with a body of water is a challenging task! If given this valuable time for failure, students can re-work their research questions or methods, making it a more meaningful experience in the end. Much like this research, students are encouraged to report findings that may not show what they had hoped…an important lesson to learn in the sciences!

Keeping the time of exposure to curriculum constant during a comparative study seems an important but challenging factor. During this study, time was in fact held constant across both treatments. However, in future studies, it is clear that a collaborative project would require more time than the 2-hours spent here. That might mean a large amount of time spent on data collection for one group. Perhaps that data collection can be supplemented with more intense training in survey methods and having students upload their own data across a larger geographic area and timescale. Education-related experiments that contain this manipulative component can be difficult to justify when students in one group may be experiencing a richer learning experience than another. Perhaps researchers could find already established citizen science projects —of a similar

topic—that are both contributory and collaborative (or co-created) to compare. This factor of time consistency across treatment groups is something that I have not seen addressed in the citizen science literature.

If I were able to conduct this research again in the future, I would modify the curriculum to better address the requirements of a collaborative project. It would be advantageous to utilize an existing collaborative citizen science project with a local scientist that could partner more closely with students for the project. Though the research for BioB was extremely helpful in communications via email, there was still a disconnect for students in this project as they could not actually see how their data was used by researchers at Colby College or directly ask questions of the scientist in real time —I communicated their questions personally with the BioB researchers. Though the background presentation was dynamic, there is also more student-centered ways to convey necessary background information. For example, students could read primary literature on a topic in small groups. This would have the added benefit of students learning how to read scientific papers and to glean ideas for research methods — however, students tend to come up with novel ideas for methods that may be stifled by such close reading. In the previously mentioned year-long study, researchers had students spend a significant amount of time looking at peer-reviewed literature and used a rubric to assess the quality of research (Gray et al., 2012). I have also had personal success in letting students engage directly with the topic in a more inquiry-based style — providing a guiding question to think about during free exploration of a plant, study area, organism, or even data-collection equipment such as water chemistry tools—before diving into a short reading, presentation, group discussion, or video about the topic.

Though the pre- and postquiz that I developed provides a starting point for future research, it would be advantageous to conduct a more rigorous pilot study for the purposes of assessing the quality of questions and multiple choice distracters. I did utilize a backwards design for creating the assessment —developing specific goals for the curriculum and methods for delivery before designing the assessment. I also mirrored the questions from already established peer-reviewed research for each section. In the study mentioned by Gormally et al. (2012) to assess outcomes in scientific literacy for an undergraduate biology program, researchers carefully developed questions through a series of working groups with faculty members from various disciplines. Piloting questions with practitioners in the field —middle school teachers, citizen science researchers, educational experts, etc.—is common practice in education research and should have been done for this study.

Assessing knowledge of content and student attitudes are both fairly straightforward. For the content questions in this study, students were unlikely to choose the correct answer by chance and were repeatedly encouraged to choose "I don't know" if they were unsure —to minimize correct answers through guessing. There is a healthy body of literature devoted to attitude changes based on experiences in environmental sciences, and so the attitudes section could be more closely modeled on the work of previous researchers stemming back to Hungerford and Volk's (1990) theoretical framework for changing behavior using environmental education.

The Nature of Science questions, however, were more challenging to develop. The SUSSI questionnaire, on which the nature of science questions were modeled, is meant for assessing scientific literacy of preservice teachers, and so required heavy

modification for a middle school age group. These questions also had no direct relationship to the BioB curriculum –although they could have been tailored to the topic of insects or bugs. Assessing scientific literacy is also a more nuanced goal than just seeing if students know the difference between control, dependent, and independent variables, how to read a graph, or when to accept or reject a hypothesis based on results. One study attempting to assess scientific literacy utilized one open-ended question and then scored responses using a rubric. Perhaps using more qualitative methodology — interviews, collecting student work samples, photovoice, or even using student-generated pre- and post-mind maps—in addition to a quantitative pre- and postquiz would yield a clearer picture of a student's overall literacy of science.

Ch. 5 – Conclusion

5.1 Overview

This study provides a model for quantitative analysis of education outcomes related to levels of participation in citizen science. It utilizes actual knowledge data (versus perceived knowledge gain) in a comparative study of contributory and collaborative citizen science. It looks at educational outcomes of citizen science for youth participants in a formal education setting. The research presented here also raises questions related to the complexity of measuring scientific literacy, how to effectively implement citizen science in schools, and comparing different modes of citizen science.

5.2 Narrative by the Researcher

During my formal and informal teaching experiences, I have witnessed the power of 'free exploration' many times. I define free exploration here as unstructured time in which students are allowed to explore –a topic, a physical space, equipment, etc.—based on their own interest and without a specific desired outcome from the teacher. Any outcome during free exploration will be a result of internally motivation, which according to neuroscientist and brain-based learning educator James Zull, is longer-lasting and easier to recall than learning done via external motivation (such as a desire to get a good grade or be praised) (2002). Examples of this free exploration can be seen during recess times in the school garden during which a student finds a germinating fava bean seed and embarks on a mission to understand this completely new phenomena. Sometimes this quest for understanding even includes the scientific process; our student searches for more seeds at varying stages of growth and makes inferences that the newly growing seed

will become a fava bean plant. Students have been known to come back to the same plant day after day to track changes, to prevent soil erosion they see by mulching with bits of bark, and to 'feed' plants by placing found worms closer to soil around the plant.

Of course, this is a best-case scenario, in which a young person becomes internally motivated to explore the world around them. Often this means that other basic needs such as adequate clothing, proper nutrition, and a nurturing home life are already being met. It also requires access to learning materials, unstructured time, varied and dynamic learning environments, and adult encouragement of curiosity. Educators – especially those in formal school settings—rarely see such conditions and thus must manufacture or direct experiences that give context and meaning to future learning.

It is also true that completely unstructured experiences are unlikely to result in the kind of learning that is desired. Experiences must be structured –albeit with flexibility for spontaneous moments and also with a deep understanding of the learners involved—should we want students to grow in academic and socially positive ways.

During one experience with the Student-Driven Research model described earlier, I experienced typically disengaged students taking on the role of scientist via an exploration with yeast. In this particular example, students were given background information regarding yeast itself, how yeast metabolizes, and extensive information on different types of sugars. They learned about structural differences between monosaccharides like fructose found in fruit juices and disaccharides like sucrose (common 'table' sugar). Then, students were shown different tools and equipment available to study their yeast. These included (but were not limited to): thermometers, Erlenmeyer flasks, balloons, graduated cylinders, rulers, various sugars (fructose,

dextrose, maltose, glucose), sugars in different 'forms' (e.g. granular sucrose and maple syrup), ice water, and hot-plates. In groups of 3, students brainstormed a list of 25 questions about yeast metabolism and chose one of their top 3 open-ended questions to focus on for their research. They (loosely) designed a method for testing their question – some had more clear hypotheses than others—and began their experimentation. Most groups needed a practice round to figure out what methods to use. In fact, their failure with some methods was vital to their ownership of the process. One group altered their initial research question and hypothesis after their 'practice round,' indicating an understanding of science as a dynamic process not a regimented step-by-step method. Afterwards, students communicated their findings via graphs, images, and explanations to their classmates. Some of them had never made graphs before, let alone from their very own data. The whole experience was transformative.

Some of my most behaviorally challenging students became the most engaged 'scientists.' It seemed that validating their own opinion about how to solve a problem was a tool for empowerment and motivation to learn. One group of students –all of whom were students with Individualized Learning Plans for learning or behavioral disabilities—discovered that orange juice produced the largest amount of yeast metabolism when compared to apple juice and Gatorade. After some research into the contents of these beverages, the students discovered that fructose –a monosaccharide— was found in higher quantities in the variety of orange juice that they used when compared to Gatorade and apple juice. While it was not the only difference, these students suggested that the yeast might be able to utilize the fructose found at higher concentrations in orange juice more quickly than other sugars. Beyond their greater

understanding of content surrounding metabolism and chemical structures, these students carried with them a greater skill in scientific processing, and perhaps more significant, the belief that they could 'do science.' One of the students in that group often proclaimed that she was 'not good at science' before that experience.

These experiences seem to indicate that science when taught as inquiry in tandem with necessary amounts of providing background information, enough scaffolding for directed experiences, and enough room for discovery and mistake-making, can yield powerful results both in improving scientific literacy and citizenship. And yet, research reveals the gap between a desire to teach via inquiry methods and actually implementing those methods in the classroom. Limitations such as time, materials, class size, pressure to cover content, and lack of confidence inhibit inquiry-based science teaching. More than just a prescription and philosophical discussion, teachers need real and accessible ways to implement science as inquiry. Citizen science may prove to be such a tool if developers can recognize this need and tailor projects to better fit an inquiry model in which students participate in the active role of *scientist* rather than merely data-collector.

5.3 Final Considerations

How can participation in citizen science affect learning outcomes relating to content knowledge, scientific inquiry, and attitudes towards science of middle school students?

How do different models of citizen science –collaborative vs. contributory—affect these learning outcomes?

This study shows that participation in citizen science increases student content knowledge specifically related to the project's topic. Due to the limitations discussed, it would be unwise to draw further conclusions beyond this preliminary conclusion. However, based on an extensive review of literature in the field of citizen science and education in addition to anecdotal evidence through my experiences in teaching, citizen science –if implemented with intent—can be an effective tool for increasing student knowledge, skills in scientific processing, and even engagement and attitudes towards science itself.

If we want a citizenry that can think rationally about problems they encounter, plan and carry out investigations, question dogma and seek evidence-based truths, distinguish between valid sources of information and fraudulent ones, and have an interest in and foundational understanding of our natural world, then we must utilize teaching tools that put students into the role of scientist. We must find the delicate balance between guided and open inquiry. This necessitates that educators resist the urge to convey every piece of scientific knowledge thus far acquired by humanity. It also requires a dedication of time and resources to allow students to have the vital experience of failure and ability to experience authentic science versus step-by-step 'cookbook' style laboratory lessons or science fair experiments.

I believe that participatory citizen science –such as collaborative or even co-created projects—has the potential to meet K-12 science education goals in the United States. Science educators –both formal and informal—should go beyond merely incorporating citizen science projects into their pedagogy to engaging students in more meaningful ways with those projects and the researchers behind them. This must be done

if we want to provide students with authentic experiences with science. We ask students to conduct water quality tests for pH and phosphorous levels, to count the number of pollinators that visit a sunflower, to tally birds in a backyard nest, or to take a picture of clouds with their now ubiquitous cell phones. But do we ask them to be scientists in the process? Does their collection of this data *mean* something significant to them? They may understand the importance of clean water or that pollinators are a vital part of our food system, but the goal of science education is to go beyond that understanding and to integrate a scientific way of thinking.

While collaborative citizen science appears to have great potential as a teaching tool, we have only begun to assess its educational impacts. There is vast opportunity for research regarding the outcomes of citizen science, especially when utilized as a teaching tool. We need studies that combine quantitative and qualitative methods for a holistic understanding of citizen science's impacts to scientific literacy. Rather than disregarding one mode of citizen science in favor of another, we must understand the differences in outcomes so that educators may engage with the most useful projects for students. Such understanding will require greater attention to comparative analysis of different modes of citizen science.

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Appendices

A. Letter to parent/guardian and permission slip to participate in BioB and thesis research

Dear Parent/Guardian:

I am a graduate student at The Evergreen State College and a science teacher in the Olympia School District. As part of my coursework for the Masters of Environmental Studies graduate program, I will be conducting a **thesis research project** titled **"Student as Scientist: An Evaluation of the Educational Impact, Scientific Literacy Impact, and Research Quality of Citizen Science in Public Schools of Olympia, WA."**

The purpose of my project is to gather information about citizen science programs and their impact on students' scientific knowledge, skills, and attitudes. **Before and after participating in a citizen science program called "Bugs in Our Backyard," your student will take a short, non-graded online quiz and survey** consisting of a maximum of 30 questions. Student work such as mind-maps, poems, drawings, and essays may also be collected as data for this research. This work would be made anonymous by blocking out students' names if it is used in the project.

Any risks to your student are minimal, and would likely be nothing greater than mild test anxiety. It will be stressed that the quiz and survey are not part of the student's grade. There will be no compensation of any kind available for your student's participation, which is completely voluntary. Your student may choose not to take the quiz and survey or to skip any question at any time without penalty.

Again, the short quiz and survey are **not graded**. They are also **anonymous** and will not be associated directly with your student. The results from the quiz and survey will be used for my own thesis research regarding citizen science impacts to students in the Olympia School District. These results will be publically available through The Evergreen State College and may be used in other scholarly publications, presentations, or at conferences. At your request, I will provide you with a copy of the final draft of the thesis paper.

Because the participants are considered 'minors' (under 18 years old), it is required that I obtain parent and/or legal guardian permission for their participation in the research study. By signing this document, you agree to allow me to use your student's quiz and survey results (anonymous and not graded) as part of my thesis research.

If you have any questions about this project or your student's participation in it, you can call me at 814.421.3086. My email address is **quay.surprise@gmail.com.** The person to contact if you have questions concerning your student's rights as a research subject or experience problems as a result of your student's participation in this project is John McLain, IRB administrator at The Evergreen State College, Library 2211, Olympia, WA 98505; Phone 360.867.6045.

Thank you for your participation and assistance!

Sincerely,

Quasar Surprise
MES Graduate Student & OSD Teacher
The Evergreen State College

I, _____ (full printed name), hereby agree to my child's participation as a subject in the research project titled "Student as Scientist: An Evaluation of the Educational Impact, Scientific Literacy Impact, and Research Quality of Citizen Science in Public Schools of Olympia, WA." It has been explained to me that its purpose is to gather information about how citizen science may impact students' scientific knowledge, skills, and attitudes. My child will participate in this research by completing a 30-questions quiz/survey before and after participation in a citizen science project called "Bugs in Our Backyard."

I have been informed that the information that my child provides (in the form of answers to the quiz and survey and any in-class materials related to the project) will be used as part of a thesis research paper and presentation. I also understand that information may also be used as part of published academic research, at scholarly conferences, or as part of related scholarly presentations.

I understand that the information provided by my child will remain anonymous and only be referred to as data from students of the Olympia School District. Quasar Surprise has agreed to provide, at my request, a copy of the final draft of this thesis paper.

I understand that risks to my child are minimal and would likely be nothing more than mild test anxiety; however, it will be stressed to students that their responses WILL NOT BE GRADED and that their participation is voluntary.

There will be no compensation or incentive of any kind for your child's participation in this project. Your student will be told that they can skip any question or abstain from the quiz/survey at any time without penalty. If I have any questions about this project or my child's participation in it, I can call Quasar Surprise at ███████████ or email them at ███████████████ Likewise, the person to contact if I have questions concerning my rights as a research subject or I experience problems as a result of my participation in this project is John McLain, IRB administrator at The Evergreen State College, Library 2211, Olympia, WA 98505; Phone ███████████

Child's Name: _____ (first) _____ (last)

Teacher's Name: _____ (first) _____ (last)

Signature:_____ Date_____

Printed Name: _____ (first) _____ (last)

B. Pre/Post Quiz – 30 questions total administered via Google Forms

Hello!

Thank you for participating in my scientific research. I want to know how participating in citizen science can affect students (like you!). You will be taking this quiz/survey before and after your participation in "Bugs in Our Backyard," a citizen science program.

The following quiz and survey will ask you:
- 10 questions about bugs
- 10 questions about science
- 10 questions on how you feel about science

These questions will not ask for any personal information. If you are unsure of a question or feel uncomfortable answering, just select the "I don't know" option. However, please try your best to answer each question.

By clicking 'agree,' you are saying that it is okay for me to use your responses in my research. Your responses will be anonymously reported.

* Required

I have read and understood the statement above. *

○ Agree

○ Disagree

Teacher & School Name

Here, I will ask you a few questions about who your teacher is, what school you go to, and what grade you are in.

My name is (First and Last) *

Your answer

My teacher is: *

Choose ▼

My school is: *

Choose ▼

I am in Group _____ *

Choose ▼

I am in ____ grade: *

Choose ▼

Questions About Bugs

Choose the best option for each question. If you are completely unsure of an answer, select 'I don't know.' Remember, this test is not graded, so just try your best!

Which of the following does NOT describe an invasive species (plant, animal, etc.) *

○ Not native to an ecosystem

○ Easily removed from an ecosystem

○ Causes harm to an ecosystem

○ Spreads rapidly

○ I don't know

The number and variety of organisms (insects, animals, etc.) in an area is known as:

○ Biodiversity

○ Ecosystems

○ Species continuum

○ Genetic diversity

○ I don't know

Biodiversity can be threatened by:

○ Agriculture

○ Invasive species

○ Climate change

○ All of the above

○ I don't know

Which of the following IS an insect:

○ Spider

○ Fly

○ Centipede

○ Pill Bug (Rolly Polly)

○ I don't know

Which term describes the transition from pupa to adult?

○ Hemiptera

○ Puberty

○ Entomophagy

○ Metamorphosis

○ I don't know

Which of the following is NOT a characteristic of all insects?

○ Have an exoskeleton

○ Have a vertebrate (backbone)

○ Have six legs

○ Have a head, thorax, and abdomen

○ I don't know

Which of the following is an example of a 'true' bug (belonging to the order Hemiptera):

○ Bee

○ Spider

○ Beetle

○ Pill bug

○ I don't know

The hard outer covering of an insect is known as the _____.

○ Endoskeleton

○ Exoskeleton

○ Macroskeleton

○ Nanoskeleton

○ I don't know

Which group of animals is the most diverse (largest number of species) on earth?

○ Birds

○ Fish

○ Spiders

○ Insects

○ I don't know

Which insect is the single most important for pollination of crops worldwide?

○ Honeybee

○ Bumblebee

○ Cabbage butterfly

○ Potato beetle

○ I don't know

Questions About Science

Choose the best option for each question. If you are completely unsure of an answer, select 'I don't know.' Remember, this test is not graded, so just try your best!

Science is:

○ A collection of facts that explain the world around us

○ A way of thinking about and exploring the world around us

○ Both a collection of facts and a way of thinking about the world

○ Conducted in a lab by scientists

○ I don't know

What is the mean (average) of the following numbers: 2, 6, 1

○ 3

○ 4

○ 6

○ 9

○ I don't know

Why do researchers use statistics (averages, probability, percentages) to interpret data?

○ Researchers are collecting data about everything and need to simplify it

○ It is easier to convince the public using numbers and statistics

○ The research must be presented in a complicated way using math

○ The data represents only a sample of a population or area

○ I don't know

Which of the following would be the best resource for background research on bugs?

○ An article in a popular science magazine like Discover

○ A website for a pesticide company that describes bugs in detail

○ An interview with a trustworthy adult or teacher

○ An article found on Google Scholar that other scientists have reviewed

○ I don't know

Experiment Description (use to answer following questions):

Topic: How does surface temperature vary with location?
Research question: Which location --the open grass, under the bushes, or on the pavement -- has the highest surface (on top of the ground) temperature in °C?
Hypothesis: The open grass will have the highest surface temperature because the soil will absorb heat from the sun.
Experiment Set-Up: The experiment will be conducted outside of our school classroom. Three sites (trials) for each location --open grass, under bushes, on pavement-- will be chosen for the experiment. Temperature in °C will be taken with a thermometer by resting the tip on the location's surface for one minute. This will be recorded on an observation table.
Observation Table:

Location	Surface Temperature °C			
	Trial 1	Trial 2	Trial 3	Average Temp.
Open Grass	20.5	20.0	21.0	20.5
Under Bushes	18.0	18.5	18.0	18.2
On Pavement	23.5	22	22.5	22.7

Graph of Data:
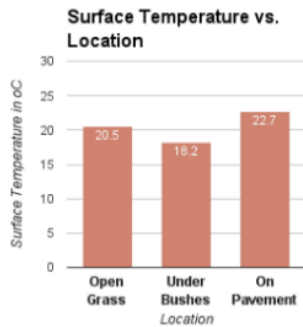
An important variable to control (keep the same) in this experiment is:

○ The level of noise at the locations

○ The time of day the temperature is recorded

○ The device used to measure temperature

○ The person taking the temperature

○ I don't know

One conclusion from this experiment could be:

○ All shaded areas are cooler than open areas

○ Bushes reflect the sun's energy leading to cooler surface temperatures below

○ The lowest surface temperature is under the bushes

○ The open grass had the highest surface temperature

○ I don't know

The variable being changed (or manipulated) in this experiment is:

○ The location (open grass, under bushes, or pavement)

○ The surface temperature

○ The device used to measure temperature

○ The person taking the temperature

○ I don't know

The variable being recorded/measured (the 'responding' variable) in this experiment is:

○ The location (open grass, under bushes, or pavement)

○ The surface temperature

○ The distance of the location from the building

○ The person taking the temperature

○ I don't know

The variable being changed (or manipulated) in this experiment is:

○ The location (open grass, under bushes, or pavement)

○ The surface temperature

○ The device used to measure temperature

○ The person taking the temperature

○ I don't know

The variable being recorded/measured (the 'responding' variable) in this experiment is:

○ The location (open grass, under bushes, or pavement)

○ The surface temperature

○ The distance of the location from the building

○ The person taking the temperature

○ I don't know

Based on results of this experiment, the researchers' hypothesis should be:

○ Accepted

○ Rejected

○ Neither

○ Re-stated in order to be accepted

○ I don't know

The conclusions of this experiment could be used to make decisions about:

○ How to design landscapes around schools located in hot environments

○ Whether or not to replace a grassy lawn with a parking lot

○ What kind of thermometer should be used for taking surface temperatures

○ How to predict and report weather conditions

○ I don't know

I like doing science.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

I think science is a hard (difficult) subject.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

I like to spend time outdoors.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

I like bugs.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

I want to know more about the natural world around me.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

I think helping scientists collect data is important.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

I believe that I can make an important contribution to science.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

I want to take more science classes at school.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

I would like a job that involves using science.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

I think it is important for the general public to be informed about science and technology.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

C. Demographic data taken from the OSPI Report Card website from the latest counts of the 2015/2016 school year.

Thurgood Marshall Middle School		
Enrollment (October 2015 Student Count)		
October 2015 Student Count	388	
May 2016 Student Count	385	
Gender (Oct. 2015)		
Male	211	54.4%
Female	177	45.6%
Race/Ethnicity (Oct. 2015)		
Hispanic/Latino of any race(s)	40	10.3%
American Indian / Alaskan Native	2	0.5%
Asian	27	7.0%
Black / African American	19	4.9%
Native Hawaiian / Other Pacific Islander	1	0.3%
White	268	69.1%
Two or More Races	31	8.0%
Special Programs (May 2016)		
Free or Reduced-Price Meals	146	37.9%
Special Education	57	14.8%
Transitional Bilingual	11	2.9%
Migrant	1	0.3%
Section 504	13	3.4%
Foster Care	N <10	
Teacher Information (2015-16)		
Average Years of Teacher Experience		18.3
Teachers with at least a Master's Degree		81.5%

Washington Middle School		
Enrollment (October 2015 Student Count)		
October 2015 Student Count	762	
May 2016 Student Count	772	
Gender (Oct. 2015)		
Male	412	54.1%
Female	350	45.9%
Race/Ethnicity (Oct. 2015)		
Hispanic/Latino of any race(s)	63	8.3%
American Indian / Alaskan Native	3	0.4%
Asian	74	9.7%
Black / African American	12	1.6%
Native Hawaiian / Other Pacific Islander	3	0.4%
White	530	69.6%
Two or More Races	77	10.1%
Special Programs (May 2016)		
Free or Reduced-Price Meals	129	16.7%
Special Education	83	10.8%
Transitional Bilingual	4	0.5%
Migrant	3	0.4%
Section 504	25	3.2%
Foster Care	N <10	
Teacher Information (2015-16)		
Average Years of Teacher Experience		17
Teachers with at least a Master's Degree		73.9%

D. Email to all science teachers in the Olympia School District

Hello OSD Science Teachers!

Some of you already know me, but my name Quasar Surprise and I teach Sustainable Agriculture at Avanti High School.

I am also a graduate student at The Evergreen State College pursuing a Masters in Environmental Studies.

I am REALLY interested in [citizen science](#)! For my thesis project, I am looking to find several classrooms interested in having me come in to lead a citizen science program with your class! I need a robust sample size for my research, and am looking to recruit 6 classes or more from around the district.

The project will take around 3-5 class periods (depending on your class length) to complete. These classes do not have to be consecutive. The project will involve outdoor field research at your school location and a pre/post survey and test (non-graded) component.

I will be sending another email in the near future with project details, but in the mean time, please email me back if you are interested!!

I'd like to start doing school visits in late September or October (but I am flexible!).

TLDR:

- Thesis research project involving Citizen Science
- Outdoor field research at school site
- 3-5 class periods
- Need to find 6 or more classes to participate
- Late September -- October (flexible)
- Email back if interested!

Thank you for your time (I know it is precious) and have an awesome second week back at school!

E. Response Rate for 30 pre/post quiz questions

Science Content Question Responses

Nature of Science Question Responses

	#Correct	# Incorrect	# I don't know
Pre	23	19	0
Post	28	13	1
Pre	17	17	0
Post	13	18	3
Pre	30	9	3
Post	30	9	3
Pre	24	7	3
Post	22	6	6
Pre	7	27	8
Post	8	31	3
Pre	8	18	8
Post	7	23	4
Pre	25	13	4
Post	26	14	2
Pre	14	10	10
Post	15	13	6
Pre	32	8	2
Post	33	9	0
Pre	18	8	8
Post	21	9	4
Pre	34	7	1
Post	34	8	0
Pre	21	7	6
Post	22	8	4
Pre	31	9	2
Post	33	7	2
Pre	19	10	5
Post	19	8	7
Pre	9	29	4
Post	9	32	1
Pre	6	17	11
Post	10	18	6
Pre	12	24	6
Post	12	27	3
Pre	6	17	11
Post	8	17	9
Pre	17	22	3
Post	19	19	4
Pre	12	11	11
Post	16	9	9

Legend: #Correct, # Incorrect, # I don't know

ATTITUDES TOWARDS SCIENCE QUESTION RESPONSES

F. BioB Curriculum Presentation

True Bugs (Hemiptera)

Western Boxelder Bug: *Leptocoris rubrolineatus*

Western Boxelder Bug: *Leptocoris rubrolineatus*

Western Boxelder Bug: *Leptocoris rubrolineatus*

Brown Marmorated Stink Bug: *Halomorpha halys*

So many stink bugs!

Brown Marmorated Stink Bug: *Halomorpha halys*

Brown Marmorated Stink Bug: *Halomorpha halys*

BMSB Parasitic Wasp: *Trissolcus japonicus*

Today: Group Capybara

1. Find bugs outside!
2. Identify them and their host plant
3. Record data on Observation Sheet
4. Upload data to Bio-B
5. Help participate in...SCIENCE!

Collecting Data
Record

Collecting Data
Identify
iNaturalist

Look CLOSELY

Identifying the Brown Marmorated Stink Bug

Brown Marmorated Stink Bug vs. Western Conifer Seed Bug

Emerald Ash Borer Look-Alikes

What Can We Find Out?

Biodiversity

Species Richness = the number of different species in an area

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Spread of Insect Ranges

Brown Marmorated Stink Bug (BMSB) Distribution Map
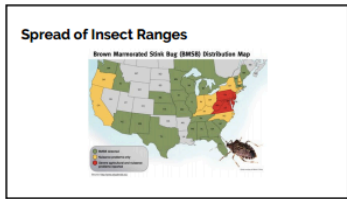
Submitting Your Data to BioB

Today: Group Liger

1. Research about _____
2. Choose a question to explore...with SCIENCE!
3. Design your field study (with a group)
4. Collect data on bugs...OUTSIDE!
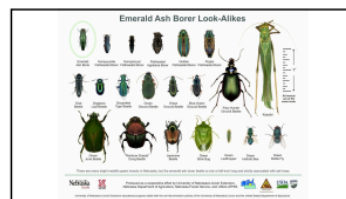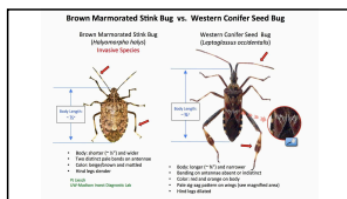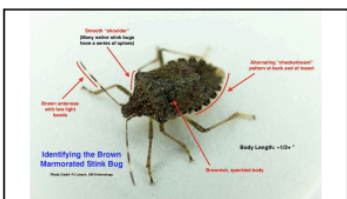5. Figure out what that data means
6. Show off what you found!

Collecting Your Data:

Look CLOSELY

The Quadrat

The almighty magical...square!

Randomize

---

3 or more Trials

Collecting Data

Identify

iNaturalist

Identifying the Brown Marmorated Stink Bug

Brown Marmorated Stink Bug vs. Western Conifer Seed Bug

Emerald Ash Borer Look-Alikes

Bugs in the Winter

Strategy #1: Avoid the cold.	Strategy #2: Don't let yourself freeze	Strategy #3: Let yourself freeze

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Bugs in the Winter

http://bugguide.net/node/view/163372

Boxelder Bugs in the Winter

http://www.extension.umn.edu/garden/insects/find/boxelder-bugs/