DISSERTATION

DESIGNING AND EVALUATING PARTICIPATORY CYBER-INFRASTRUCTURE SYSTEMS FOR MULTI-SCALE CITIZEN SCIENCE

Submitted by

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WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY GREGORY J. NEWMAN ENTITLED DESIGNING AND EVALUATING PARTICIPATORY CYBER-INFRASTRUCTURE SYSTEMS FOR MULTI-SCALE CITIZEN SCIENCE BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

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ABSTRACT OF DISSERTATION

DESIGNING AND EVALUATING PARTICIPATORY CYBER-INFRASTRUCTURE SYSTEMS FOR MULTI-SCALE CITIZEN SCIENCE

Widespread and continuous spatial and temporal environmental data is essential for effective environmental monitoring, sustainable natural resource management, and ecologically responsible decisions. Our environmental monitoring, data management and reporting enterprise is not matched to current problems, concerns, and decision-making needs. Citizen science programs create opportunities for more continuous and widespread data collection, fill data gaps, and inform decisions. These programs are increasing in number and breadth. They operate at multiple spatial and temporal scales, tackle a wide array of environmental challenges, engage volunteers from all walks of life, and create volumes of scientific data. Information management systems flexible enough to support the varied nature of these data are rare, overly technical, hard to use, difficult to understand, poorly defined, and lack effective training materials.

Flexible systems require creative attention to sustainable technology, stable institutional resources, innovative database designs, effective educational materials, and interoperable services. They require computationally efficient geospatial analysis and imaging techniques capable of handling massive amounts of data collected across vast geographic scales and they must provide effective training materials for people to learn the skills required by the citizen science process. Participatory cyber-infrastructure systems are needed to meet the needs of multi-scale citizen science programs.

This dissertation research investigated, designed, developed, implemented, tested, and evaluated a participatory cyber-infrastructure system built to support multi-scale citizen science. My objectives were to: (1) examine the art and science of multi-scale citizen science support, (2) evaluate the usability of a web mapping application created through cyber-infrastructure for invasive species citizen science programs, (3) compare the effectiveness of static and multimedia online communication approaches for training citizen scientists, and (4) offer guidelines for the development of cyber-infrastructure systems adept enough to support the needs of citizen science programs operating at multiple spatial and temporal scales in many domains. I created a participatory cyber-infrastructure system and developed a framework to situate citizen science programs based on their scope, scale, and activities. I used the cyber-infrastructure system to create a website specific to invasive species citizen science projects (www.citsci.org) and evaluated the usability of the website (n=16) to determine general perceptions, discover potential problems, and iteratively improve features. I compared the effectiveness of online static and multimedia tutorials to teach citizen science volunteers (n=54) how to identify invasive plants; establish monitoring plots; measure percent plant cover; and use Global Positioning System devices. I also continuously received feedback from citizen science organizations using the cyber-infrastructure system.

Results demonstrate that cyber-infrastructure systems can be adept enough to support the needs of citizen science projects operating at multiple spatial and temporal scales across many domains when built with a flexible architecture. Cyber-infrastructure use resulted in 27 online projects contributing 5,196 species occurrences. Features for volunteer management; communication among volunteers and coordinators; data entry; program evaluation, online analysis; and reporting integrated into cyber-infrastructure systems will improve their effectiveness. Careful attention must be given to the usability of complicated map and decision support features. Map-based and early alert tasks required a long time to complete and had low completion rates. Mean task completion rates ranged from 25 to 75% for map tasks and 0% to 33% for early alert features. Overall, the average time to complete tasks ranged from 00:01:42 to 00:02:17 and the mean completion rate ranged from 36 to 90% across all scenarios. Citizens trained online through static and multimedia tutorials provided less ($p<0.001$) correct species identifications (63% and 67%) than professionals (83%) across all species, but did not differ ($p=0.125$) between each other. The variability in percent cover estimates between static (+/-10%) and multimedia (+/-13%) participants did not differ ($p=0.86$ and 0.08 respectively) from those of professionals (+/-9%) and the tutorial approach had minimal influence ($p=0.07$) on the variability of participant plant cover estimates. Volunteers trained online struggled with plot setup and GPS skills regardless of tutorial approach. Overall, the tutorial approach did not affect the field skills and abilities learned by volunteers. The development and evaluation of a cyber-infrastructure in support of multi-scale citizen science discussed herein situates citizen science programs within a framework of their scope, scale, and activities; de-fragments data; reduces complexity; helps ensure comparability; fills data gaps; refines our understanding of web usability; improves our understanding of online educational approaches; and closes the communication gap between scientists and citizens. It increases the number and variety

of people able to contribute information to address pressing environmental problems while participating in local, regional, and global environmental stewardship.

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LIST OF ACRONYMS

CBM	Citizen-Based Monitoring
CBM	Community-Based Monitoring
CGIS	Collaborative Geographic Information Systems
DSS	Decision Support Systems
ECMN	Environmental Collaborative Monitoring Networks
EDSS	Educational Decision Support Systems
GIS	Geographic Information Systems
GPS	Global Positioning Systems
GSDSS	Group Decision Support Systems
ICT	Information and Communication Technologies
IT	Information Technology
PDA	Personal Digital Assistants
PGIS	Participatory Geographic Information Systems
PPGIS	Public Participation Geographic Information Systems
SDI	Spatial Data Infrastructure
USGS	United States Geological Survey
VGI	Volunteered Geographic Information
WBMM	Web-Based Multi-Media
WMA	Web Mapping Application

CHAPTER 1 INTRODUCTION

A brisk September morning greets Judy as she and a team of 16 other volunteers embark on a "BioBlitz" at a wetland in western Wisconsin. Dew has formed on the milkweed seed pods and tall grasses are illuminated like upside down icicles as the sun rises over a nearby hardwood forest. Sarah, the citizen science director at a local nature reserve, is feverishly trying to single-handedly coordinate her volunteers, manage field equipment, record scientific data, teach field skills, and answer questions. The months leading up to today's sampling event involved tiresome coordination, logistical planning, protocol development, quality assurance/quality control procedures, training material creation, and database design. Yet, Sarah is uncertain about how the data will be collected and integrated with other datasets and how it will be disseminated to land managers to help inform decisions. Will her volunteers collect high quality data? How can she streamline data entry and dissemination? Are there ways to make volunteer management, training, and coordination more efficient and effective? This scenario is occurring over and over in many situations whereby citizen volunteers collect data to advance science. Sarah is not alone.

The number of citizen science organizations, programs, and volunteers actively recording the locations of species is growing faster than the very flowers, birds, frogs, wildlife and worms they seek to record. Programs like the North American Breeding Bird Survey (Peterjohn and Sauer 1993), the Christmas Bird Count (National Audubon Society 2005), Frogwatch USA (MacKenzie et al. 2002), and Great Lakes Worm Watch (Hale 2010) have built upon the first account of citizens observing nature and recording data on Christmas day, 1900 (National Audubon Society 2005). These organizations are poised to significantly contribute to, and become involved with, conservation efforts and environmental stewardship. Examples include citizen science organizations, volunteers, 4-H groups, high school biology classes, Boy Scout troops, garden clubs, community-based monitoring programs, and many others. Yet, as more citizens become stewards of local lands, more coordination, direction, and education is required for these efforts to be effective. The academic, management, and informatics infrastructures necessary to establish goals, recruit volunteers, market programs, train participants, retain members, collect data, and report results (Cooper et al. 2007) must be further developed and refined. Sarah needs help. After all, she is only one in a sea of coordinators engaged with involving the public in science.

> *Meanwhile, in northern Minnesota, a cool autumn day greets a group of volunteers busy spreading a mustard seed solution on small plots of soil to entice invasive earthworms to rise to the surface. Heather advises the group on the correct dosage to pour over each plot. As the worms rise, specimens are taken and sent to a lab at the University of Minnesota-Duluth. These invasive worms threaten the diversity of forest understory vegetation and reduce tree seedling germination. John meticulously counts each individual and prepares his specimens for submittal. A soft snow begins to fall, signifying the beginning of winter bird count season for John and his cohort of friends seeking even more backyard ecology experiences...*

The volunteer coordinators of these and countless other similar efforts share frustrations about data collection, data quality, data storage, and data dissemination. Sarah and Heather are seeking innovative ways to more effectively manage the data collected by volunteers like John and provide better materials to teach him the skills needed to become an effective citizen scientist. There is a growing need for better information management of scientific data collected by citizens and for science communication approaches tailored to a diverse public. How can these programs facilitate more efficient data management and field training programs? Can online cyber-infrastructure systems help address the challenges facing these volunteer coordinators? What roles might a cyber-infrastructure play to improve citizen science programs?

1.1 Introduction

> *"Conservation ecology requires … research in what might be called applicable science - a mix of theory, basic research, and illuminating applied examples. It requires analysis and examples of novel ways to develop incentives such that individual self interests better reinforce [the] social goals of conservation … [and] … it requires experiments in novel ways to develop citizen science as an antidote to the power… that now so distorts the use of information..."*
>
> *~ C.S. Holling (1998)*

> *"The nation's environmental monitoring and reporting enterprise … is not matched to the problems, concerns, and decision-making needs of the 21st century. Despite significant investment [from] highly skilled practitioners, information on the state of [our] environment is often fragmented, overly technical, not comparable from one place to another, or simply unavailable. This lack of systematically organized, high-quality, scientifically credible, and readily … available information hampers the development of effective responses to environmental challenges. Attempting to manage our … natural resources without this information is like driving a vehicle with the front and rear windshields largely obscured. Without being able to assess at a glance where we are, where we have been, and the direction we are going…, we as a society are unlikely to engage in the type of informed discourse needed to reach effective decisions on important environmental issues."*
>
> *~ The H. John Heinz III Center for Science, Economics, and the Environment (2008)*

Environmental degradation, habitat loss, climate change, species invasions, biodiversity loss, and disruption of ecosystem processes threaten the quality and sustainable nature of life on earth. These environmental challenges are diverse, occur across multiple spatial and temporal scales, interact with each other in complex ways, and require new approaches to information management and decision support (Argent et al. 2009). Effective environmental monitoring, sustainable natural resource management, and science-based environmental decisions require collection, storage, standardization, retrieval, classification, manipulation, analysis, dissemination, visualization, quality assessment, communication, and synthesis of spatial and temporal environmental data (Gray et al. 2005). These tasks transform data through a cycle consisting of data, information, knowledge, and wisdom (Debons 2008) that originate from many sources, including indigenous cultures, scientific disciplines, citizen-based initiatives, social discourse, and keen observations made by villagers, elders, scientists, sociologists, economists, citizens, naturalists, and the lay public, among others (Figure 1-1). The multiplicity and diversity of these new information providers increases the quantity of available data, but also makes assessing the credibility, quality, validity, and reliability of these data difficult; it places an unparalleled burden on individual consumers to locate, assess, understand, and use information appropriately (Flanagin and Metzger 2008, Zimmerman 2008, Ottinger 2010). We lack the information science capacity needed to effectively manage and assess these data; transform it into useable information and knowledge; communicate its credibility and appropriateness for environmental decisions; and better inform our ecological stewardship practices.

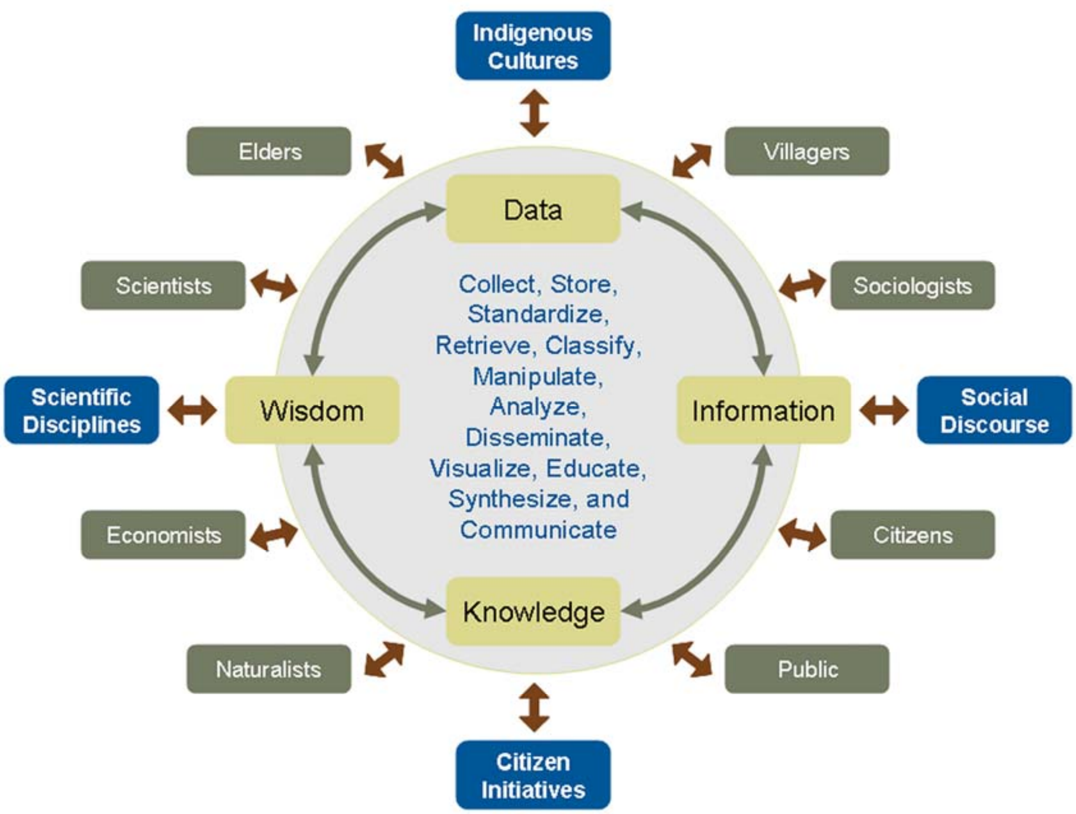

Figure 1-1. The many contributors to collective knowledge. Collective knowledge encapsulates data, information, knowledge, and wisdom and is an emergent property of

indigenous cultures, social discourse, citizen-based initiatives, and scientific disciplines. There are many contributors to collective knowledge; examples are provided.

The capacity to effectively and efficiently manage environmental information requires increased data collection capabilities in conjunction with improved storage, standardization, retrieval, assessment, classification, manipulation, analysis, education, visualization, communication, dissemination, and synthesis abilities (Gray et al. 2005). Citizen participation in environmental monitoring activities related to these tasks is not new (Gouveia and Fonseca 2008) and citizen science programs continue to expand in scope and breadth (Bonney et al. 2009, Newman et al. 2010a). Examples include projects associated with climate change (Cohn 2008), invasive species (Delaney et al. 2008), conservation biology (Galloway et al. 2006, Losey et al. 2007), biodiversity monitoring (Danielsen et al. 2005a, Lepczyk 2005, Couvet et al. 2008, Lovell et al. 2009), population ecology (Peterjohn and Sauer 1997, Rosenberg et al. 1999), water quality monitoring (Wilderman et al. 2004), street mapping (Haklay and Weber 2008), and traffic congestion (Goodchild 2007), among others (Silvertown 2009).

Historically, environmental monitoring systems aimed to improve the efficiency of environmental data collection and storage. As ecological risks escalated, these systems evolved from data storage systems into decision support systems and now embrace public participation (Gouveia and Fonseca 2008). Although public participation models range from citizen involvement through data access and use to data collection and analysis (Gouveia and Fonseca 2008, Danielsen et al. 2009), recent extensions to these models aim to improve science literacy (Brossard et al. 2005) and regard citizens as scientists rather than solely citizen technicians (Lakshminarayanan 2007). From a data collection standpoint, public participation in science is related to many terms such as citizen science, Community Based Monitoring, Participatory Monitoring Networks, Public Participation Geographic Information Systems, and Volunteered Geographic Information. These approaches span a spectrum encompassing varying levels of community member involvement (Wilderman et al. 2004, Cooper et al. 2007, Danielsen et al. 2009). The research described herein uses the term citizen science broadly to encompass all of these approaches when referring to cyber-infrastructure in support of multi-scale citizen science. I focus on citizen science research models whereby geographically dispersed volunteers form networks to assist scientific research using standardized protocols in collaboration with professional scientists (Cooper et al. 2007). Regardless of approach or model, engaging the public in data collection increases the volume of available scientific data and places new demands on an already impoverished data management enterprise.

To improve our citizen science data management enterprise, I investigated, designed, developed, implemented, tested, and evaluated a cyber-infrastructure built to support multi-scale citizen science. Specifically, my objectives were to: (1) examine the art and science of multi-scale citizen science support, (2) evaluate the usability of a web mapping application created through cyber-infrastructure for invasive species citizen science programs, (3) compare the effectiveness of static and multimedia online communication approaches for training citizen scientists, and (4) offer guidelines for the development of cyber-infrastructure systems adept enough to support the many needs of citizen science programs operating at multiple spatial and temporal scales in many disciplines. The development and evaluation of a cyber-infrastructure in support of multi-scale citizen science discussed herein situates citizen science programs within a framework consisting of their scope, scale, and activities; de-fragments information;

reduces complexity; ensures data comparability; fills data gaps; refines our understanding of web usability; improves our understanding of online educational approaches; and closes the communication gap between scientists and citizens. It increases the number and variety of people able to contribute information to address pressing environmental challenges and participate in local, regional, and global environmental stewardship.

1.2 Background

1.2.1 Why citizen science?

The concept of citizen science is not new and the term is used in many situations to represent scenarios in which citizens participate in the scientific process along with professionals (Bonney et al. 2009). Citizen science typically involves trained volunteers participating in scientific studies as field assistants who collect data (Cohn 2008, Cornell Lab of Ornithology 2008). According to Silvertown (2009), a citizen scientist is “a volunteer who collects and/or processes data as part of a scientific inquiry.” Citizen science enlists the public in collecting large quantities of data across an array of habitats and locations over long time frames (Cooper et al. 2007, Bonney et al. 2009). Citizen science programs have been remarkably successful in advancing scientific knowledge and their contributions provide a vast amount of data about species distributions around the world (Bonney et al. 2009).

Many organizations and people collect environmental data for a variety of purposes. The number of non-profit organizations, citizen scientists, and volunteers continue to rise. For example, Birdlife International members exceed 2,500,000 worldwide (BirdLife International 2007), operate in over 100 countries and territories, and contain local memberships often numbering in the hundreds or thousands (Roberts et al. 2005). Recreational and amateur bird watching alone attracts over 2.6 million people in the UK (Target Group Index (c); British Market Research Bureau 2003; cited in Roberts et al. 2005) and 45 million in the U.S. (U.S. Department of the Interior et al. 2001). These citizen observers not only participate locally, but also travel internationally in search of rich biodiversity (Roberts et al. 2005). Today, citizen science programs continue to expand in scope and breadth and even assist in monitoring earthquake activity (Cochran et al. 2009). Yet, data gaps still exist and we lack strategically collected data to help inform sustainable ecological decisions. More strategic data collection is needed by more collectors to fill these gaps – we need to collect the data we often do not want to collect in places where we may not prefer to sample.

1.2.2 Why multi-scale?

Both professional and citizen science networks operate across many spatial scales including global, national, regional, state-wide, and local scales. Their longevity also varies across temporal scales ranging from the short- to the long-term. Examples of global professional networks include the Global Invasive Species Information Network, the Global Biodiversity Information Facility, the Delivering Alien Invasive Species Inventories for Europe network, the Encyclopedia of Life, Discover Life, and the Mammal Networked Information System. National professional networks include the National Ecological Observatory Network, the Long Term Ecological Network, The Geosciences Network, the National Phenological Network, and the United States Geological Survey Non-indigenous Aquatic Species information resource. National citizen science initiatives include eBird, The Christmas Bird Count, Project BudBurst, and Journey North. Examples of regional citizen science programs include the Invasive Plant Atlas of New England, Invaders of Texas, the Southeast Exotic Plant Pest Council, the Invasive Plant Atlas of the Mid-South, the Great Lakes Worm Watch program, and the Cactus Moth Detection Network. Examples of statewide programs include Wisconsin NatureMapping and the Wisconsin River Alliance. Local programs include the City of Fort Collins Natural Areas Program Amphibian Monitoring Project and local Lake Management Associations. These initiatives are often unaware of the potential roles they can play in more coordinated efforts that collectively comprise our environmental monitoring and reporting enterprise.

1.2.3 Why participatory cyber-infrastructure systems?

Participatory cyber-infrastructure systems are software applications deployed through the Internet on the World Wide Web that involve public participation in spatial and temporal data collection, contribution, analysis, and interpretation. They represent new research environments that support advanced data acquisition, storage, management, integration, mining, visualization and other computing and information processing services over the Internet; they promote peer-to-peer collaboration; data and information resources; online instruments and observatories; and visualization and collaboration services (National Science Foundation 2007). Cyber-infrastructure enables distributed knowledge communities that collaborate and communicate across disciplines, distances and cultures (National Science Foundation 2007). Participatory cyber-infrastructure systems in support of multi-scale citizen science improve our environmental information science capabilities by providing data management and exchange capabilities to citizen science programs. Examples include the nearly 7 million participant-identified and annotated places that now reside in Wikimapia (Flanagin and Metzger 2008), the 200 million plus users offering location based data through Google Earth (Google 2007), the volumes of street data publically available through Open Street Map (Goodchild 2007), the geo-tagged photos online at the popular photo-sharing site Flickr (Flanagin and Metzger 2008), and the multitude of geospatial "mashup" web applications that combine disparate data from multiple sources into newly integrated resources (Miller 2006). They are one example of the many approaches to Public Participation Geographic Information Systems which focus on community interactions with Geographic Information Systems (GIS) inextricably tied to the social and geographic context of system production and implementation (Craig et al. 2002). Often, cyber-infrastructure systems form educational systems that support science-based environmental decisions. In this way, they may be seen as Educational Decision Support Systems when they integrate online educational resources with public participation in data collection and decision support. These so-called participatory web mapping applications may equip millions of 'citizen sensors' with an online place to upload geospatial information, thereby increasing the availability of such information worldwide (Goodchild 2007). They are an example of Collaborative Geographic Information Systems that are themselves situated in the broader context of Group Spatial Decision Support Systems (Balram et al. 2009).

Why design, develop, and evaluate cyber-infrastructure systems in support of multi-scale citizen science? If designed, developed, and evaluated effectively, cyber-infrastructure systems support the needs of citizen science projects that, in turn, inform and empower citizens and benefit scientists, land managers, and decision makers. Previous attempts to engage the public in collaborative data collection and analysis through Public Participation Geographic Information Systems used industry-standard desktop applications to involve participants in GIS in lieu of online systems, claiming that users “see [online] applications as manipulative and frustrating because they have begun to see what a GIS *they can control* [emphasis added] can do” (Merrick 2003). Indeed, even today, most online Public Participation Geographic Information Systems are still in no way “participatory” or transparent; they are clumsy, slow, and difficult to use systems that control content, layout, visualization, available analysis capabilities, and the methods by which users interact and participate (Merrick 2003). Although desktop GIS applications may offer some degree of greater flexibility, they often generate datasets that remain stored on a single desktop computer and that are not integrated with other datasets for broader reuse. We need participatory cyber-infrastructure systems that stakeholders themselves can control to a greater degree and that are flexible enough to deliver features specific to specific program needs.

1.3 Goals and Objectives

1.3.1 Research goal

The overall goal of my dissertation research was to investigate, design, develop, implement, test, and evaluate a cyber-infrastructure in support of multi-scale citizen science. To this end, my research consisted of system development, experimental research projects, and first-hand experiences with citizen science programs using the cyber-infrastructure created. The research projects involved a preliminary needs assessment created through the cyber-infrastructure itself; continuous qualitative feedback on the citizen science website created for this research (www.citsci.org); a formal usability evaluation of this website; and paired experimental research training events in Colorado and Wisconsin (*n*=347 total participants) to evaluate the effectiveness of a national citizen science program for invasive species citizen monitoring efforts. The experimental research training events were a collaborative effort between me and my colleague Alycia Crall at the University of Wisconsin-Madison Nelson Institute of Environmental Studies. The portion of these events that was specific to my dissertation involved comparing different online training approaches to teach field data collection skills. Collectively, these research projects; the cyber-infrastructure in support of multi-scale citizen science created, the websites developed through the cyber-infrastructure itself; and the three separate submitted manuscripts (Chapters 2, 3, and 4) culminated in this dissertation. Chapter 2 has been accepted for publication in the International Journal of Geographical Information Science. Chapter 3 has been submitted to the Journal of Applied Environmental Education and Communication, and Chapter 4 will be submitted to Ecological Informatics. These chapters were written as stand-alone peer reviewed journal articles per the guidance of my advisor. However, I made every attempt to integrate the stories from these chapters into a coherent and cohesive dissertation. This research was interdisciplinary and benefitted from the talents of a multi-disciplinary research team. To all who contributed I am grateful.

1.3.2 Research objectives

My objectives were to: (1) examine the art and science of multi-scale citizen science support, (2) evaluate the usability of a web mapping application created through cyber-infrastructure for invasive species citizen science programs, (3) compare the effectiveness of static and multimedia online communication approaches for training citizen scientists, and (4) offer guidelines for the development of cyber-infrastructure systems adept enough to support the needs of citizen science programs operating at multiple spatial and temporal scales in many domains. In Chapter 2, I created a participatory cyber-infrastructure system and developed a framework to situate citizen science programs based on their scope, scale, and activities. In Chapter 3, I used the cyber-infrastructure system to create a website specific to invasive species projects (www.citsci.org) and evaluated its usability to determine general perceptions, discover potential problems, and improve website features. In Chapter 4, I compared the effectiveness of online static and multimedia tutorials to teach citizen science volunteers how to identify invasive plants; establish monitoring plots; measure percent cover; and use Global Positioning System devices. Throughout my research, I received continuous feedback from citizen science programs using the many websites created through the cyber-infrastructure system. The specifics of each chapter follow.

In Chapter 2, I examine the art and science of multi-scale citizen science support. I discuss within- and among-project dimensions and propose a framework to situate citizen science projects based on their scope, scale, and activities. I postulate that this framework expands the definition of citizen science to incorporate aspects of community-based monitoring and other similar approaches and situates citizen science in a broader context that enables more synergy between the many projects emerging today. I illustrate the benefits of the proposed framework and the flexibility of the cyber-infrastructure system (Appendix A) by discussing the scope, scale, and activities of several citizen-based initiatives.

In Chapter 3, I evaluate the usability of the CitSci.org website (*n*=16). I determined general perceptions, discovered potential problems, and iteratively improved website features. Detailed descriptions of use case scenarios, task completion rates and times, and reliability analyses for usability concepts are shown in Appendix A. Given the usability evaluation, I re-designed the website, improved content, enhanced ease of use, simplified the map interface, and added features. I discuss citizen science websites in relation to online Public Participation Geographic Information Systems, examine the role(s) websites may play in the citizen science research model, discuss how citizen science research advances GIScience, and offer guidelines to improve citizen science websites.

Finally, in Chapter 4, I compare the ability of online static and multimedia tutorials to teach citizen science volunteers (*n*=54) how to identify invasive plants; establish monitoring plots; measure percent cover; and use Global Positioning System devices. The chapter summarizes results using indices for Global Positioning System use skills. Detailed results are shown in Appendix C. In this chapter, I discuss my results in relation to cognitive load theory, advance organizers, and attention cueing and offer recommendations to developers of online tutorials for adult volunteer citizen scientists.

1.3.3 Research approach

I used a non-traditional research and development approach to accomplish the goals and objectives of my dissertation research. I was faced with the simultaneous tasks of development and maintenance of a cyber-infrastructure system, stakeholder trainings, customer support tasks, participant recruitment, tutorial development, experiment logistics, and traditional statistical analyses. To achieve these goals and objectives, I collaborated with Alycia Crall for the Wisconsin and Colorado training events and borrowed approaches from many disciplines. The interdisciplinary nature of this research posed many challenges, but brought many benefits. It mingled technical infrastructure development with more formal research techniques along with qualitative observations. Thus, my approach was more constructivist or post-positivist in nature rather than purely positivist (Lindlof and Taylor 2002).

CHAPTER 2 THE ART AND SCIENCE OF MULTI-SCALE CITIZEN SCIENCE

2.1 Abstract

Citizen science and community-based monitoring programs are increasing in number and breadth and create volumes of scientific data. Data management systems flexible enough to support the varied nature of these data are rare and focus on specific project needs. I examine the art and science of multi-scale citizen science support, focusing on issues of integration that arise when projects span multiple spatial, temporal, and social scales across many domains. My objectives were to: (1) clarify terminology; (2) describe a framework for multi-scale citizen science support; (3) develop a cyber-infrastructure for multi-scale citizen science; and (4) illustrate the benefits of a multi-scale approach through several case studies. I found that citizen science projects differed in their scope, scale, and activities. I propose a framework responsive to their purpose, domain, objectives, audience, accessibility, and data quality. I show that carefully designed citizen science activities involve formulating a research question; developing, testing, and refining protocols; recruiting, managing, and training volunteers; managing data; disseminating information; and evaluating program effectiveness. Using the proposed framework as a guide, I built a cyber-infrastructure to support multi-scale

citizen science projects. My results indicate that such systems can be adept enough to support the needs of citizen science projects operating at multiple spatial and temporal scales across many domains when built with a flexible architecture. Program evaluation tied to this framework and integrated into cyber-infrastructure improved our ability to track effectiveness and strategically place projects within the context of parallel efforts. My examination of citizen science case studies found several benefits to the cyber-infrastructure, including the ability to quickly create custom web skins and the ability of projects within the CitSci.org website to customize data entry forms. I describe a vision for the future of citizen science data management, informatics, and cyber-infrastructure support.

Keywords: Cyber-infrastructure, volunteers, community based monitoring, participation, GIS, informatics.

2.2 Introduction

Citizen science and community-based monitoring programs are experiencing a resurgence (Silvertown 2009). Citizen-based initiatives monitor streams, birds, marine species, climate change, air quality, water quality, macro-invertebrates, terrestrial invasive species, astronomy, and earthquakes, among others (Cornell Lab of Ornithology 2008, Newman et al. 2010a). As the number and breath of these projects increase, so do the volumes of ecological data they generate (Bonney et al. 2009). Online data management systems capable of supporting the varied nature of these data are rare and those that do exist are typically difficult to use and focus on specific project needs (Newman et al. 2010b). Project-focused systems use schemas specific to a particular domain and often do not incorporate global data standards or controlled vocabularies necessary for efficient data sharing or system interoperability. Despite the importance of social aspects of participatory monitoring networks (Bell et al. 2008), most data management systems focus on data entry and storage. They typically do not include features to facilitate communication among citizens, volunteer coordinators, scientists, and other stakeholders. These systems also tend to be tailored to the needs of only one audience and often do not leverage existing systems in similar domains or nearby geographic locales.

Compounding these issues is the fact that users and stakeholders of online data management systems are diverse and each has unique objectives. Examples include scientists, professionals, decision makers, land managers, politicians, naturalists, and the lay public. Their objectives range from contributing quality data to helping scientists answer research questions; from informing local decisions to influencing policy; from engaging in social networks to participating in online creative commons; and from learning about the environment to simply creating opportunities to enjoy nature. These goals require different features and data management approaches ranging from providing fact sheets and summary statistics to downloading datasets for analysis and modeling. The real and acclaimed benefit of citizen contributed data lies in the integration of these data with other datasets and in the development of data management systems capable of supporting and integrating existing efforts across domains and scales. We need flexible data management systems that simultaneously accommodate the needs of many stakeholders.

Citizen-based programs emerging today are created for a variety of purposes, including long term monitoring, science-based research, community networking, social empowerment, science literacy, environmental education, youth career development in science, technology, engineering, and mathematics, and community service. A common outcome of these varied projects is data that may be broadly used. Developing a long-term cyber-infrastructure in support of these programs requires creative attention to sustainable technology, persistent human arrangements, stable institutional resources, and innovation in system design to accommodate and adapt to many stakeholder requirements (Ribes and Finholt 2009). A recent publication by Bonney et al. (2009) articulates these citizen-based information technology challenges well: "… as citizen science efforts grow in scope, the need for innovative tools in database management, scientific analysis, and educational research will be greater, … networking technologies and… database solutions will be imperative, [and] computationally efficient geospatial analysis and imaging techniques [will be needed] … to handle the massive amounts of monitoring data … collected across vast geographic scales."

To begin addressing these challenges, I sought to: (1) clarify citizen science terminology; (2) develop a framework for multi-scale citizen science support; (3) create a cyber-infrastructure in support of multi-scale citizen science; and (4) illustrate the benefits of a multi-scale approach through several case studies. I discuss within- and among-project dimensions and propose a framework to situate citizen science projects based on their scope, scale, and activities. I detail the development and use of a cyber-infrastructure for multi-scale citizen science and conclude by offering a vision for the future of citizen science data management, informatics, and cyber-infrastructure support.

2.3 Definitions

At the forefront, it is important to define citizen-based approaches and how they differ from each other to better understand the linkages and shared outcomes they create. Unfortunately, terminology related to these approaches can be very confusing. Some authors speak of Participatory Monitoring Networks (Bell et al. 2008); others envision Environmental Collaborative Monitoring Networks (Gouveia and Fonseca 2008); some focus specifically on Volunteered Geographic Information (VGI; Elwood 2008c), others talk of public engagement in science and technology (Powell and Colin 2008), and still others discuss Decision Support Systems (Haagsma and Johanns 1994) or Environmental Decision Support Systems (Cortes et al. 2000, Poch et al. 2004). I summarize these definitions and approaches in Table 2-1.

Table 2-1. Various citizen-based initiative approaches and their definitions.

Approach	Focus	References
*Community Based Monitoring**		
"…a process where concerned citizens, government agencies, industry, academia, community groups and local institutions collaborate to monitor, track and respond to issues of common community concern."	Issues of common community concern	(Whitelaw et al. 2003)
*Citizen Based Monitoring**		
A network of informed citizen advocates for management and protection of [natural] resources.	Citizen advocacy	(Stepenuck 2010)
Citizen Science		
Trained volunteers participating in scientific studies as field assistants who collect data. Volunteers who collect and/or processes data as part of a scientific inquiry.	Answer scientific questions raised by researchers	(Cohn 2008, Bonney et al. 2009, Silvertown 2009)
Decision Support Systems		
A class of information systems (including but not limited to computerized systems) that support business and organizational decision-making activities. An interactive software-based system intended to help decision makers compile useful information from a combination of raw data, documents, personal knowledge, or business models to identify and solve problems and make decisions. Wiki. See Keen? See Argent?	Decision support and artificial intelligence	(Argent et al. 2009)
Environmental Decision Support Systems		
An intelligent information system that reduces the time in which decisions are made in an	Software to assist environmental	(Cortes et al. 2000)

environmental domain, and improves the consistency and quality of those decisions.	decision makers	(Haagsma and Johanns 1994) (Guariso and Werthner 1989) (Poch et al. 2004) (Argent et al. 2009)
Environmental Collaborative Monitoring Network		
A proposed framework that combines the concepts of traditional environmental monitoring networks with the ideals of the open source movement. These networks are organized based on three building blocks: (1) Motivated Citizens; (2) Sensing Devices; and (3) Back-End Information Infrastructure	Networks of sensors	(Gouveia and Fonseca 2008)
Volunteered Geographic Information		
A process of acquiring geographic information [from volunteers and the public] that combines elements of Web 2.0, collective intelligence, and neo-geography	Geographic information contributed by volunteers	(Goodchild 2007)
Participatory Geographic Information Systems		
The integration of geo-spatial information technologies and systems (GIT&S) into community-centered initiatives. The merger of community development with geo-spatial technologies for the empowerment of less privileged communities. PGIS implies making GIT&S available to disadvantaged groups in society in order to enhance their capacity in generating, managing, analyzing and communicating spatial information. It is geared towards community empowerment through measured, demand-driven, user-friendly and integrated applications of geo-spatial technologies.	Community empowerment through integrated applications of geospatial technologies	(Rambaldi et al. 2006)
Participatory Monitoring Network		
"Nature-based monitoring organizations that [use] volunteers to collect records and assist with surveys"	Volunteer data collection	(Bell et al. 2008)
Public Participation Geographic Information Systems		
Public participation geographic information systems (PPGIS) pertains to the use of geographic information systems (GIS) to broaden public involvement in policymaking as well as to the value of GIS to promote the goals of nongovernmental organizations, grassroots groups, and community-based organizations. An interdisciplinary research, community development and environmental stewardship tool grounded in value and ethical frameworks that promote social justice, ecological sustainability, improvement of quality of life, redistributive justice, nurturing of civil society, etc.	Social justice focus through many GIS implementations	(Craig et al. 2002) (Sieber 2006) (Aberley and Sieber 2002)
Community Networking		

"Nonprofit organizations that seek to provide online spaces for people who live in the same place to communicate and share information."	Social networking	(Longan 2007)

* These terms are often used synonymously.

Because the majority of citizen-based approaches fall under the auspices of citizen science, Community-Based Monitoring, Participatory Monitoring Networks, Public Participation Geographic Information Systems, or Volunteered Geographic Information, I limit my description to these specific approaches. Below, I describe each of these terms in detail and make comparisons between them. For the purposes of this paper, when I refer to cyber-infrastructure in support of multi-scale citizen science, I use the term citizen science broadly to encompass all of these approaches.

2.3.1 Citizen science

The concept of citizen science is not new and the term is used in many situations to represent many scenarios in which citizens participate in the scientific process along with professionals (Bonney et al. 2009). Citizen science typically involves trained volunteers participating in scientific studies as field assistants who collect data (Cohn 2008, Cornell Lab of Ornithology 2008). According to Silvertown (2009), a citizen scientist is "…a volunteer who collects and/or processes data as part of a scientific inquiry." Citizen science enlists the public in collecting large quantities of data across an array of habitats and locations over long time frames (Cooper et al. 2007, Bonney et al. 2009). Citizen science projects are remarkably successful in advancing scientific knowledge and their contributions provide a vast amount of data about species occurrences and distributions around the world (Bonney et al. 2009).

This form of citizen science focuses on data collection by volunteers to address research questions across broad spatial and temporal scales. This approach requires significant oversight, coordination, protocol development and refinement, training, data management infrastructure, and financial support (Cohn 2008, Bonney et al. 2009). Preeminent examples include the effective citizen science projects coordinated by the Cornell Lab of Ornithology, including Project FeederWatch, PigeonWatch, NestWatch, NestCams, Great Backyard Bird Count, eBird, Celebrate Urban Birds, CamClickr, BirdSleuth, and Birds in Forested Landscapes (Cornell Lab of Ornithology 2008, Bonney et al. 2009).

Another form of citizen science focuses on public engagement, with goals and objectives less data collection oriented and more policy oriented (Powell and Colin 2008). Still others think of citizen science from a distributed computing perspective whereby citizens "volunteer" computers to a pressing cause such as monitoring seismic activity for early response and community safety (Cochran et al. 2009). My experiences show that there are many smaller citizen science initiatives in addition to notably larger efforts. It is these smaller initiatives that often lack data management support, may be uncoordinated and isolated from each other, and may benefit from cyber-infrastructure support.

2.3.2 Community Based Monitoring

There are many instances of public participation in science in the sense that citizens participate in monitoring activities. These programs often fall under the umbrella of "Community-Based Monitoring" or "Citizen-Based Monitoring." Community-Based Monitoring is defined as "…a process where concerned citizens, government agencies, industry, academia, community groups and local institutions collaborate to monitor, track and respond to issues of common community concern" (Whitelaw et al. 2003). The distinction between Community-Based Monitoring programs and citizen science lies primarily in the degree to which program goals and objectives are directed towards answering scientific questions versus contributing to long term monitoring that may in turn lead to science based decisions, and the degree to which participants are involved in the process of doing science. The level of community involvement in Community-Based Monitoring programs varies and spans five categories, including: externally driven, professionally executed monitoring; externally driven monitoring with local data collectors; collaborative monitoring with external data interpretation; collaborative monitoring with local data interpretation; and autonomous local monitoring (Danielsen et al. 2009). In contrast to Community-Based Monitoring, citizen science focuses on science inquiry rather than pure monitoring. It too consists of a spectrum of community member involvement. In some instances, citizen science may not really be scientific at all in the sense that those participating may not be actively *doing* science. For example, they may not be involved in question development, hypothesis testing, data analysis, or data interpretation. Citizen science aims to collect data to address questions raised by researchers, whereas Community-Based Monitoring aims to track trends in natural resource conditions through time to inform policy decisions. In Community Based Monitoring, emphasis is placed on monitoring to promote sustainability, leadership by the community instead of individual organizations, and the use of monitoring data to inform decision-making (Whitelaw et al. 2003).

2.3.3 Participatory Monitoring Networks

Participatory Monitoring Networks are defined as "Nature-based monitoring organizations that [use] volunteers to collect records and assist with surveys" (Bell et al. 2008). Participatory Monitoring Networks include various forms of collaboration between professional and amateur 'nature specialists' and are deemed networks "…because of the way in which information is circulated within them, between individuals and groups, and … channeled to partner organizations" (Bell et al. 2008). The emphasis of Participatory Monitoring Networks is on the network aspect of monitoring, whereas Community Based Monitoring focuses on informing decisions and engaging communities in issues of common concern. The similar term "Community Networking" generally refers to "nonprofit organizations that seek to provide online spaces for people who live in the same place to communicate and share information" (Longan 2007). This perspective of a monitoring network emphasizes the social aspects in online spaces (Longan 2002, 2005, 2007). Participatory Monitoring Networks and Community Networks have been used in conservation to monitor invertebrate diversity, stream water quality, forest understory vegetation, plant diversity, and many more. These networks, like citizen science, demand flexible and efficient data management systems that are targeted to their particular needs and features that facilitate communication among networked participants.

2.3.4 Public Participation Geographic Information Systems

The term Public Participation Geographic Information Systems focuses on community interactions with GIS inextricably tied to the social and geographic context of system production and implementation (Craig et al. 2002). Public participation is meant as “grassroots community engagement” (Craig et al. 2002). This concept hinges upon the citizen participation ladder (Craig et al. 2002, adapted from Weiderman and Femers 1993). This ladder is a continuum comprised of six stages, including: public right to know; informing the public; public right to object; public participation in defining interests, actors, and determining agendas; public participation in assessing risks and recommending solutions; and public participation in final decisions (Wiedemann and Femers 1993, Craig et al. 2002). Most citizen science projects focus on the first two stages. Public Participation Geographic Information Systems pushes these boundaries and consists of continuums whose outcomes are best understood by addressing the questions of who is informed, who is empowered, and who benefits from the technology (Laituri 2003). Craig (2002) and Seiber (2006) provide comprehensive literature reviews of Public Participation Geographic Information Systems. Unfortunately, the core literature consists of inconsistent vocabulary that does not build well on past research and that has resulted in a field struggling to establish an identity (Tulloch 2008). Nevertheless, Public Participation Geographic Information Systems has sparked critical thinking about GIS, social ramifications of technology and power (Elwood 2008b), and the role of the public in spatial decision making.

2.3.5 Volunteered Geographic Information

Volunteered Geographic Information is a recent term used to signify geospatial data contributed by volunteers. The distinction here lies primarily in that these data may or may not be scientific or collected and submitted for scientific purposes. Similarly, data may or may not have been collected strictly for monitoring purposes. Instead, data may be collected for any combination of reasons; they may be scientific, utilitarian, and/or anecdotal. For example Open Street Map enlists volunteers to map all streets in the world. The project has amassed some 33,000 registered users, of which 3,500 are actively generating some 300+ million track points thus far (Haklay and Weber 2008). Similarly, the popular website Flickr allows members to geo-tag their photographs – a form of VGI itself – and wikimapia allows citizens to submit geo-referenced descriptions of places of interest resulting in a "volunteered gazetteer" now replete with over 4.2 million vetted entries (Goodchild 2007). These are just a few of the many examples of spatial web 2.0 'mash-ups' that enlist, use, or depend on volunteered geospatial information in what has come to be known as 'crowd-sourcing' (Howe 2006). The credibility of these data has been under scrutiny (Flanagin and Metzger 2008) and depends upon the context in which these data are being used and evaluated. In a citizen science context, stakeholders often require rigorous data quality assurances. Volunteered Geographic Information for citizen science represent information judged objectively based on shared and enforced standards among professionals insisting on credibility as defined by position and attribute accuracy rather than credibility as defined by perceived trustworthiness (Flanagin and Metzger 2008). In a more open domain such as street mapping or geo-tagged photos, credibility as defined by trustworthiness and timeliness may be more important. Nevertheless, debate remains over what relevant information ought to be collected by volunteers and for what purpose: "Instead of the current free-for-all of geographic facts collected by sites such as Wikimapia, citizens could be invited to provide specific kinds of information of greater relevance to geographic understanding, in the spirit of citizen science" (Goodchild 2008).

2.4 A Framework for Multi-Scale Citizen Science

Given the variety of citizen based approaches, I developed a framework to situate projects based on their scope, scale, and activities (Figure 2-1). The proposed framework accommodates different levels of citizen and professional participation in each aspect of a project's scope, scale, and activities and acknowledges that there are tensions and continuums for each aspect (Figure 2-1). The scope of citizen science projects includes their purpose; domain of focus; objectives; intended audience; degree of accessibility; and desired data quality. The scales at which these projects operate span multiple spatial, temporal, and social scales. Citizen science activities include research question development, project management, marketing, communication, recruitment, volunteer management, data management, information dissemination, and program evaluation (Bonney et al. 2009; Figure 2-2). The scope, scale, and activities of a given project operate in both within- and among-project dimensions.

	Aspect	Tension / Continuum	
Scope	Purpose	Perform services	Influence policy
	Domain	Focused	Broad
	Objectives	Create/Act	Learn/Change
	Audience	Lay public	Scientists
	Accessibility	Marginalized	Elite
	Data Quality	Low	High
Scale	Spatial	Local	Global
	Temporal	Short	Long
	Social	Individual	Community
Activities	Research question	Bottom up	Top Down
	Protocol	Pre-existing	Newly Created
	Recruitment	Targeted	Non-Targeted
	Training	Pragmatic	Conceptual
	Volunteer Management	Cursory	Intensive
	Data Management (QA/QC)	Loose	Restricted
	Information Dissemination	Local	Global
	Program Evaluation	Formative	Summative
Support	Level of Engagement	Category I	Category V
	Level of Service Provided	Production	Experimental
	Funding Mode	Development	Maintenance
	Developer Motivations	User requirements	Design Intents
	Research Model	Research	Development

Figure 2-1. A framework for multi-scale citizen science. The framework includes the scope (brown), scale (red), and activities (blue) of citizen science programs along with the necessary cyber-infrastructure support (green). Each aspect of multi-scale citizen science has associated continuums or tensions. These aspects of scope, scale, and activities are generally applicable to both within- and among-project dimensions.

2.4.1 Within-project dimensions

The scope of a given citizen science project within the project itself varies. Projects are developed for different purposes along a continuum from focused to broad (Figure 2-1). Examples of focused purposes include performing restoration or monitoring activities. Broad purposes include informing decisions, improving environmental literacy, or influencing policy (Figure 2-2). The more tacit objectives that naturally follow from these overarching purposes include act-oriented objectives such as teaching kids or collecting data to more change-oriented objectives such as influencing individual behaviors. These objectives are specific to the domain of a given citizen science project, such as birds, streams, wildlife, climate, air, soil, bats, worms, or frogs. The intended audience of citizen science projects range from the lay public to land mangers, decision makers, and professional scientists (Figure 2-1). The desired degree of access and data quality also varies. Access refers to cognitive access, social access, cultural access, technological access, and economic access (Laituri 2003). Data quality aspects include accuracy, precision, credibility, and trustworthiness (Figure 2-2; Flanagin and Metzger 2008).

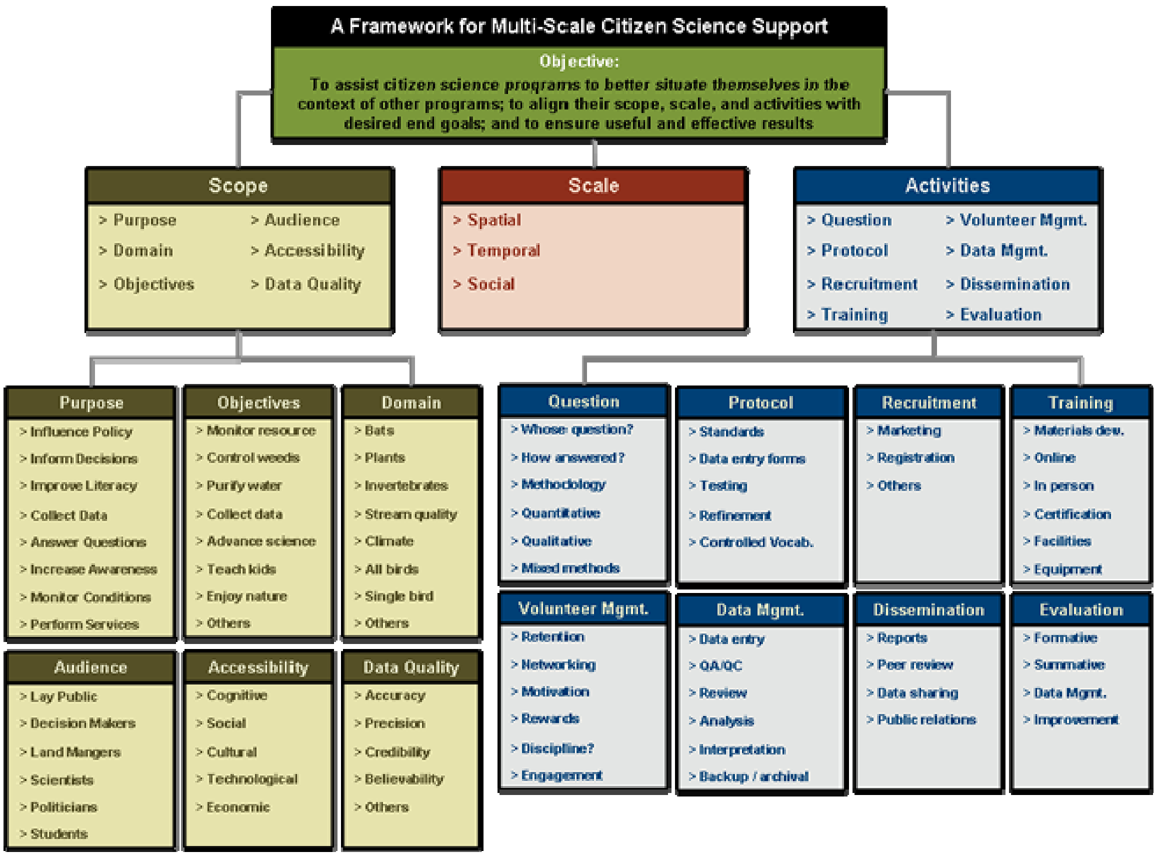

Figure 2-2. A framework for multi-scale citizen science illustrating examples of the scope (brown), scale (red), and activities (blue) of a variety of citizen science projects.

The scale of a given project involves spatial, temporal, and social scales (Figure 2-1). The spatial scale ranges from local to global, the temporal ranges from short- to long-term, and the social ranges from individual- to community-focused. Local lake management association activities are an example of local scale programs. An example of a regional scale program is the Invasive Plant Atlas of New England program. Global-scale programs include eBird and Journey North. Examples of short term projects include one-time only volunteer opportunities and programs devoted to amphibian monitoring in a city natural area, for example. Long-term examples include annual surveys such as the Christmas Bird Count and detailed data collection efforts at Long Term Ecological Research sites. Finally, social scales involve individual-oriented projects offering opportunities for individuals to collect data on their own and community-oriented projects geared towards events such as a community Bio Blitz.

Within a project, common citizen science activities include research question development; project management; marketing; communication; recruitment; volunteer management; data management; information dissemination; and program evaluation (Bonney et al. 2009). Issues of who develops the research question and for what purpose arise along with what methods are used to answer it (e.g., quantitative or qualitative). To my knowledge there have been few if any examples of citizen science programs that engage the public using qualitative methods. Rather, these methods tend to be used in top down approaches for program evaluation or human dimensions of natural resource studies. Protocol development and refinement involves the use of data standards, data entry forms, protocols, and controlled vocabularies for pick lists or checkboxes; it is an art itself. Volunteer recruitment entails marketing and issues of volunteer registration, motivation (Van Den Berg et al. 2009), and retention. Training requires material development, use of traditional and/or multimedia online resources (Newman et al. 2010a), and the delivery of face to face training sessions. Managing volunteers can be complicated. Existing systems such as Volgistics (www.volgistics.com) can be used, but these systems operate separately from field data management systems. Dissemination of project results is typically accomplished through reports, peer reviewed articles, data sharing, and online materials. Finally, program evaluation involves formative and summative evaluation along with logic models to document short- and long-term outcomes against measureable benchmarks.

Deciding on how to approach each of these activities and where on each continuum a given project may reside (Figure 2-1) is critical to overall program success. Mismatches in the relative positions of a program on each continuum can lead to tensions between group goals, data quality, and program outcomes (Nerbonne and Nelson 2008). I developed the framework (Figure 2-1, Figure 2-2) to help prevent such mismatches and to provide coordinators with a means to decide where on each continuum their program is best situated.

2.4.2 Among-project dimensions

Among project dimensions refer to the degree to which citizen science programs coordinate with other programs. The scope of among-project connectivity involves the magnitude of connectedness. It defines the purpose, goals, and objectives of among-project interactions along with desired outcomes. The scale of interoperability among projects includes local, regional, national, and global scales. The activities required to achieve cooperation include collaborative meetings, use of data sharing protocols, use of data standards, and evaluation of the cooperatives formed to ensure goals are met and to answer the question of how effectively programs meet their among-project goals. Measureable benchmarks are needed to ensure that these evaluation questions can be answered; data management systems must be designed to store and analyze these evaluation data.

2.5 A Cyber-Infrastructure for Multi-Scale Citizen Science Support

2.5.1 History

My colleagues and I built the Global Organism Detection and Monitoring System between 2005 and 2008 to support invasive species data management, analysis, and modeling activities envisioned by the USGS National Institute of Invasive Species Science (Graham et al. 2007). The system used technology developed by my team and engineered to provide fast and reliable online interactive mapping capabilities at multiple spatial and temporal scales. It was built using User Centered Design (ISO 13407 1999) and a software lifecycle of iterative investigation, design, requirements specification, development, implementation, testing, and maintenance (Jacobson et al. 1999). Emerging citizen based invasive species programs such as the Invasive Plant Atlas of New England (IPANE; http://nbii-nin.ciesin.columbia.edu/ipane/), the Early Detection and Distribution Mapping System (EDDMapS; http://www.eddmaps.org/), the Cactus Moth Detection and Monitoring Network (http://www.gri.msstate.edu/research/cmdmn/), and Texas Invaders (http://www.texasinvasives.org/) inspired me to re-purpose our existing system to support citizen science projects. Thus, I created a website devoted to volunteers collecting and reporting invasive species data (CitSci.org; www.citsci.org). CitSci.org was built as a front-end web skin on top of our underlying system architecture. The underlying system serves several other related websites through similar targeted web skins, including the Global Invasive Species Information Network (www.niiss.org/gisin; Graham et al. 2009), an environmental literacy assessment website (www.niiss.org/msp), a website dedicated to the invasive species Tamarisk (www.tamariskmap.org), and a website devoted to mapping trails in Larimer County, Colorado (http://cotrails.colostate.edu).

Each of these websites share a common theme: they all rely on participation from stakeholders to keep data current in real-time. In this sense, they are examples of web 2.0 applications. The term web 2.0 is synonymous with web applications that facilitate interactive information sharing, interoperability, user-centered design, and collaboration on the World Wide Web (Lake and Farley 2007). Examples include web-based communities, web applications, social-networking sites, video-sharing sites, wikis, blogs, mash-ups, and folksonomies. A web 2.0 site allows its users to interact with other users or to change website content, in contrast to non-interactive websites where users can only passively view information provided to them (Lake and Farley 2007). Although my websites are examples of web 2.0 technology, they are conservative in their degree of openness and their reliance on third party Application Programming Interfaces.

There are of course many benefits to using open forums (e.g., see the popularity and success of Wikipedia, Wikimapia, and Open Street Map; Haklay and Weber 2008) and free and open source software show great promise for fields such as landscape ecology (Steiniger and Hay 2009). However, stakeholder concerns over data quality and developer concerns over the longevity, reliability, and performance made me balance innovative web 2.0 alternatives against pragmatic solutions. For example, land managers using citizen contributed data are unwilling to spend time and money to control a population of an invasive species if a species is incorrectly identified (a stakeholder concern) and developers are unwilling to wait for minutes for a third party web service response or deal with a lack of documentation when using a new Application Programming Interface (a developer concern). I embrace the participatory nature of web 2.0 collaboration, open source approaches, and cutting-edge technologies. However, like other cyber-infrastructure developers, I am also simultaneously required to ensure reliability, performance, usability, data quality, daily use satisfaction, and features specific to the needs of stakeholders (Ribes and Finholt 2009).

2.5.2 Features for multi-scale support

To meet these often conflicting ideals (Ribes and Finholt 2009), a flexible cyber-infrastructure must adapt to the needs of projects focused on different domains operating at multiple spatial, temporal, and social scales (Figure 2-3). Instead of developing a website for each purpose, I identified several features important to a cyber-infrastructure for multi-scale citizen science. Common to most projects regardless of their scope, scale, or purpose is a least common denominator set of core data (Figure 4). This simple quartet of minimal data consists of an *object* found at a *location* at some point in *time* along with *measured attributes*. This flexible object-oriented approach (Kamath et al. 1993) supports a variety of disparate data. I assign these core data to a project to organize them and empower citizen science coordinators to create their own online spaces specific to their needs. Project managers approve data contributors (e.g., serve as gatekeepers) and create customizable data entry forms specific to their protocols. Despite the ability to customize projects created on CitSci.org, some citizen science programs require a user interface implementation specific to their scope, scale, and activities beyond the level of specificity allowed in CitSci.org. Thus, I added a web skin module to our core database design

(Figure 2-4) to store information about the design, relevant data, and visible features for each web skin tailored to specific program needs.

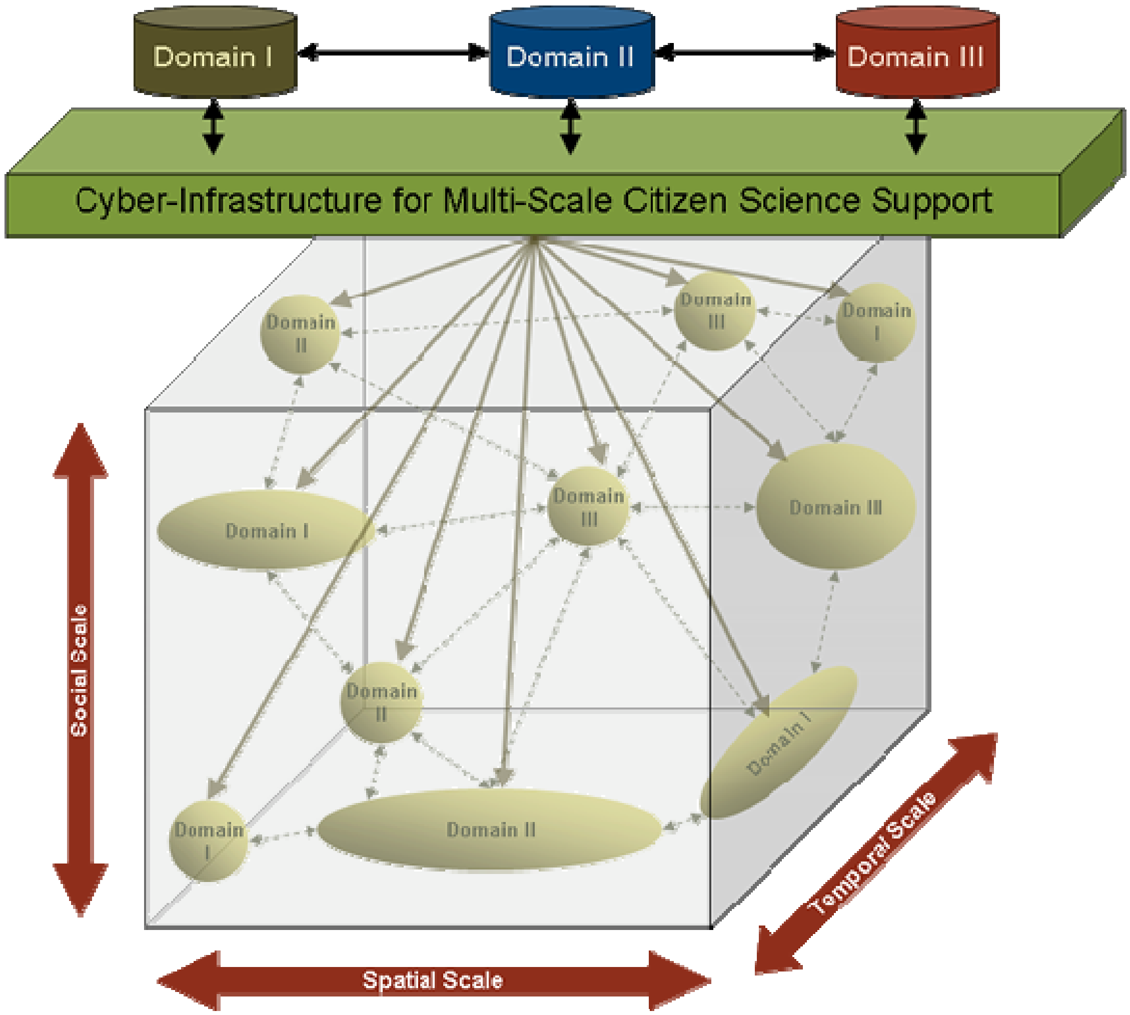

Figure 2-3. Cyber-infrastructure support for multi-scale citizen science projects and activities. There may be many instances of citizen science programs in Domain I (e.g., birds) that are situated in different spatial, temporal, and social spaces. Each citizen science program interacts with each other (dashed lines) and is supported by a cyber-infrastructure (solid lines). There may be several regional and domain-specific databases (dark canisters) that are interoperable and that exchange data between each other and a cyber-infrastructure.

A web skin is an aesthetic change of appearance of the same webpage specific to a certain domain. Web skins make the same web page appear differently and as part of a different website. The advantages of a web skin approach are many. Web skins allow developers to maintain only one system architecture for many websites. Maintenance costs are shared by all, thereby leveraging existing technology (Ribes and Finholt 2009). The cyber-infrastructure includes online features to create and manage web skins online using an administrative back-end, including the ability to create and edit menu items, create and edit Cascading Style Sheets without the need to understand this syntax, develop color palettes, and change basic layout such as web skin width (fixed and flexible width), navigation menu location (left, top, or both) and navigation menu width. Other features helpful to support citizen science projects include a questionnaire creation tool. Questions can be built as multiple choice (checkbox), radio button, drop-down menu pick lists, text entry, or text area questions. The questions can be ordered and labeled and options can be added or changed. The questionnaires are assigned to projects and project managers can automatically analyze and visualize results. These features can be used for online program evaluation and are part of the cyber-infrastructure. I also created a web service Application Programming Interface to deliver dynamic maps for citizen science organizations who wish to embed maps into their own website along with a web service data exchange protocol (Graham et al. 2008).

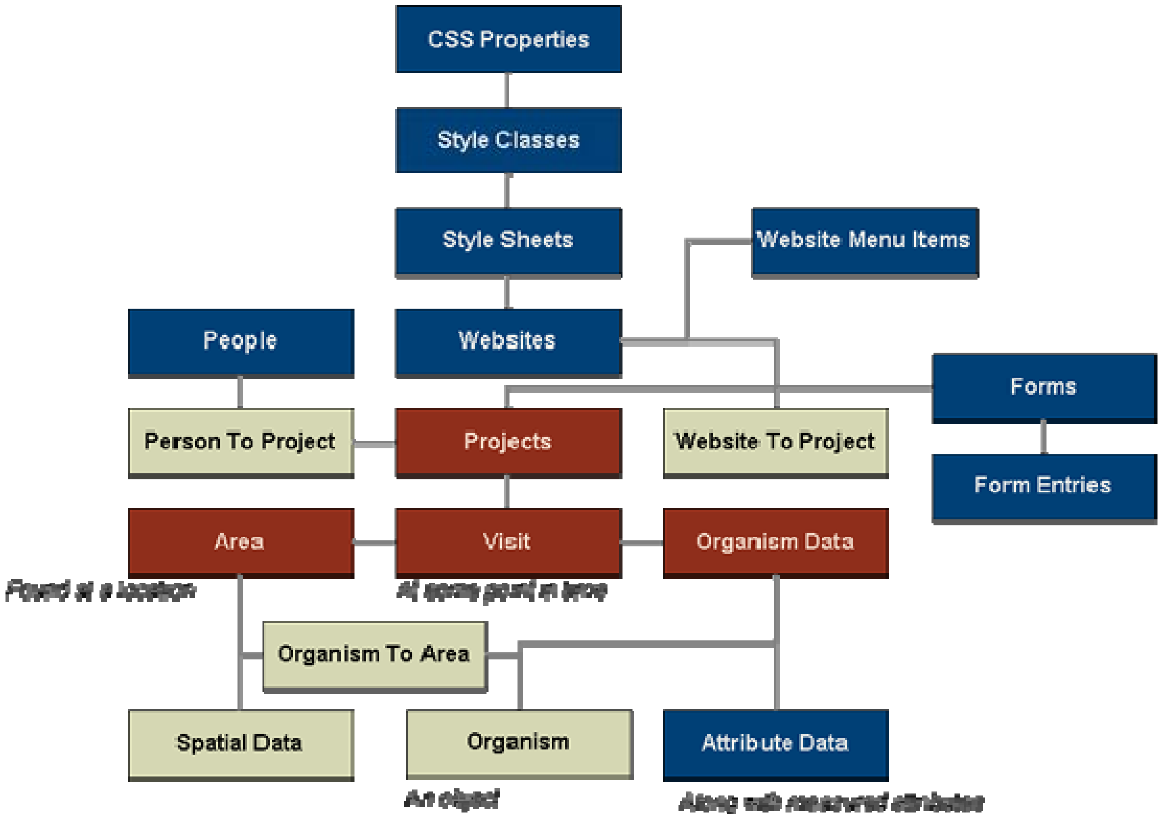

Figure 2-4. Entity Relationship Diagram for web skin related tables of the multi-scale citizen science cyber-infrastructure database schema including core tables for *objects* found at a *location* at some point in *time* along with *measured attributes*. Diagram includes Cascading Style Sheet tables and data entry form tables. Core database object tables are shown in red. Adapted from Graham et al. (2008).

2.5.3 Standards for multi-scale interoperability

Of special concern is the use of data standards. Data standards facilitate data exchange and sharing through web service protocols (Figure 3). Without standards, data may still be exchanged in meaningful ways through semantic markup languages and metadata, but these approaches require technological expertise. For practitioners, data standards help link disparate data. They bridge boundaries between heterogeneous communities, but they may also create and reinforce them (Ottinger 2010). For example, data standards can establish scientific authority among experts and help those reusing data to determine credibility (Ottinger 2010). If data are to be effectively integrated and reused across projects (i.e., the among-project dimension), trust and an understanding of how the data were collected must be an obvious component of merged datasets. A recent study of ecologists' data reuse experiences show that trust in data sometimes stems from what is observed or measured while at other times is more closely tied to who observed or collected it (Zimmerman 2008). Standard data collection protocols may not be adequate indicators of data quality. The ability to determine the appropriate use(s) of data collected by others is critical to subsequent reuse (Zimmerman 2008).

Standards also play an important and often hidden role in shaping the uneven terrain between citizen scientists and experts (Ottinger 2010). Data standards may establish some knowledge as authoritative and some communities as credible generators of data while marginalizing alternative knowledge production processes such as those emerging from citizen science (Ottinger 2010). Given this, some advocate that citizens themselves develop standards through emergent processes often present in web 2.0 applications and social networks. For example, in Open Street Map, volunteer citizens themselves create controlled vocabularies for places of interest. Should plant life-forms be labeled grasses, forbs, and shrubs or herbaceous and woody plants - the answer may emerge and be decided on by those using the system. These same emergent processes are similar to constructivist approaches in qualitative research (Lindlof and Taylor 2002) and are proclaimed to be a good method for policing data quality: "The best data quality control is no data quality control at all" (Coast 2010; personal communication).

Once standards are developed, they facilitate data sharing. For example, in an information technology context, data standards make it easier for REST protocols to be developed for efficient data exchange through web services. They may also make it easier for ecologists reusing data to integrate disparate data sources. However, studies among professional ecologists show that data sharing often takes place between close associates and relies on social interaction (Committee on the Future of Long-term Ecological Data 1995). The reasons for this are complex and include a lack of incentives for ecologists to share data and a culture that values creative and independent research above secondary use of data (Zimmerman 2008). Networks of sensors and cyber-infrastructure support for continental-scale ecological processes (e.g., NEON) create a need for new epistemological tools to integrate large volumes of data (Zimmerman 2008). These challenges are not entirely technological; they are social and cultural. The ability to understand how data was collected is the most important factor for data reuse and data sharing (Zimmerman 2008). The purpose of research dictates data collection methods, and this, in turn, limits secondary use of data. Thus, the multi-scale nature of citizen science projects represents both the greatest advantage and barrier to among-project benefits. All data are limited, and their limitations are pitfalls to reuse if they are not understood. Ecologists use their knowledge about the relationship between purpose, methods, and limitations to make sophisticated decisions about appropriate reuse; data standards alone do not serve as measures of data quality because they do not tell secondary users if the data were collected skillfully (Zimmerman 2008). Successful systems for sharing data succeed not only because of standardization, but also on account of the metadata they make public about the data.

2.5.4 Maintenance and long-term support

The hubris surrounding technical solutions for effective data standards, data sharing, and cyber-infrastructure development often mask complications experienced by developers (Ribes and Finholt 2009). Novel platforms often do not meet the needs of stakeholders; they do not offer the functional stability required by daily use, they do not simultaneously promote knowledge seeking and data contributing motivations (Phang et al. 2009), and they lack human resources to maintain and upgrade existing technology (Ribes and Finholt 2009). Developing a cyber-infrastructure requires long term funding and support. Developers speak of problems in the spheres of science policy, funding, organizing work and maintaining technical systems (Ribes and Finholt 2009). Primary concerns include motivating contributors, aligning end goals, and designing for use (Ribes and Finholt 2009). I overcame these challenges by creating online projects, using a "train the trainer" approach, relying on a flexible database schema, using an object oriented design, and integrating a web skin management system into the cyber-infrastructure along with flexible subsystems that can be reused for many purposes (e.g., my online questionnaire system). Thus far, use of the cyber-infrastructure by citizen science programs has resulted in 10 online projects yielding over 1900 invasive species locations.

2.6 Example Projects

To illustrate the flexibility of the cyber-infrastructure system, I describe several case studies of projects using CitSci.org and several examples of web skins. The scope, scale, and activities of these examples are summarized in Table 2-2. Specifically, I highlight three CitSci.org projects, including Great Lakes Worm Watch, Project R.E.D., and the City of Fort Collins Natural Areas Program Amphibian Monitoring Project. I then briefly discuss two web skins created for more specific purposes, including T-Map and COTrails.

Table 2-2. Example CitSci.org projects and web-skins and their associated scope, scale, and activities.

Project	Scope*	Scale**	Activities***
CitSci.org Projects			
Great Lakes Worm Watch	Worm assessments	R – ST - C	(P,T,R,C,D,E)
Project R.E.D. (Riverine Early Detectors)	Aquatic invasive species monitoring	R – LT – C	(P,T,R,C,D,E)
City of Fort Collins Amphibian Monitoring	Amphibian monitoring	L – LT – I	(P,T,R,C,D,E)
Web Skins			
CitSci.org	Multi-project	N – LT – C	(P,DM,C,D,E)
T-Map	Tamarisk mapping	G – LT – I	(P,DM,C,D,E)
COTrails	Trails mapping	R – LT – I	(DM,C,D)

* **Scope**: Synopsis of Purpose, objectives, domain, audience, access, and data quality.
** **Scale**: Spatial – Local (L), Regional (R), National (N), and Global (G); Temporal – Short-term (ST) and Long-term (LT); and Social – Individual (I) and Community (C).
*** **Activities**: Protocols (P), training (T), recruitment (R), data management (DM), communication (C), dissemination (D), evaluation (E).

2.6.1 Example CitSci.org projects

The Great Lakes Worm Watch project (http://www.greatlakeswormwatch.org/) is dedicated to providing tools and resources for citizens to document the distributions of exotic earthworms across the Great Lakes region (Hale 2010). The project was created prior to the inception of CitSci.org and already had an active constituency of volunteers, educational materials, and research protocols. It was established on CitSci.org July 21, 2008 to provide volunteers with online data entry and mapping capabilities. Since then, the project has created four customized data entry forms, some with complicated protocols consisting of subplots within plots. To date, volunteers have contributed 28 surveys consisting of 19 unique taxonomic identifications, such as 89 Earthworm (*Oligochaeta*) sightings, 29 Leaf Worm or Beaver Tailed Worm (*Lumbricus rubellus*) sightings, and 28 Canadian Gray Worm (*Aporrectodea turberculata*) sightings.

The scope of the project is regional and its purpose is to increase scientific literacy and public understanding of the role of exotic species in ecosystem change and what citizens can do to participate. The project objectives are to document the distribution and spread of exotic earthworms and increase knowledge about their impacts to the Great Lakes region (Hale 2010). The audience ranges from third grade students to college undergraduates and professionals. The accessibility of the project ranges from understanding by the lay public to detailed and exacting protocols geared towards specialists. Data quality is controlled by verification of samples sent to experts at the University of Minnesota- Duluth. The scale of the project is regional and typically short-term due to a lack of site re-visits. Socially, the project is community-oriented, although some individual contributors have participated. Project activities follow Bonney et al. (2009). Among-project collaborations are many, including national partnerships with the National Science Foundation, regional collaborations with the Minnesota Department of Natural Resources, the Northeast Regional Sustainable Development Partnership, Minnesota's NOAA Lake Superior Coastal Program, and the Minnesota Environment and Natural Resources Trust Fund, and local partnership with the Boulder Lake Environmental Learning Center.

The Great Lakes Worm Watch project presented challenges to the cyber-infrastructure because their protocols required subplots within plots. The flexible system architecture was readily adapted to meet this need and I worked with the program to ensure that protocols were standardized with national protocols and that controlled vocabularies were used. Additionally, this project had established a generic data entry form to document work presence along with a Level I, II, and II data entry form to accommodate three levels of volunteer sophistication. The cyber-infrastructure customized data entry form creation features accommodated these different forms without any programming changes.

Project R.E.D. (Riverine Early Detectors) has been "Paddling with a purpose" since March 1st, 2009 and has submitted 132 surveys to date of Japanese Hop (*Humulus japonicus*), Japanese Knotweed (*Polygonum cuspidatum*), Curly Pondweed (*Potamogeton crispus*), Purple-loosestrife (*Lythrum salicaria*), Common Reed (*Phragmites australis*), Eurasian Watermilfoil (*Myriophyllum spicatum*), and Flowering Rush (*Butomus umbellatus*). The project offers free trainings to volunteers for 15 species of concern and engages the public as monitors of rivers by canoe, kayak, or on foot (http://www.wisconsinrivers.org/index.php?page=content&mode=view&id=171).

The purpose of this project is to raise awareness about invasive species in river corridors and engage local citizens in the fight against invasive species. The project objective is to provide early detection of invasive species threatening Wisconsin's Rivers to enable containment or eradication by managing agencies. The spatial scale of this project is throughout Wisconsin and the project aims to monitor rivers through time. The project domain is focused on aquatic invasive species. Data quality is controlled through excellent volunteer training programs. The social scale is community focused given typical excursions on the river in groups. The project has forged partnerships with several local and regional initiatives, including the River Alliance of Wisconsin, the Rock River Coalition, and the Riveredge Nature Center.

Project R.E.D. presented challenges to the cyber-infrastructure given their active use of photo verification. Volunteer take photographs of each infestation and submit their photos online at CitSci.org. I found that improved photo management features similar to Facebook or Flickr will be required form experiences with Project R.E.D.

The City of Fort Collins Natural Areas Program Amphibian Monitoring Project is a volunteer based program to monitor native and non-native amphibian species in Fort Collins Natural Areas based on standardized national audio surveys. The project submitted 111 surveys across 32 natural areas throughout summer 2009. These surveys identified 6 species, including Western Chorus Frogs (*Pseudacris triseriata*), Woodhouse Toads (*Bufo woodhousii*), Bullfrogs (*Rana catesbeiana*), Plains Spadefoots (*Spea bombifrons*), and Northern Leopard Frogs (*Rana pipiens*). Chorus frogs were the most widespread, being recorded at 24 natural areas (City of Fort Collins Natural Areas Program 2009). Woodhouse's toads were recorded at 16 natural areas and the bullfrog (Rana catesbeiana), an invasive species which often eats native amphibians, was recorded at 10 locations. These 10 sightings represent many more locations than were documented during previous years, indicating an increased threat by this species (City of Fort Collins Natural Areas Program 2009). The project encompasses a local spatial scale and intends to continue annually. Data quality is controlled through a training program at the beginning of each summer field season and the use of audio CD ROMs for call index reference guides.

This project made use of a standardized call index (Nelson and Graves 2004) for volunteers to report as attributes of amphibian sightings. I was able to add the new attribute type and attribute values online easily using the administrative backend of the cyber-infrastructure. The controlled vocabularies used for the call index includes: (0) No individuals calling; (1) Individuals can be counted, there is space between calls; (2) Calls of individuals can be distinguished, but there is some overlapping of calls, and (3) Full chorus, calls are constant, continuous, and overlapping.

2.6.2 Example web skins

CitSci.org itself is a web skin developed in support of multi-scale citizen science projects. Although CitSci.org is quite flexible in meeting the specific needs of many projects, some projects may require a custom web skin. For example, a flagship species of concern may generate enough socio-political concern to warrant a targeted web skin rich with more detailed information and online resources about a single species. A single species approach affords those using the system the luxury of not having to search for a species to submit data, but rather use a simplified user interface with a single submit button (since it is already known which species is being reported). To prototype a single species approach, I created T-Map (www.tamariskmap.org) that focused specifically on the invasive species Tamarisk.

Another situation that warrants a web skin involves trails mapping. To illustrate this approach, I developed COTrails, a website supporting collaborative mapping of trails throughout Larimer County, Colorado. COTrails offers simple search capabilities to search for trails by name, by length, by difficulty, or by managing agency (National Park Service, U.S. Forest Service, city governments, etc.). It affords those with permission to contribute new up-to-date trail information in the event of trail re-routes following restoration or erosion control efforts. The cyber-infrastructure allowed us to customize menu items for this web skin, easily develop new web pages for the purposes of trail information, reuse core base classes for similar web pages, and tailor the map application to pre-load trails and trail sections.

A common database for these seemingly disconnected projects has unanticipated advantages. For example, trails data contributed through COTrails can now be used as a predictive layer to determine the degree to which proximity to trails may be correlated to the occurrences of a given invasive species. An unanticipated advantage of the flexible cyber-infrastructure lies in its ability to quickly and easily develop unique systems for unique circumstances.

2.7 Discussion

My research and development experiences creating a cyber-infrastructure in support of multi-scale citizen science underscored the importance of flexibility in system architecture and capabilities. Knowing up-front what level of cyber-infrastructure support is needed by a project and how a project fits within the broader citizen science landscape is critical. The framework for multi-scale citizen science situates projects and provides those developing cyber-infrastructure with a sparse matrix of circumstances from which to plan for in advance. Other frameworks related to citizen science structure an analysis of PGIS empowerment by combining four catalysts (information, process, skills, and tools) with two social scales (individuals and communities; Corbett and Keller 2005). Empowerment within my framework is conceptual and related to the research activities of volunteer recruitment, retention, and motivation. Similar to my framework's within- and among-project dimensions, Bell et al. (2008) uncovered the social interactions that occur within and between participatory monitoring networks through ethnographic research in Europe. The authors focused on features to facilitate the recruitment, retention and motivation of volunteers participating in organized biodiversity monitoring. They found that these networks must "...strike a dynamic balance between recruitment and retention, bringing in new volunteers while consolidating existing [members]" and that to expand and sustain volunteer participation, networks must engender enthusiasm "…by providing an inspiring environment where trust, respect, recognition, value and enjoyment can flourish" (Bell et al. 2008).

My experiences developing cyber-infrastructure indicate that appropriate web 2.0 social networking features may address these needs. These features allow developers to be responsive in meeting the needs of multiple citizen science programs by empowering each project to customize their own projects. The cyber-infrastructure system empowers volunteer coordinators to serve as gatekeepers who in turn empower volunteer citizen scientists. This approach - using user levels and project roles - is similar to that of Poch et al. (2004) who advocate for user profiles with different privileges and responsibilities. Online web skin creation features for administrators are instrumental to help cyber-infrastructure developers serve the needs of many projects simultaneously because it allows them to develop web skins tailored to each project quickly. These features allow developers to survive the challenges of cyber-infrastructure development for 'the long now' – allowing them to have one foot in system development and maintenance while also meeting research goals and objectives for innovation, technological advancement, and publication (Ribes and Finholt 2009).

2.8 Conclusions

I conclude by offering a vision for the future of citizen science data management, informatics, and cyber-infrastructure support. I envision continued cyber-infrastructure development that makes use of web services to enable data sharing among and between different regional databases and more national cyber-infrastructure support systems.

Some systems may be focused on a particular scientific domain while others may be more focused on citizen science. Better use of shared controlled vocabularies, data standards, and standardized protocols will integrate these projects and leverage their assets in creative ways. Such integration will enable meta-analyses across projects and ensure minimal duplication of effort locally and regionally. However, expanded data sharing capabilities may not necessarily lead to improved information dissemination; instead, it may simply lead to the phenomena of information abundance (Flanagin and Metzger 2008). Future cyber-infrastructure support systems will need to offer value added data analysis and summarization services prior to final data exchange to reach their full potential. Summary reports and statistics using integrated datasets will help complete the data dissemination lifecycle – bringing meaningful results back to land managers, decision makers and the citizen 'data collectors' themselves. Integrated program evaluation capabilities will help cyber-infrastructure systems better assess program performance essential to program evaluation and future funding support. Finally, web 2.0 features such as Really Simple Syndication feeds and social networking features will improve communication among and between multi-scale citizen science programs.

Pressing questions remain. What factors determine whether a citizen science project should use existing cyber-infrastructure features such as those available on CitSci.org or whether they warrant the more customized features of a web skin? What are the capabilities and capacities of those using cyber-infrastructure? What are the capabilities of multi-scale cyber-infrastructure support for traditional ecological knowledge collected by volunteer participants from many cultures? What technology is appropriate for these multi-scale audiences? Will cyber-infrastructure decrease the marginalization of such audiences or increase it? Future citizen science program success may hinge on the flexibility and adaptability of cyber-infrastructure to the domain, scope, and scale of the multitude of citizen science programs emerging today.

CHAPTER 3 USER FRIENDLY CITIZEN SCIENCE

3.1 Abstract

Citizen science websites are emerging as a common way for volunteers to collect and report spatial ecological data. Engaging the public in citizen science is challenging, and, when involving online participation, data entry, and map use, becomes even more daunting. Given these new challenges, citizen science websites must be easy to use, result in positive overall satisfaction for many different users, support many different citizen science tasks, and ensure data quality. To begin reaching these goals, I built a geospatial citizen science website, evaluated its usability, and gained experience by working with and listening to citizens using the website. I sought to determine general perceptions, discover potential problems, and iteratively improve the website. While the website was rated positively overall, map-based tasks identified a wide range of problems. Given these results, I re-designed the website, improved content, enhanced ease of use, simplified the map interface, and added features. Finally, I discuss citizen science websites in relation to online public participation geographic information systems, examine the role(s) websites may play in the citizen science research model, discuss how

citizen science research advances GIScience, and offer guidelines to improve citizen-based web mapping applications.

3.2 Introduction

The number of citizen science organizations, programs, and volunteers actively recording the location of species is growing faster than the flowers, birds, frogs, wildlife and worms they seek to record. It is estimated that there are approximately 15 million citizens watching or recording birds in the U.S. alone (Bhattacharjee 2005). Additionally, there are over 4,200 conservation organizations listed in an online conservation directory (National Wildlife Federation 2009) and likely many more engaged in conservation activities using volunteers. Programs such as the North American Breeding Bird Survey (Peterjohn and Sauer 1993), NatureMapping (Dvornich et al. 1995), Project FeederWatch (Bonney and Dhondt 1997, Lepage and Francis 2002), Frogwatch USA (MacKenzie et al. 2002), Project Tanager (Rosenberg et al. 1999) and eBird built upon the first account of citizens observing nature and recording data on Christmas day, 1900 (the Christmas Bird Count; National Audubon Society 2005). Today, citizen science projects continue to expand in scope and breadth and now include projects associated with climate change (Cohn 2008), invasive species (Delaney et al. 2008), conservation biology (Galloway et al. 2006, Losey et al. 2007), biodiversity monitoring (Danielsen et al. 2005b, Lepczyk 2005, Couvet et al. 2008), population ecology (Peterjohn and Sauer 1997, Rosenberg et al. 1999), water quality monitoring (Wilderman et al. 2004), street mapping (Haklay and Weber 2008), and traffic congestion (Goodchild 2007), among others (Silvertown 2009). As these so-called ‘voluntary citizen sensors’ grow in number and continue to adopt new spatial web 2.0 technology (Goodchild 2007), we must better understand the relationship between people and computers; the usability of web mapping applications; and the intricate ways in which people expect to reason with, learn about, and communicate their geographical world. Applied citizen science research improves our understanding of these relationships and pushes us to explore novel geospatial information representation and visualization methods; invent new ways to ensure data quality; improve approaches to express spatial data accuracy and precision in ways meaningful to the user; and expand the very limits of GIScience itself.

3.2.1 Citizen science

What is "citizen science?" The term citizen science has been used in many situations to represent many different scenarios in which citizens participate in the scientific process along with professionals. Citizen science typically involves trained volunteers participating in scientific studies as field assistants who collect data (Cohn 2008, Cornell Lab of Ornithology 2008). According to Silvertown (2009), a citizen scientist is "a volunteer who collects and/or processes data as part of a scientific inquiry."

The citizen science research model is one of many along a spectrum of approaches to community-based science and monitoring that encompasses varying levels of community member involvement (Wilderman et al. 2004, Cooper et al. 2007, Danielsen et al. 2009). In the citizen science research model, the public is involved in data collection across broad geographic regions and long time frames to address questions raised by researchers (Cooper et al. 2007). One of the cornerstones of this model is that participating citizens disseminate the information they collect, thereby increasing awareness of the scientific research questions being addressed (Couvet et al. 2008). Recent principles proposed to guide good citizen science suggest that this dissemination must come full circle; professional scientists must disseminate research results, feedback, and updates back to volunteers (Cooper et al. 2007, Silvertown 2009). To be effective, citizen-based efforts will require standardized monitoring protocols and the ability to efficiently disseminate information on to decision makers (Conrad and Daoust 2008). They will require effective project management; sufficient citizen buy-in; innovation in quality assurance tools, recruitment strategies; marketing; and information systems (e.g., web mapping applications) adept enough to communicate goals, recruit volunteers, market programs, train participants, collect quality data, communicate results to stakeholders, and retain members (Cooper et al. 2007).

To meet these challenges, many organizations are developing websites to support their volunteers and facilitate data entry and dissemination. Indeed, the increase in the number of citizen-based websites available to the public may be one of the many factors driving the growth and explosion of citizen science (Silvertown 2009). As the number of organizations grow, so do the number of websites. For example, the Invaders of Texas (http://www.texasinvasives.org/invaders/), the Invasive Plant Atlas of New England (IPANE; http://nbii-nin.ciesin.columbia.edu/ipane/), Wisconsin NatureMapping (http://www.wisnatmap.org/), EDDMapS (http://www.eddmaps.org/), the Community Collaborative Rain, Hail, and Snow (CoCoRaHS; http://www.cocorahs.org/) network, Water Action Volunteers (http://watermonitoring.uwex.edu/wav/), OpenStreetMap (http://www.openstreetmap.org), eBird (http://ebird.org/content/ebird/), wikimapia (http://wikimapia.org/), and EarthTrek (http://www.goearthtrek.com/) are just a few of the many websites now supporting citizen science and citizen-based activities.

Many of these websites use Google Maps technology, interact with the Google Earth desktop application, and disseminate citizen-contributed geospatial information using interactive web mapping applications. These technologies and applications now create user expectation for fast performance and the ability to quickly and easily post information. They are one example of the many approaches to Public Participation Geographic Information Systems. They may equip millions of citizens with an online place to upload geospatial information, thereby increasing the availability of such information worldwide (Goodchild 2007). However, as more web mapping applications are developed, more attention must be given to their usability, user satisfaction, required tasks, data quality, and applicability related to each purpose and audience they are being built to support.

Of special concern is the diversity of people using websites. Website developers must account for the fact that their users come from all walks of life. They represent a variety of age groups and cultures, form diverse social structures, and possess different levels of technological sophistication. They are lifelong-learners who speak different languages, posses different levels of prior computer experience, have different goals and motivations, and may be marginalized from new technology. They are high school biology students, amateurs, retired scientists, science teachers, volunteer coordinators, conservation group members, scientists, land managers, bird watchers, hikers, and outdoor enthusiasts who typically care about nature, have some understanding of the scientific process, and are concerned about environmental problems (Cohn 2008). Creating websites in support of such diverse audiences is both needed and fraught with challenges. These audiences need websites that are easy to use, satisfying, supportive of many common tasks, and are equipped with data quality features. Future volunteer retention, motivation, and overall program success may hinge on the usability and ultimate success of these websites.

Finally, interactive web mapping applications and visualization demand that users posses some level of spatial literacy. Spatial literacy refers to the ability to understand spatial relationships, comprehend how to represent geographic space, and the ability to reason and make key decisions about spatial concepts (National Research Council et al. 2006). Often, citizen scientists collect information using Global Positioning Systems. Correct data collection and contribution requires an understanding of such fundamental concepts as datums, projection, map units, and resolution. Citizen science websites aim to simplify some aspects of data collection and contribution so that a lack of understanding of these concepts does not hinder their ultimate success. These websites advance the development of other web mapping applications and present a growing arena for further GIScience research.

3.2.2 Website usability research

Despite commercial website usability design guidelines (Nielsen 2000), the usability of geospatial citizen science websites involving complex data entry features need additional evaluation. Traditional web evaluation approaches involve both quantitative and qualitative assessments (Zimmerman and Paschal 2009) that employ usability engineering (Good et al. 1986, Nielsen 1993, Coltekin et al. 2009). Usability factors evaluated include satisfaction, efficiency, and effectiveness (Coltekin et al. 2009) and are often measured with task completion rates/times and standardized questionnaires that measure participants' attitudes or preferences (Chin et al. 1988, Lewis 1995, Brooke 1996, Tullis and Stetson 2004, Pearson and Pearson 2008).

However, evaluating the usability of more complex user interfaces like Public Participation Geographic Information Systems (Haklay and Tobón 2003), interactive map applications (Nivala et al. 2008), data entry systems, digital repositories (Zimmerman and Paschal 2009), geovisualization environments (Koua et al. 2006), spatial decision support systems (Carver et al. 2001), and collaborative GIS networks (Balram et al. 2009) require more specialized evaluation techniques (Coltekin et al. 2009). Human Computer Interaction methods and User-Centered Design (ISO 13407 1999) improve the design and evaluation of complex user interfaces (Haklay and Tobón 2003) and aid corporate web mapping application development (Nivala et al. 2007). Additional research (Henderson 1996, Chen et al. 1999, McLoughlin 1999, Bentley et al. 2005) suggests that web designers be more sensitive and responsive to cultural differences that may exist between themselves, their target audiences, and those using their products (Rogers et al. 2007). Although common web mapping applications such as Google Maps, MSN Maps & Directions, MapQuest, and Multimap have been evaluated (Nivala et al. 2008), and although eye movement analysis techniques may better evaluate complex interactive map displays (Coltekin et al. 2009), research is needed to address the new challenges citizen science web mapping applications pose for GIScience. Usability methods must adapt to different citizen science roles, situations, and tasks to evaluate many system components such as content, connectivity, capabilities, content, and levels of participation (Laituri 2003).

To directly wrestle with these challenges, I built an interactive citizen science web mapping application, conducted a usability evaluation, and gained experience by listening to website users. My objectives were to build the website, determine general perceptions, discover potential problems, iteratively improve the website, discuss citizen science websites in relation to online PPGIS, examine the role(s) websites may play in the citizen science research model, discuss how citizen science research advances GIScience, and offer guidelines to improve citizen-based web mapping applications.

3.3 Methods

I built a citizen science website (www.citsci.org) between 2005 and 2008 (Figure 3-1) to support volunteers who collect and report invasive species data (Crall et al. 2009). The website uses technology developed by my research team (Graham et al. 2007) and engineered to provide fast and reliable online interactive mapping capabilities at multiple spatial and temporal scales. This technology drives several related websites through targeted web skins, including the USGS National Institute of Invasive Species Science (www.niiss.org), the Global Invasive Species Information Network (www.niiss.org/gisin; Graham et al. 2009), an environmental literacy assessment website (www.niiss.org/msp), and a website dedicated to the invasive species Tamarisk (http://www.tamariskmap.org).

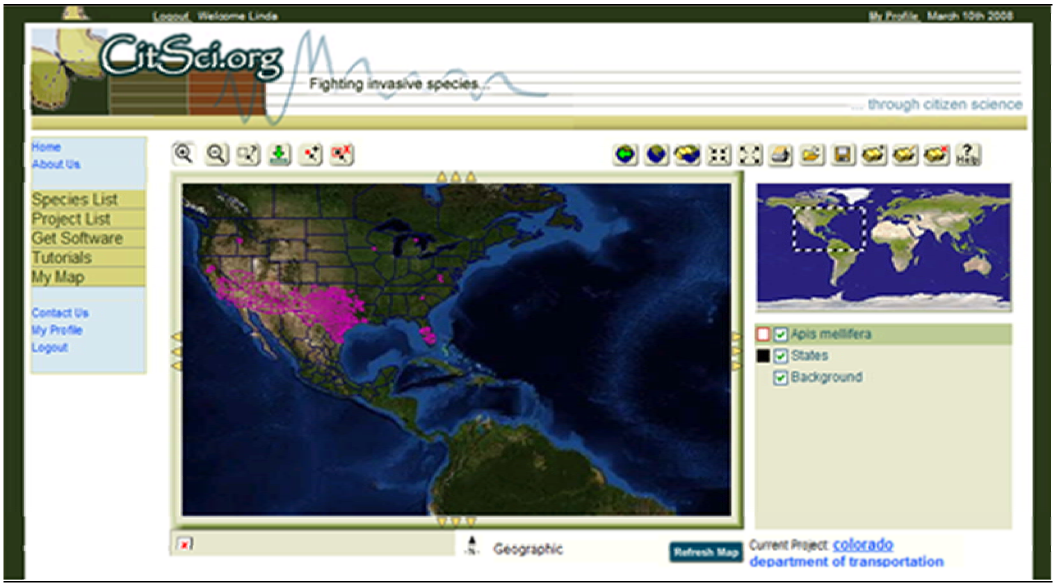

Figure 3-1. The CitSci.org web mapping application when evaluated (February, 2008).

3.3.1 Website development, features, and intended use

My research team built the citizen science website using a User Centered Design approach (ISO 13407 1999). I incorporated user feedback from user interviews (Crall et al. 2009) into the initial website design to help ensure stakeholder-driven tasks drove the requirements specification. The software development lifecycle I used included iterative investigation, design, requirements specification, development, implementation, testing, and maintenance - a process similar to the Unified Software Development Method (Jacobson et al. 1999). At the time of evaluation, the website provided a broad range of features (Table 3-1) for citizen scientists to collect and report invasive species location and attribute information.

The website allows citizen science organizations to create online projects managed by volunteer coordinators who in turn manage project members. This ensures that only those with permission may contribute locations of invasive species to certain online projects. Website features include registration; login/logout; a “My Profile” page where users request to change their user level; a project list page where users request to join projects; an early alert system where users request to receive emails when new species are added in and around locations of interest; a map application that allows users to add species they wish to view, add new locations, get information about species locations, and change the color of species layers; the ability to search for projects and species; the ability to view information about species on a “Species Profile” page; features to support sensitive data (Jarnevich et al. 2007); data quality features; the ability for project managers to create their own customized data entry forms; and data download features (Table 3-1). For the usability evaluation, my scenarios (Appendix B) focused on registration; the “My Profile” page; email alerts; species profiles; map features; and the “Project Profile” page.

3.3.2 Usability evaluation

I sampled citizen scientists from Fort Collins, Colorado, using a snowball sampling approach and obtained a purposeful sample of 16 citizen scientists for usability testing at the Center for Research on Communication and Technology Usability Laboratory at Colorado State University. Participants were volunteers from various citizen science groups with many occupations. They represent retired teachers, a retired scientist, a bookkeeper, a U.S. Forest Service employee, a lab tech, a librarian, students, and a master gardener. Participants claim to spend as little as 5% and as much as 100% of their time as citizen scientists. Overall, participants claimed to have numerous years of experience using a personal computer (*M*=17; *SD*=4.4), using the World Wide Web (*M*=11; *SD*=2.6), and filling out applications/forms online (*M*=8; *S*D=3.6) and their self-reported level of expertise was high on a 1 to 7 scale (1=None and 7=High) for using a personal computer (*M*=5.6; *SD*=1.3), using the World Wide Web (*M*=5.75; *SD*=1.13), and filling out applications/forms online (*M*=5.8; *SD*=1.0). Of the 16 participants, 63% claim to visit other invasive species websites and 13% visit other citizen science websites.

Participants learned about the research, received a $25 cash honorarium, signed a consent form, and completed a protocol analysis yielding four task-based scenarios and one exploratory scenario (Appendix B). These standard web usability methods (Haklay and Tobón 2003, Nivala et al. 2008) did not include a GIS "chauffeur" (Nunamaker et al. 1991) because such experts are not realistically available to citizen scientists. I observed the time to complete each task from a separate video room, documented problems, and recorded whether or not participants successfully completed each task. I asked participants to talk aloud and stopped them after four minutes or when they became frustrated. I videotaped each participant and kept observation logs. Participants completed a post-protocol survey including 30 questions on a 1 (Strongly Agree) to 7 (Strongly Disagree) scale (*N*=16) to evaluate web usability concepts (Zimmerman and Akerelrea 2004), 17 questions on a 1 to 7 scale to asses user experiences with scenario-related tasks (*N*=14), and eight questions to determine prior computer experience and expertise on a 1 to 7 scale. Finally, the post-protocol survey also included open-ended questions probing what participants liked or disliked about the site, what they found difficult to use, any sections of the website they found irritating, and recommendations they felt would make the site more user-friendly.

3.3.3 Citizen science feedback

After the usability evaluation, I continued to document user feedback and gain experiences with website users between February 2008 and December 2009. I conducted additional user interviews, received feedback from an online analysis needs assessment, conducted field experiments with citizen scientists, and listened to feedback from users creating projects and entering data. These interactions resulted in 10 additional online projects yielding over 1900 additional invasive species locations that provided us with more user-based experiences and insights.

3.4 Results (Lessons Learned)

While the vision and development of CitSci.org yielded technical results specific to invasive species data management practitioners (Graham et al. 2007, Jarnevich et al. 2007, Graham et al. 2008, Graham et al. 2009), this study focuses on lessons learned from website development and use of geospatial data, evaluation, and user feedback. Thus, this research resulted in the development of the geospatial website (Figure 3-1); usability evaluation information (general perceptions, potential problems, and suggested improvements); and feedback from users leading to new and improved features (Table 3-1). I follow these results with a discussion of citizen science websites in relation to online PPGIS, an examination of the role(s) citizen science websites may play in the citizen science research model, and a discussion of how this research advances GIScience. I conclude with guidelines for citizen-based web mapping applications.

Table 3-1. Existing and future web mapping application features and the role(s) they support

Role	Feature	Existing*	Planned**
Project Management			
	Request to join online projects	X	
	Approve/deny requests to join projects***	X	
	Change project managers and change member roles***	X	
	Activate/de-activate projects***	X	
Communication & Feedback			
	Create and disseminate questionnaires***	A	
	Analyze questionnaires results automatically in real-time	A	
	Email project members***		X
	Control email settings (Allow members to send emails or not) ***		X
	Create and send monthly project newsletters***		X
	Email project manager	XX	
Data Entry			
	Create customized project data entry forms***	X	
	Enter data by clicking on the map	X	
	Enter data using a generic data entry form	X	
	Enter data using customized project data entry forms	X	
Quality Control			
	Check for Latitude >90 or <-90, Longitude >180 or <-180	X	
	Check for UTM Easting >500000 or Northing > 50000000	X	
	Provide error checking for all form variables		X
	Use pick lists for controlled vocabularies	X	
Data Download			
	Download all data for a project	X	
	Download all data for a species		X
	Download data from the map for a selected area of interest	X	
	Download data meeting advanced query specifications		X
Analysis			
	Calculate overall total number of contributions to date	A	
	Calculate the number of contributions per year by project		X
	Create project statistics as charts	XX	
	Report the most frequently reported species	XX	
	Display and reward the member with the most contributions		X
	Display and reward the project with most contributions		X
Decision Support			
	Activate early warning email alerts	X	
	Define locations of interest for early alerts	X	
	Define species of interest for early alerts	X	
	Make predictive models (MaxEnt species distribution models) ****	XX	
Training			
	View online tutorials	XX	X
	Download GPS & website tutorials		X
	Watch online training videos	XX	X

Role	Feature	Existing[*]	Planned[**]
	Take online exams (e.g., become certified Level 1,2,3 volunteer)		X
Logistics			
	Checkout equipment	A	
	Schedule events[***]		X
Technical Support			
	Read online help	X	
	Receive phone support		X

[*] X=Existing prior to evaluation; XX=Existing post-evaluation based on results; A=Existing admin.
[**] Planned future feature based on feedback and recommendations from citizen scientists.
[***] Feature/task only available for approved project managers.
[****] See Phillips et al. (2006).

3.4.1 Development and use of geospatial data

Results related to website development show that careful attention must be given to the selection of programming languages, software packages, spatial database, and data structures. The design of the underlying spatial database is critical and must be flexible and general. The storage, retrieval, and fast rendering of large volumes of geospatial vector and raster data must be accommodated; results show that using cached data and tiled maps similar to the Google Maps approach best supports the potentially unlimited volume of volunteer contributed geospatial information. Developing a scalable and object-oriented code base allows for flexibility as new use cases arise and new features are requested. However, there is a fine line between flexibility and rigorous adherence to standardized controlled vocabularies essential to ensure data quality. Both are important and both require user interface simplicity. I found that web skins allow for targeted user interface designs that simplify and improve the user interface while still maintaining underlying system flexibility for multiple purposes at multiple spatial and temporal scales. Cost benefit analyses must be performed to select programming languages; no single language is best for all applications and languages must be selected based on their suitability to required tasks. Finally, I learned to design for dynamic user-contributed content; layout must adapt to varying length content and photo size.

3.4.2 Evaluation (general perceptions, problems, and improvements)

While the Citizen Science website provides a broad range of information and participants rate the website positively overall, completing basic website tasks and map-based tasks identified a wide range of problems (Figure 3-1, Table 3-2). Most participants had a difficult time with aspects of registration, navigation, early warnings, adding layers to the map for a given species, and map features. Except for two participants with prior GIS experience, most had a difficult time understanding the concept of layers on the map "legend." They also had difficulty understanding map icons and tool tip terms. The terms and icons used for map function buttons were not salient to non-GIS participants even though they were consistent with industry standards. Common buttons such as 'Save' and 'Print' were more easily understood. This emphasizes the role of spatial literacy and the need for a fundamental understanding about web mapping applications.

Table 3-2. Task completion time (minutes), rates (%), and related problems by scenario

Task Problem	Scenario 1		Scenario 2		Scenario 3		Scenario 4*		Mean	
	Time	%	Time	%	Time	%	Time	%	Time†	%
1: Register as a citizen scientist → *Confused by questions*	3:49	0	2:41	100	2:44	100	2:28	100	2:55	75
2: Set early alert settings to on → *Did not know to edit profile*	2:44	33							2:44	33
3: Define locations of interest → *Did not understand concept*	1:50	0							1:50	0
4: Join a project → *Did not notice button*	3:22	33	1:14	67	3:26	75	2:54	75	2:44	63
5: Learn about invasive species → *No problems noticed*	1:00	100	1:32	100	1:05	75			1:12	92
6: Find invasive species → *Problem with task wording*	2:55	33	1:09	67	1:00	100			1:41	67
7: Create and print maps → *Could not locate link*	2:38	67	1:19	33	2:46	100			2:14	67
8: Use map help features → *Wanted search capabilities*	1:20	0	2:59	67	3:36	100			2:38	56
9: Create species location maps	2:18	33	1:46	67	1:53	75	2:39	100	2:09	69

Task Problem	Scenario 1		Scenario 2		Scenario 3		Scenario 4*		Mean	
	Time	%	Time	%	Time	%	Time	%	Time†	%
→ *Confused by 'map occurrences'*										
10: Save species location maps	1:26	33	0:45	67	0:56	100	2:00	75	1:16	69
→ *Did not understand concept*										
11: Load and print saved map	0:30	33	1:26	33	1:43	75	1:36	50	1:18	48
→ *Did not understand 'load'*										
12: Request to become initiator	2:03	67	2:11	67	1:06	100			1:46	78
→ *Could not find link*										
13: Change the color of a layer							3:26	25	3:26	25
→ *Wanted to change it directly*										
14: Edit the label o layer							1:00	75	1:00	75
→ *Did not understand editing a layer*										
Overall	2:09	36	1:42	67	2:01	90	2:17	71		

* Scenario 4 focused on map tasks; it included reworded tasks 10 and 11 and two new tasks (13 and 14)
† Note: all times are in minutes and seconds (mm:ss).

Based on scenario tasks, numerous problems emerged (Table 3-2). Participants had a difficult time finding the Register link. They had difficulty adding species locations to the map. To do so, the website provided a link on the "Species Profile" page that was labeled "Map Occurrences" that automatically added a species layer to the map and displayed all species locations. Participants searched the "Species Profile" page initially, but overlooked the "Map Occurrences" link. Next, they would go to the "My Maps" page but not figure out how to add locations for a species (to do so they could have clicked the "Add Layer" button along the top of the map and add a layer for a species).

In summary, map tasks and email alert tasks took a long time to complete and had low completion rates (Table 3-2); these features were not intuitive to participants. The mean completion rates ranged from 25 to 75%.for map tasks (tasks 7, 9, 10, 11, 13, and 14). Although only evaluated in scenario 1, email alert features (tasks 2 and 3) had low completion rates (33% and 0% respectively). Throughout all tasks, participants could not find key links easily. The links and buttons to "Register," "Join a Project," and view "Map Occurrences" were continually overlooked and not well understood. The "Email Alert" and "Locations of Interest" links were not easily found nor understood. Most participants were able to learn about invasive species, register, and request to change their user level (92%, 75%, and 78%, respectively). Overall, the average time to complete tasks ranged from 00:01:42 to 00:02:17 and the mean task completion rate ranged from 36 to 90% across all scenarios. The average time to complete a task for each scenario was: scenario 1 (N=3; 00:02:09), scenario 2 (N=3; 00:01:42), scenario 3 (N=4; 00:02:01), and scenario 4 (N=4; 00:02:17). Task completion rates ranged from 0 to 92%; task 1 (select locations of interest for early alerts) saw a 0% completion rate while task 5 (learn about invasive species issues) was successfully completed by most participants (92%).

3.4.3 User feedback

Results from continued interactions with website users following web evaluation show that I overlooked many tasks citizen scientists and volunteer coordinators need to accomplish online (Table 3-1). For example, both user groups need effective mechanisms to communicate with each other. Both audiences suggested email features be added to web mapping applications to facilitate communication about upcoming trainings, field data collection events, and data quality concerns. Below I provide examples of feedback I received.

Some feedback illustrated the effectiveness of online training and instruction:

"…your instructions on one page of your website were wonderful. Basically you gave an item by item description of how to do the particular task and had it right there on the page rather than via a link. It was just very helpful and very well done."

Other feedback suggested new features:

“I would like to be able to have my own boxes for things like how much time they spent monitoring or pulling weed[s]. That information is necessary so I earn in-kind matching money for my grants.”

“I wish that my volunteers had a way to query for their results (by map or list). I suppose it would be really valuable if I could query by recorder too. If I map Japanese hops … by presence and absence, I cannot tell which is which by the legend. I have had volunteers enter their lat/long incorrectly. I have caught these instances; however, they cannot simply go back to their survey and correct the error. They must delete the survey and begin again.”

“When [volunteers] are on the map and click the Add a Point icon, [can] they be directed to the project data form instead of just the standard one? As it is now, they have to enter lat/long coordinates for each point and really only use the map for viewing observations that have already been entered. Any chance we could provide you with a layer of our Natural Area boundaries that could be draped over the Google map so that volunteers could see [them]? Our GIS dept has tried to work with map server companies like Tele Atlas to submit data … and apparently it is not very easy.”

“…is there a built in listserv ability with CitSci.org? Will we be able to send out an email, newsletter or the like to all the members of our project?”

Additional feedback emphasized the need for simplicity:

“Right now, I'm wondering how I'm going to sell this … to my [volunteers]. They don't want to spend anytime online … If they do …, it had better be simple and fast or they simply won't do it and [I will] have lost a [volunteer].”

"[Last year] … it was old fashioned: Here's your piece of paper, scan it, email it, fax it, or send it… But what we'd like to do for next year is have an online database so that people can login [and enter their data]…. it needs to be *simple* [emphasis added by interviewee]… it needs to be for lack of a better word 'dumbed down.' I think it needs to [use] common names as much as possible. It needs to be [for] the layman."

When asked about data entry options, citizen scientists emphasized simplicity. Although excellent mobile systems are being developed (e.g., iPhone and Android mobile applications; see What's Invasive; http://whatsinvasive.com/), results suggest that mobile Personal Digital Assistant devices only add another level of complexity to an already steep learning curve ripe with usability challenges. I found that it is best to keep field data collections methods simple (e.g., use paper forms that directly match online forms), yet still offer web service protocols for remote connections with advanced users using mobile devices for real-time data entry. There will always be early adopters!

Finally, results indicate that volunteers are motivated more by increased levels of participation and rewards than by complex and hard to understand geospatial features. For example, participants in this study wanted to edit layers, change colors, and display filtered query results, yet they had difficulty accomplishing these tasks. When asked how they would perform such tasks, they could not articulate how the user interface would be implemented and did not realize the complexity of the feature they were asking for. Yet, simple features like reporting the total number of new sightings for each project or charting the most frequently reported species for each project went unnoticed, but were used regularly.

3.5 Discussion

My usability research objectives were to: (1) develop a citizen science website; (2) determine general perceptions; (3) discover potential problems; (4) improve the website; (5) discuss citizen science websites in relation to online PPGIS; (6) examine the role(s) websites may play in the citizen science research model; (7) discuss how citizen science research advances GIScience; and (8) offer guidelines to improve citizen-based web mapping applications. Although the web usability evaluation helped me examine and address objectives (2), (3), and (4), continued development of the citizen science website and additional interactions with citizen science volunteers and volunteer coordinators following the formal usability evaluation helped me gain insights related to objectives (5), (6), and (7). I now discuss results related to these latter objectives based on my experiences and conclude with guidelines for citizen-based web mapping applications (objective 8).

3.5.1 Citizen science websites in relation to online PPGIS

Public Participation Geographic Information Systems (PPGIS) applications focus on community interactions with GIS inextricably tied to the social and geographic context of system production and implementation (Craig et al. 2002). It consist of components and continuums whose outcomes are best understood by addressing the questions of who is informed, who is empowered, and who benefits from the technology (Laituri 2003). Citizen science projects focus on data collection by volunteers across broad geographical regions (Cooper et al. 2007) with the aim to inform and empower citizens and benefit scientists, land managers, and decision makers. Both approaches struggle to ensure high quality data. PPGIS applications struggle with spatial data accuracy and precision, whereas citizen science applications must control the accuracy and precision of spatial data, taxonomic data, attribute data, and temporal data. Initial PPGIS projects used industry-standard desktop applications to involve participants in GIS in lieu of online systems, claiming that users "see [online] applications as manipulative and frustrating because they have begun to see what a GIS *they can control* [emphasis added] can do" (Merrick 2003). Indeed, even today, most online PPGIS applications are still in no way "participatory" or transparent; they are clumsy, slow, and difficult to use systems that control content, layout, visualization, available analysis capabilities, and the methods by which users interact and participate (Merrick 2003).

Citizen science web mapping applications face these same limitations – but these limitations need not be technological. Instead, perhaps they stem from decisions grounded in the need for quality data, system usability, and intended audience. Although "canned" black box features are best to be avoided (Merrick 2003), volunteers require simple features that are within their cognitive access. They need to experience initial easy success. Once successful, they may explore complex questions in more depth and have patience for more complex user interface designs and features. More advanced users (project managers/volunteer coordinators) require systems *they can control*, *explore* (e.g., trialability; see Rogers 2003), and *customize* where appropriate.

Thus, although citizen science websites share many attributes with PPGIS applications, there are several important differences. Citizen science applications focus on scientific data collection of spatial and non-spatial information and require simplicity, data quality, and features for multiple user groups. Data quality of both spatial and non-spatial information is essential to their success. PPGIS applications also relate non-spatial information to spatial data. However, some PPGIS approaches place less attention on the quality (accuracy and precision) of their non-spatial attribute information (e.g., the descriptions of places of interest, photos of a location, etc.), seeing this information only as geospatially referenced posts. If a place description or location is incorrect, others may comment on the error and eventually change it using blogs or open wikis, but what are the ramifications of the temporary inaccuracies? If science-based decisions are to be made using citizen-contributed data, controlled and accurate data are essential for correct decisions and conclusions. Otherwise, scientific trust will never be achieved.

Finally, citizen science applications require communication mechanisms among project members and between members and volunteer coordinators. Some geographically focused PPGIS initiatives consist of contributors who may or may not know each other and that likely have little communication interaction (e.g., wikimapia.org), whereas others coordinate through "mapping parties" (Haklay and Weber 2008) similar to volunteer trainings. Regardless of the level of interaction, citizen science projects mandate effective communication among and between participants, coordinators, and scientists.

3.5.2 The role of websites in citizen science

Because citizen science activities blur with community based monitoring programs along a spectrum of no local participation to entirely local endeavors (Danielsen et al. 2009), more attention must be given to the role(s) websites play for their many user requirements (Table 3-1). Citizen scientist requirements, like those of most map users (Meng 2005), are not sufficiently understood. End user requirements are too often not considered (Meng 2004) and may go well beyond efficient map use (Table 3-1).

They may involve tasks that require non-map related features, social networking features (e.g., blogs, email list serves, and bulletin boards), in-person trainings using white-boards situated in traditional meeting rooms, online training resources, mobile field equipment devices that themselves pose significant usability challenges (Stevenson et al. 2003, Siek et al. 2005), and certifications and digital awards for accomplishments and contributions to foster motivation and participation (Longan 2005, 2007).

Given these tasks, websites may serve many citizen science roles, including Project Management, Feedback, Data Entry, Quality Control, Communication, Data Download, Analysis, Decision Support, Training, Logistics, and Technical Support roles (Table 3-1). Some map application developers and citizen science researchers envision exciting new roles for their applications that engage citizens in problem definition as scientists (Lakshminarayanan 2007); potentially improve volunteer scientific and spatial literacy (Brossard et al. 2005); and foster group user interaction with a GIS using hand gestures and dialogue (MacEachren et al. 2005). These roles may only be appropriate for certain audiences. Novel technology supporting these new roles will follow the technology adoption curve (Rogers 2003). However, they may further marginalize individual access to hardware, software, data, and cognition (Laituri 2003, Merrick 2003) at the expense of serving critical roles like generating high quality Volunteer-contributed Geospatial Information (VGI) slated for scientific research and decision support.

Although citizen science websites will undoubtedly be leveraged to serve these new roles, and although new web technology (e.g., web 2.0, CSS, Flex, etc.) now make the development of beautiful and complex user interfaces supporting these roles easy, careful consideration of the appropriateness of these roles and technology is needed.

Complex user interfaces allow for an increased amount of customization by the user that requires increased levels of understanding. If citizen scientists cannot understand features, they become more frustrated than they would without the features and disengage. A “less is more” approach focused on user tasks may better meet their needs (Jones et al. 2009).

3.5.3 How citizen science research advances GIScience

Citizen science research is advancing GIScience in many ways (Table 3-3). It is expanding the science questions asked by GIScience to integrate questions of social science with questions of the scientific disciplines citizen participants are involved with. Traditional GIScience questions of how to represent geographic phenomena digitally, how to visualize accuracy, how to render infinite amounts of data while maintaining flat performance, etc., remain, but there are now additional questions. How do web applications ensure data quality, communicate uncertainty and error, simultaneously allow for dual-purpose contributions (e.g., those fostering motivation through wiki-like photo uploads and posts and those designed for rigorous scientific data collection and dissemination), and allow for public participation in scientific inquiry itself - a tasks GIS is touted to help improve through enhanced visual displays.

Table 3-3. How citizen science research advances GIScience.

GIScience Question*	Citizen Science Contribution
Representation	Formulate best practices for representing species locations on the Earth’s surface from a citizen scientist perspective. (points)
Communication	Discover ways to better communicate the relationship between the representation (species location) and the user. (use of a plus (+) to indicate more locations can be seen upon further zoom)
Visualization (Display)	How do methods of display affect the interpretation of geographic data? How can the science of cartography be extended to take advantage of the power of the digital environment? What basic properties of display determine its success? (use cartographic symbols meaningful to citizen scientists such as flags for surveys)
Relationship between the	How do people, rather than machines, think about the world? How

representation and the user	can computer representations be made more like the ways people think? How do people reason with, learn about, and communicate their geographical world? (Volunteers think they found a species; they do not think that they 'made a visit to an area and detected a species occurrence')
Data Quality	How to assess the accuracy and precision of a representation? How to measure its accuracy? How to measure what's missing, its uncertainty? How to express these measures in ways that are meaningful to the user? How to visualize them?
Data Storage	How to best store geospatial information? (Use Cached tiles generated on the fly as needed to allow users to customize their own cartographic representation)
Data models/Structures	Store/retrieve representation efficiently (Use cached data not federated searches – see Graham et al. (2009))

* Adapted from Goodchild (1997).

Citizen science research forces GIScience to consider volunteer perspectives. Decisions need to be made regarding display of features that either require certain permissions or that require certain data to exist (e.g., display the download treatments button only if there are treatment data; only show 'edit project information' links to logged in project managers). Decisions also need to be made about who sees which features; CitSci.org now provides online species distribution modeling capabilities. Results from this study show that volunteers still do not use map applications effectively. Without the fundamentals of spatial literacy, how then will they be able to create more sophisticated outputs such as predictive models? Do applications need to hide these capabilities from volunteers and only expose them to those trained in modeling?

Furthermore, problems identified by this study represent only the surface of deeper problems. For example, volunteers view maps as the gospel; they often lack spatial literacy and do not understand methods used to create maps. This leads to misinterpretation. They do not understand that when a map of an invasive species does not show locations in their state, it does not mean that the species is not located in their state. Instead, it only implies that no data have yet been contributed for the species in their state. Unfortunately, our website does not visualize these concepts yet; future web mapping applications need to better communicate and visualize them. Citizen science research advances GIScience by asking these questions and requiring these challenging new features.

3.6 Conclusions

Citizen science research offers a pragmatic counter-balance to geospatial research that together advances and transforms GIScience by identifying use cases across a wide spectrum of activities - from spatial data collection to storage to dissemination to mapping to analysis to retrieval. One of the things that emerged from this study is that it is important to identify use cases that users want to do and that they know they can do using web mapping applications. The typical citizen scientist traditionally arrives at a website on the recommendation of their volunteer coordinator or by word of mouth. They bring with them preconceived notions of what is possible (and what is not possible), even if more things might be able to be accomplished. For example, participants arriving with knowledge of GIS might have an easier time understanding and completing map tasks whereas those unfamiliar with GIS might have more difficulty. It is important to communicate to users the purposes of a website. These purposes may span the entire citizen-based data collection, entry, and analysis process. Citizen science research, then, forces GIScience to look broadly at each of the phases in this process and find ways to ensure usability and data quality at each step. Our research highlighted the need to better understand user needs and use cases; more clearly communicate the purposes of citizen science websites; and create features related to these tasks that are easy to use. Although integration of GIS into K-12 education promises to transform the spatial literacy of the volunteer workforce, until then, volunteers from grassroots citizen science organizations will continue to come to the table with less expertise and formal training in contributing, using, and obtaining geospatial data (Elwood 2008a) and the limited technological sophistication of these volunteers will remain a reality. Citizen science usability research promises to advance and transform GIScience to better accommodate this reality.

3.6.1 Guidelines for web mapping applications

In this study, I developed a citizen science website with an interdisciplinary research team that allowed me to explore web mapping application problems, roles, and features. Given these experiences, I offer the following guidelines to improve citizen-based web mapping applications.

- Communicate the purposes of the website and the roles they support
- Build features for both project managers and volunteers and clearly separate them
- Develop customizable data entry forms that ensure data quality yet remain simple
- Create simple map applications that visualize accuracy, precision, and uncertainty
- Add fun features to foster motivation and continued involvement
- Incorporate spatial literacy learning into the use of the website
- Add information to help with map interpretation (improve cognitive access)
- Provide a cursory understanding of spatial concepts through online help
- Allow users to formulate their own research questions and answer them (analysis)
- Add features for communication between volunteers and volunteer coordinators
- Research and develop features to map attributes and visualize their accuracy

- Create transparent features that are used and explored by volunteers and volunteer coordinators; avoid limited black box systems (Merrick 2003).
- Allow users to experiment, to "fail," and to play around by creating a test site.
- Only offer PDA's to advanced users, early adopters, and young volunteers
- Make use of web skins to target specific use cases and tasks and simple searches
- Provide rich content even in the absence of user contributed web content
- Clearly distinguish social networking (blogging) content from science content
- Assign volunteer coordinators a data quality role and create features for data review
- Communicate scientific rigor where appropriate
- Incorporate communication features to augment face to face communication through all project phases (e.g., training; data collection, entry, dissemination, and analysis; and communication from scientists back to volunteers)
- Avoid advertisements and animations altogether or, if required, keep them off data entry forms, profile pages, the home page, and map pages (Nivala et al. 2008)
- Create online questionnaire creation and delivery tools similar to Survey Monkey© to better integrate user feedback and participation

This study illustrated the need to: (1) integrate usability and user feedback into web mapping application design, and (2) create features that target user needs, support the many roles of various user groups, and control data quality. We must integrate usability and user feedback into web mapping application design because user requirements are demanding and often unknown; websites support challenging new roles;

user tasks and the user environment are unfamiliar to developers; and applications are used by large numbers of diverse users (Nivala et al. 2007). The ways to identify end-user requirements vary along a continuum ranging from end-user involvement prior to product design to no end-user involvement whereby developers assume they "…already [know] what to do, and how, so that … end-users … [will] like it" (Nivala et al. 2007). The latter approach assumes that features are based on the expert knowledge and 'know-how' of developers. Involving volunteers in the design of the very websites they end up using will improve websites and embodies the very essence of participatory citizen science. Future research must focus on better ways to identify user requirements throughout the design life-cycle. Additionally, determining how to address key issues related to understanding the geospatial data being used and created is critical and will fuel new GIScience research and applications.

Thus, this study discovered that volunteers want to communicate with each other, collect, contribute, and 'publish' their data online, be given easy to use and customized data entry forms created by their volunteer coordinators, use websites targeted to their specific tasks, create bar charts, pie charts, and compare locations treated for invasive species with one method to locations treated with another (e.g., perform analyses; unpublished data), and be real scientists themselves. They also want to be sent scientific outcomes of their efforts. Websites must support these user-suggested features and new roles. They must discover ways to ensure data quality, make these types of analyses easy to perform, and motivate participants. Future research must assess the affects of usability and website design on data quality, volunteer retention rates, motivation, and future website use. Does website satisfaction translate into greater motivation for continued website use and volunteering that, in turn, yield greater volunteer retention? How does citizen science linked to PPGIS further the practice of GIScience and inform a citizenry increasingly dependent upon such products to understand and participate in the complex and changing world of the 21st Century?

CHAPTER 4 TEACHING CITIZEN SCIENCE SKILLS ONLINE

4.1 Abstract

Citizen science programs are emerging as an efficient way to increase data collection and help monitor invasive species. Effective invasive species monitoring requires rigid data quality assurances if expensive control efforts are to be guided by volunteer data. To achieve quality, effective online training is needed to improve field skills and reach large numbers of remote sentinel volunteers critical to early detection and rapid response. I evaluated the effectiveness of online static and multimedia tutorials to teach citizen science volunteers (n=54) how to identify invasive plants; establish monitoring plots; measure percent cover; and use Global Positioning System units. Participants trained using static and multimedia tutorials provided less (p<0.001) correct species identifications (63% and 67%) than professionals (83%) across all species, but did not differ (p=0.125) between each other. However, their ability to identify conspicuous species was comparable to professionals. The variability in percent cover estimates between static (+/-13%) and multimedia (+/-9%) participants did not differ (p=0.077, p=0.857) from those of professionals (+/-10%); the tutorial approach used did not influence (p=0.071) the ability of participants to estimate percent plant cover. Trained

volunteers struggled with plot setup and GPS skills. Overall, the online approach used did not influence conferred field skills and abilities. Traditional or multimedia online training augmented with more rigorous, repeated, and hands-on training in specialized skills required for more difficult tasks will improve volunteer abilities, data quality, and overall program effectiveness.

4.2 Introduction

Citizen science initiatives are emerging as an effective approach to engage the public in science (Krasny and Bonney 2005, Lee et al. 2006, Schnoor 2007, Cohn 2008, Couvet et al. 2008, Silvertown 2009), create environmental collaborative monitoring networks (Gouveia and Fonseca 2008), increase data collection across broad geographic regions and long time frames (Cooper et al. 2007), and address complex environmental issues (Peterjohn and Sauer 1997). For example, citizen science programs now tackle issues as diverse as macro-invertebrate monitoring (Fore et al. 2001, Nerbonne and Nelson 2008, Lovell et al. 2009), bird monitoring (Lepage and Francis 2002, Lepczyk 2005, Greenwood 2007), marine invasive species monitoring (Delaney et al. 2008), climate change (Cohn 2008), conservation biology (Galloway et al. 2006, Losey et al. 2007), biodiversity monitoring (Danielsen et al. 2005a, Couvet et al. 2008), population ecology (Rosenberg et al. 1999), water quality monitoring (Wilderman et al. 2004), and terrestrial invasive species monitoring (Brown et al. 2001), among others (Cornell Lab of Ornithology 2008). Although citizen science offers many benefits (Cooper et al. 2007, Cohn 2008) and motivations for participation vary (Van Den Berg et al. 2009), involving the public in citizen science and empowering them to perform tasks on their own creates tensions over data quality, group goals, and project outcomes (Nerbonne and Nelson

2008). In the context of monitoring an invasive species, land mangers require rigid data quality assurances given the costs associated with control and mitigation efforts. In this context, geospatial invasive species data collected by volunteers represent information judged objectively based on shared and enforced standards among professionals insisting on credibility as defined by taxonomic, position, and attribute accuracy rather than credibility as defined by perceived trustworthiness and believability (Flanagin and Metzger 2008). Therefore, to be viewed credible and useful for decision making, invasive species monitoring programs that use volunteers must demonstrate the ability to collect large volumes of quality data; the urgent need to prioritize expensive control efforts demands a large amount of high quality data that may only be realized through a combination of data collected by professionals and volunteers alike.

Obtaining quality data from trained volunteers is possible (Brandon et al. 2003, Galloway et al. 2006) and is positively correlated with the degree to which citizen science groups perform tasks on their own (Nerbonne and Nelson 2008). To achieve widespread high quality data for terrestrial invasive plant monitoring applications, effective and training that capitalizes on the self-directed nature of adult learners (Kerka 2002, Merriam et al. 2007) becomes paramount. Training must develop volunteers with the knowledge, skills, abilities, and motivation to correctly identify species, establish monitoring plots, measure attributes, record observations, and submit data. To capitalize on the acclaimed benefit of increased numbers of ‘citizen sensors’ (Goodchild 2007), invasive species trainings must also reach large numbers of remote sentinel volunteers able to realize early detection and rapid response goals due to their dispersed geographic locations. However, little is known about the effectiveness of different online tutorial approaches to teach adult citizen science volunteers the skills and abilities necessary to map and monitor invasive species populations. Thus, I evaluated the effectiveness of online static and multimedia tutorials to teach citizen science volunteers how to identify invasive plants; measure percent cover, use a Global Positioning System (GPS) unit, and establish monitoring plots. I focused on web-based training approaches because online resources can reach more remote volunteers capable of detecting isolated invasive species populations and because hands–on trainings delivered by volunteer coordinators or scientific staff are often limited in their ability to reach geographically dispersed volunteers.

4.3 Online invasive species education

Invasive species threaten the integrity of natural ecosystems, decrease hotspots of native biodiversity, and cost the U.S. billions in control and restoration efforts annually (Stohlgren et al. 1999, Mack et al. 2000, Lodge and Shrader-Frechette 2003, Pimentel et al. 2005). Citizen-based extension efforts such as the Master Naturalist (Savanick and Blair 2005) and Master Gardener (Moravec 2006) programs are broadening in scope to encompass environmental sustainability and conservation principles (Moravec 2006, Van Den Berg et al. 2009). Many citizen-based programs are collecting data on invasive species issues and may fill important data gaps (Crall et al. 2009). As more volunteers become engaged, more effective and widespread training is required.

Advances in information and communication technologies offer new opportunities for citizen participation in environmental monitoring (Gouveia and Fonseca 2008) and may improve teaching and learning (Leask 2001) in traditional face to face (Selinger 2001), distance (DiBiase 2000), and blended (Thorne 2003, Balram and

Dragicevic 2008) learning environments. The continued development and application of information and communication technologies to invasive species science and to improved online training materials required for successful volunteer training offers hope to engage the public in this important environmental issue. Experiences integrating citizen science with invasive species research thus far (Brown et al. 2001, Delaney et al. 2008, Crall et al. 2009) illustrate several barriers to success, including the challenges, difficulties, and costs associated with adult learning and technology adoption by marginalized volunteers; web-based tutorial development; and data quality.

4.3.1 Adult learning and technology adoption by adult volunteers

Adults are lifelong learners who continuously learn in formal, informal, and non formal settings (Merriam et al. 2007) and who gain knowledge through many faculties, including mind, body, emotion, and spirit (Kimmerer 2003). Andagogy, the “art and science of helping adults learn” (Knowles 1980, p. 43), assumes that adults are self-directed learners, accumulate rich resources for learning through life experiences, become ready for learning as their social roles develop, are problem centered, use knowledge in immediate applications, and are primarily motivated by internal factors (Kerka 2002, Merriam et al. 2007, Van Den Berg et al. 2009). For adult learners seeking knowledge, skills, and abilities applied to invasive species issues, new technologies such as Global Positioning Systems that promise improved data quality but require new skills become simultaneous opportunities and barriers. To reap the potential benefits of these new technologies, volunteers are faced with learning and adopting them. For invasive species adult education, we need to understand what approaches best teach new technological and subject matter-specific skills, while also accounting for the many factors affecting new technology adoption by potentially marginalized volunteers. There are many challenges associated with the diffusion and adoption of innovations (Rogers 2003), especially those geared towards improving data quality by volunteers who possess domain-specific knowledge but who may lack technological sophistication. Well designed web tutorials must account for these challenges, individual motivations, social influences (Longan 2007), and life experiences to retain and motivate volunteers over time (Dirkx and Prenger 1997).

4.3.2 Web-based tutorial development

Formal distance education is "…planned learning that normally occurs in a different place from teaching…" and requires special course design and instruction techniques, electronic and technological communication methods, and organizational arrangements (Moore 1996). Web-based multi-media tutorials have been shown to provide effective instruction, especially when used in blended learning environments (Zerger et al. 2002). For example, Mackey and Ho (2008) found that students respond favorably to usability factors and that multimedia instruction may enhance course lectures and readings and improve perceived learning. However, the development of Web-based multi-media tutorials is a complex endeavor. Park and Hannafin (1993) offer 20 empirically based guidelines for the design of interactive multimedia based on early psychological, technological, and pedagogical foundations. These foundations led to the cognitive load theory and the cognitive theory of multimedia learning, which claim that there are separate processing systems for image and textual information and that learning is the process by which learners establish links between these two representations (Mayer 2001, 2005). Effective online instructional design must account for these representations and the different cultural backgrounds (Bentley et al. 2005, Rogers et al. 2007) and learning styles (Mestre 2006) of those engaged in learning.

However, most of these comparisons and guidelines focus on knowledge gains using various tutorial approaches in formal educational settings. Little is known about the effectiveness of online tutorial approaches to teach the skills necessary for volunteer invasive species monitoring. Additionally, most comparisons evaluate online tutorials from a pre/post knowledge gain perspective; the effectiveness of tutorials from a data collection skills and abilities perspective is not well understood. Here, I focus on evaluating the effectiveness of different tutorials to develop volunteers proficient in species identification, plot measurement (e.g., estimating percent plant cover), Global Positioning Systems use, and plot setup skills.

4.3.3 Data quality

Several studies have compared data quality of volunteers to professionals, including comparisons for bird surveys (McLaren and Cadman 1999), forest vegetation surveys (Brandon et al. 2003), invertebrate biodiversity surveys (Lovell et al. 2009), benthic macro-invertebrates (Penrose and Call 1995, Fore et al. 2001), and invasive plant monitoring (Brown et al. 2001). For biodiversity surveys, volunteers collect comparable data to professionals (Fore et al. 2001, Lovell et al. 2009), especially when using more constrained and less subjective methods (Lovell et al. 2009). Generally, volunteers collect comparable data for easy to recognize species, but cryptic or rare species are difficult to identify (Penrose and Call 1995, Lovell et al. 2009). Despite these comparisons, little research has compared volunteer abilities against professionals when trained using different training approaches. Thus, my objectives were to: (1) evaluate the effectiveness of online static and multimedia tutorials to teach citizen science volunteers how to identify invasive plants; measure percent cover; use Global Positioning System units, and establish monitoring plots; and (2) compare species identification and percent cover measurement abilities of volunteers trained with static and multimedia tutorials to those of professionals.

4.4 Methods

This research was part of a larger experimental effort to evaluate the effectiveness of a national citizen science program (Crall et al. 2010). Here, I report methods and results related only to static and multimedia online training approaches. I recruited volunteers and professional botanists from the Madison, Wisconsin and Fort Collins, Colorado regions to evaluate the ability of static and multimedia tutorials to train citizen scientists how to identify invasive species, how to measure percent plant cover, how to use a GPS unit, and how to set up a standardized monitoring plot. I obtained basic demographic information and willingness to participate using an online questionnaire and randomly assigned those interested in online trainings to either a static or multimedia tutorial group.

I conducted two-day training events; one at the University of Wisconsin-Madison Arboretum (May, 2009) and the other at the Colorado State University Environmental Learning Center (July, 2009). The online training sessions occurred one week prior to each field event listed above. Static tutorial participants received an email link to each of five traditional HTML tutorials, while multimedia participants received links to five multimedia tutorials. I created tutorials with identical content except for the species covered (specific to each state; Table 1). Tutorials varied only in their communication approach. Static tutorials included text and images only whereas multimedia tutorials included text, images, flash animations, and audio voice-overs. Participates viewed tutorials as often as they wished throughout one week prior to field events. Following each session, participants arrived at the event; learned of the day's agenda, goals, and objectives; and formed groups. Participants performed tasks at each of four stations. At stations 1 (plot measurement) and 2 (species identification), participant abilities were compared against those of professionals, while at stations 3 (Global Positioning Systems use) and 4 (plot setup) only static and multimedia participant abilities were compared.

4.4.1 Participant recruitment and characteristics

I recruited 103 volunteers interested in online trainings, 54 in Wisconsin and 49 in Colorado. Of those interested, 20 participated in the online training sessions and field events in Wisconsin and 34 participated in Colorado (n=54) resulting in participation response rates of 37% and 69%. I mailed control group surveys to a total of 201 recipients (153 in Wisconsin and 48 in Colorado) and received 75 and 35 returned questionnaires yielding response rates of 49% and 73% (n=110). My goal was to ensure that participants were comparable to those not participating. Other studies show that learning gains, for example, may be biased because those who participate already possess a high degree of science literacy or subject matter expertise (Brossard et al. 2005). Therefore, I conducted chi-square comparisons to check for differences in survey factors between Wisconsin, Colorado, participant, and control populations. Comparisons between Wisconsin and Colorado participants showed no significant (p<0.01) differences in gender (χ^2=0.2; p=0.692), education, (χ^2=3.4; p=0.636), profession (χ^2=6.4; p=0.783), income (χ^2=1.1; p=0.780), and age (χ^2=13.6; p=0.018). Therefore, I combined Wisconsin and Colorado online participants for all subsequent analyses. Participant ages ranged from 18-24 to 65-75 and were 28% male and 72% female.

4.4.2 Field stations

At station 1, I evaluated plot measurement abilities. I used the United States Forest Service (USFS) Forest Inventory and Analysis plot to assess participant abilities to estimate percent cover for six herbaceous and woody species in five replicate FIA plots in each state. Participants recorded presence/absence and percent cover as defined by the FIA protocol for each plot. We used one-way Analysis of Variance (ANOVA) procedures to compare deviations from the mean for subplot (herbaceous) and whole plot (woody) percent cover estimate performance for each group by species.

I evaluated participant and professional species identification abilities for six invasive species of concern in each state at station 2. State weed coordinators helped select test species and categorize them as either conspicuous (easy to identify) or inconspicuous (difficult to identify) based on expert opinion (Table 4-1). I created five replicate search areas (~1 m x 100 m) along trails. Prior to sampling, I selected 25 individual species in each search area (n=125), including both test species and non-test species. A professional botanist knowledgeable of the species at each event in each state identified all 125 flagged individuals, providing baseline master species lists. I compared participant identifications to these master lists to determine false positive and false negative identifications for each participant. I used one-way Analysis of Variance comparisons to compare percent correct, false positive and false negative identifications among groups.

Table 4-1. Species used for station 2 (species identification) exercises.

Species: Common Name (*Scientific Name*)	Category*	Description
Wisconsin		
Garlic Mustard (*Alliaria petiolata*)	I	Forb
Dames Rocket (*Hesperis matronalis*)	I	Forb
Common buckthorn (*Rhamnus cathartica*)	I	Shrub/tree
Asian bittersweet (*Celastrus orbiculatus*)	II	Vine
Honeysuckle (*Lonicera spp.*)	II	Shrub
Glossy buckthorn (*Frangula alnus*)	II	Shrub/tree
Colorado		
Leafy spurge (*Euphorbia esula*)	I	Forb
Dalmation toadflax (*Linaria dalmatica*)	I	Forb
Russian olive (*Elaeagnus angustifolia*)	I	Shrub/tree
Musk thistle (*Carduus nutans*)	II	Forb
Houndstongue (*Cynoglossum officinale*)	II	Forb
Hoary cress (*Cardaria draba*)	II	Forb

* Species were classified as either easy to identify (I), difficult to identify (II).

At station 3, I evaluated the ability of participants to use a Global Positioning System unit to mark waypoints and navigate to a saved location. I established ten locations and pre-recorded their coordinates using a Trimble Global Positioning System unit (accuracy +/- 1 m). Each stake was located at a minimum distance of 50 m from each other. Participants recorded waypoints (i.e., datum, zone, UTM easting, UTM northing, accuracy) for each stake and recorded the identity of the stake they navigated to using a waypoint labeled "TEST" pre-set in their Global Positioning System unit. A station evaluator provided instructions to participants and took notes of any problems. I calculated a Global Positioning System ability score for each participant by summing correct datum, zone, and navigation responses with waypoints correctly taken within 15m buffers of each stake determined using ArcGIS 9.3. I compared the Global Positioning Systems ability scores of static and multimedia participants using two-sample t-tests.

At station 4 I evaluated the ability of participants to establish a USFS Forest Inventory and Analysis plot (Figure 4-1) using a kit I provided containing a compass, a 10 m measuring tape, 12 stakes, and a 1 m^2 collapsible quadrat. Each participant set up an

Forest Inventory and Analysis plot following the protocol taught online. A station monitor graded each participant by checking radius distance, compass azimuths, quadrat distance from plot center, and quadrat placement. I compared the percent correct set up score for static and multimedia participants using two-sample t-tests.

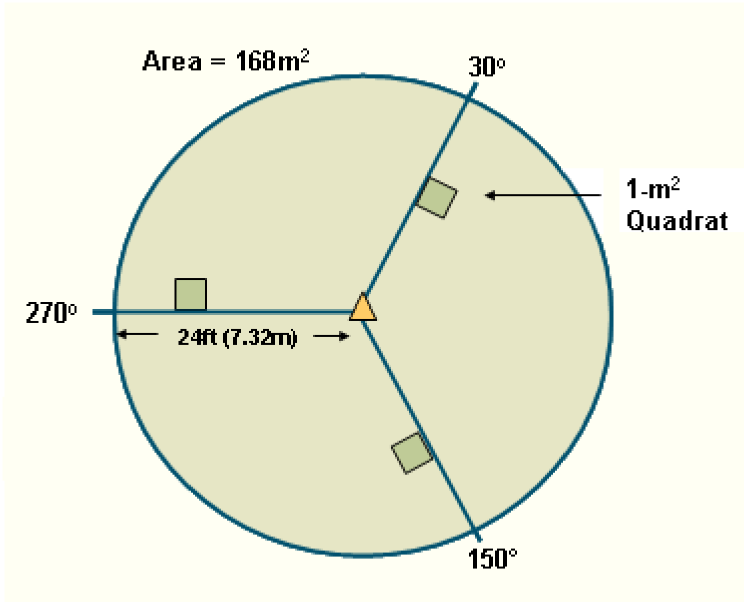

Figure 4-1. USFS Forest, Inventory, and Analysis plot used for Station 1 exercises.

4.5 Results

4.5.1 Station 1 – Plot measurement

When comparing the variability of percent plant cover estimates of those trained with static tutorials, those trained with multimedia tutorials, and those of professionals, skills slightly differed between groups (F=3.2; p=0.04). However, comparisons between groups showed no differences; percent cover estimates between professionals (+/-9%) and static participants (+/-10%) did not differ (p=0.86). Similarly, percent cover estimate variability between professionals (+/-9%) and multimedia participants (+/-13%) did not differ significantly (p=0.08). The tutorial approach used only marginally influenced

(p=0.07) the percent cover estimates between static and multimedia participants (Figure 1). For whole plot estimates (the tree/shrub/vine species including Russian olive, common buckthorn, glossy buckthorn, honeysuckle, and Asian bittersweet), these trends continued; there were no significant differences (F=1.9; p=0.15) between groups in whole plot percent cover estimates.

4.5.2 Station 2 – Species identification

The level of training a participant received influenced their ability to correctly identify invasive species (F=34.2; p<0.001). Participants that were trained using static tutorials provided fewer (p<0.001) correct species identifications (64%) than professionals (75%) across all species (Figure 4-2). Similarly, those trained with multimedia tutorials identified fewer (p<0.001) species correctly (68%) than did professionals (75%). However, participants that were trained with static tutorials and multimedia tutorials showed no difference (p=0.17) in their identification abilities (Figure 4-2). Incorrect identifications by static participants, multimedia participants, and professionals differed for both false positive (F=17.9; p<0.001) and false negative (F=24.7; p<0.001) identifications. Professionals exhibited fewer (p<0.001) false negative identifications (14%) than those trained with static (22%) and multimedia (15%) tutorials. Professionals reported fewer false positive identifications (11%) than either static (14%; p=0.02) or multimedia (18%; p<0.001) participants. Volunteers trained with static tutorials incorrectly reported more (p<0.001) species occurrences they were trained to identify (22% false negatives) that those trained with multimedia tutorials (15%) and fewer (p=0.02) false positives (14%) than multimedia participants (18%).

Species identification ability differences between groups (static, multimedia, and professionals) varied by species (F=154.4; p<0.001). Species categorized as difficult to identify (Table 4-1) resulted in fewer correct identifications by static and multimedia participants than professionals. In Wisconsin, glossy buckthorn, common buckthorn, and Asian bittersweet proved to be the most difficult to identify, whereas garlic mustard and honeysuckle were more easily identified by all three groups. In Colorado, leafy spurge, musk thistle, and Dalmation toadflax were more easily identified, whereas houndstongue and hoary cress were challenging. Professionals consistently exhibited greater correct identifications and had less false positive and false negative identifications for all species evaluated. However, professionals struggled with glossy buckthorn identification (15%) and hoary cress identification (70%).

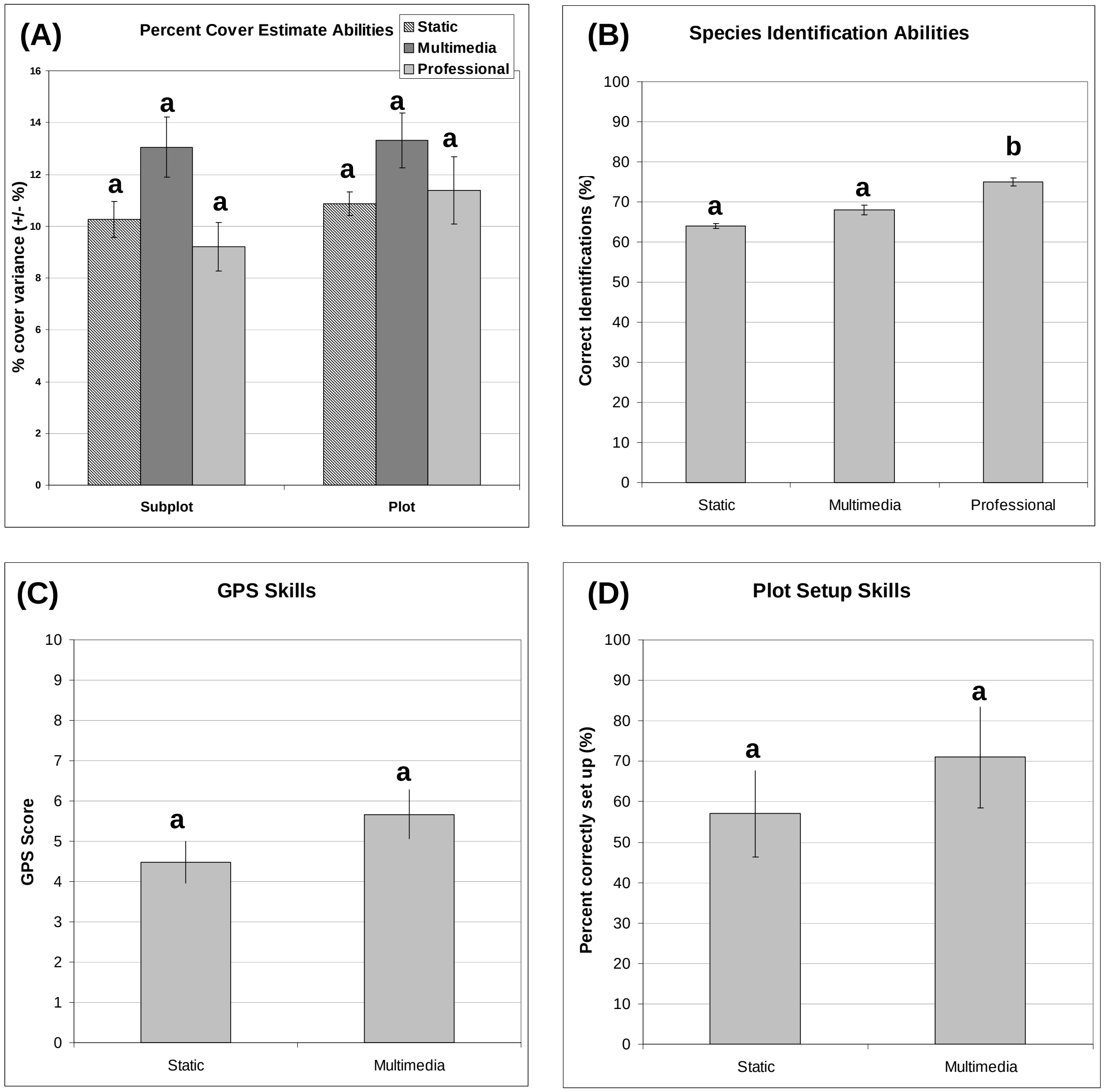

Figure 4-2. Participant skills following training for static and multimedia online trainings for (A) subplot and whole plot percent cover estimate variability - Station 1, (B) species identification abilities – Station 2, (C) GPS skills – Station 3, and (D) plot setup skills – Station 4. Error bars are standard errors. Means with different letter are significantly different ($p<0.05$) when comparing static, multimedia, and professional groups for each response variable measured.

4.5.3 Station 3 – GPS skills

The Global Positioning System skills of participants as measured by the ability of participants to properly record the zone, datum, and waypoints within a 15 m buffer of known locations along with their ability to navigate to a saved location did not differ (*t*=1.5, *p*=0.16) between static and multimedia participants (Figure 4-2). The mean Global Positioning System score for static participants was 4.5 (*SE*=0.5), while the mean score for multimedia participants was 5.7 (*SE*=0.6). Specific Global Positioning System skills learned were low: 43% of static and 53% of multimedia participants correctly recorded the UTM zone, 57% of static and 80% of multimedia participants correctly recorded the datum, 70% of static and 80% of multimedia participants correctly navigated to their assigned location, and 63% of static and 74% of multimedia participants correctly recorded waypoints within 15 m of known locations.

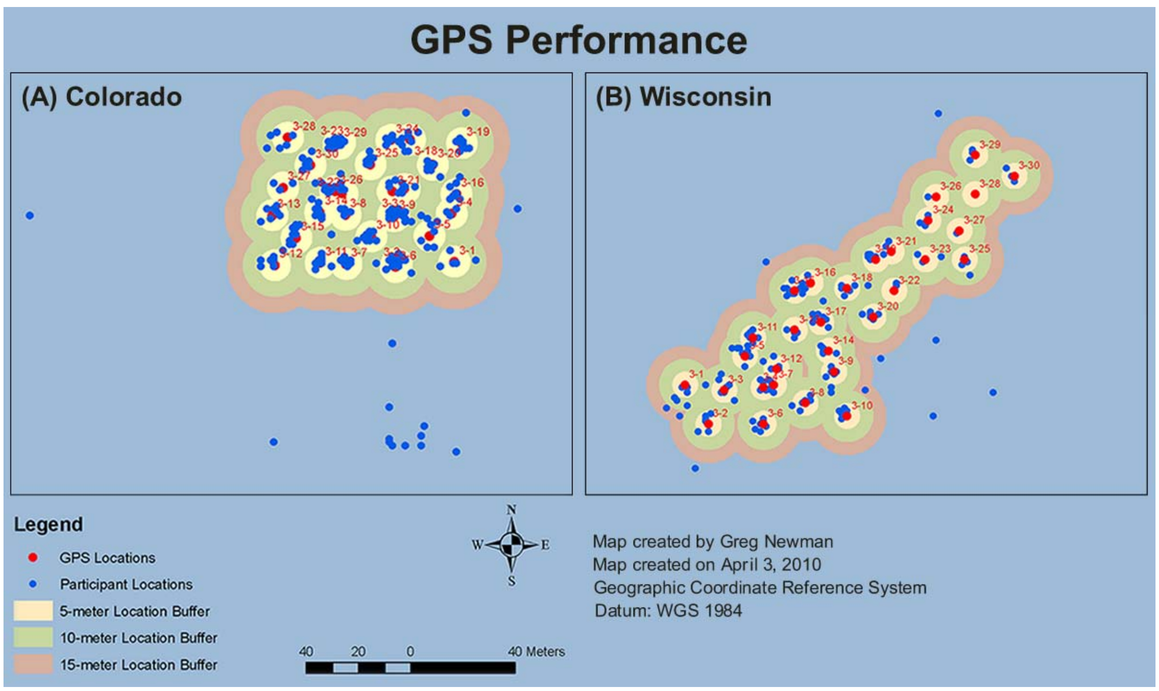

Figure 4-3. Spatial visualization of the Global Positioning System (GPS) locations (red) and locations recorded by participants (blue) in both Colorado (A) and Wisconsin (B) study sites, showing 5, 10, and 15 meter buffers surrounding the GPS locations. The source of these data included volunteer participants and research staff tasks with establishing the known locations.

4.5.4 Station 4 – Plot setup

Station 4 evaluated the ability of participants to establish USFS Forest Inventory and Analysis plots. Results indicate no differences (*t*=0.9, *p*=0.38) between static (57%

correct) and multimedia (71% correct) participants (Figure 4-2). Plot set up errors consisted of incorrect radius distance measurements, subplot placements, azimuths, and various compass errors. Participants in Wisconsin showed greater difficulty in plot set up skills than those in Colorado and all participants continually asked about compass use.

4.6 Discussion

My results indicate that the mode used to deliver online tutorials does not significantly influence the resultant skills learned by citizen scientists interested in invasive species monitoring. The differences between the static and multimedia tutorials I developed focused on the addition of audio and video animations for the multimedia tutorials. I aimed to keep the content identical between the static and multimedia versions and only vary the mode of delivery. The duplication of spoken material with written material has been shown to decrease retention regardless of whether written material appears statically or sequentially in animated fashion (Jamet and Le Bohec 2007). The multimedia tutorials we developed and evaluated duplicated spoken and written material sequentially in animated fashion and also included some animated visual material. The cognitive load theory (Sweller 1999) and the theory of multimedia learning (Mayer 2001, 2005) predict that the visual channel in our multimedia approach will overload participants and lead to decreased learning. However, I saw no difference between multimedia and static tutorials in terms of knowledge transfer to applied field skills. I evaluated the multimedia approach using animated text and images in concert with audio given conjecture that such an approach may improve motivation and enthusiasm for future volunteerism. However, when comparing self-reported level of motivation on a 1 to 5 Likert scale for each tutorial section after the training events, the multimedia GPS tutorial elicited significantly (t=2.5; p=0.02) less (M=3.5; SD=0.8) participant motivation than did the static tutorial (M=4.0; SD=0.6). Other tutorials for species identification and monitoring protocols were not significantly ($p>0.05$) different in their ability to elicit future motivation for these tasks between static and multimedia approaches. Additionally, multimedia participants self-reported a lower level of comfort in identifying invasive plant species (M=2.9; SD=0.8) than did static participants (M=3.4; SD=1.0).

Attention cueing, the addition of non-content information (e.g., coloring, arrows) that directs attention to those aspects that are important in an animation or instruction, may improve learning from multimedia and decrease cognitive load (de Koning et al. 2007). However, I employed cueing to point out key identification characteristics for species taught in our multimedia tutorials and found that those trained with the multimedia tutorials performed no better overall in field skills than those trained using static tutorials. Advance organizers (introductory passages designed to serve as an organizing or anchoring focus for the material and to relate it to existing cognitive structures) have been shown to improve retention of material (Ausubel 1960) and images and visualizations may increase the effectiveness of science communication (Trumbo 2000). I used these techniques in both static and multimedia tutorials, introducing topics generally and providing images for context. I also used headings to organize material and hopefully improve recall (Krug et al. 1989). Nevertheless, challenging tasks such as species identification and Global Positioning Systems use remain difficult for volunteer knowledge transfer to field skills when this information is obtained through online tutorials.

Although static and multimedia participants had access to field guides and training materials during sampling similar to circumstances described in Delaney (2008), our results for correct species identification abilities (63% for static participants and 67% for multimedia participants) were lower for terrestrial invasive plants than those found for third-grade (80%) and seventh grade (95%) participants tasked with discriminating between native and invasive crab species (Delaney et al. 2008). In my case, the abilities of participants trained online to identify species using both static and multimedia tutorials were significantly lower than professionals. These results contradict studies assessing the abilities of volunteers trained in person compared to professionals to identify terrestrial invasive plant species (Brown et al. 2001) and perform biodiversity sampling for terrestrial invertebrates (Lovell et al. 2009), indicating important differences in in-person and online training approaches. Thus, although prior research indicates that trained volunteers can provide valid high quality data (Penrose and Call 1995, Brown et al. 2001, Fore et al. 2001, Brandon et al. 2003, Delaney et al. 2008, Nerbonne and Nelson 2008, Lovell et al. 2009), my results caution that these trends may not hold true for volunteers trained online using either static or multimedia approaches. Perhaps most valuable were comments I received at the end of the entire event from participants that solidify our results suggesting few differences if any in tutorial approach and field abilities and the overall limited effectiveness of online tutorials:

"I think it is very difficult to do this training online. I need to see in 3D what I am supposed to be learning (i.e. the invasive plants and the GPS)."

“I think the hardest section for me was the species identification because of the limited amount of visual aids to show in greater detail the differences between some species.”

“The identification part was okay, but I'm not sure if I could identify the plants correctly. It would have been nice to have some sort of ‘test’ … to check your ability to [identify] the plant and… give you the opportunity to study some finer features of the plants if you were incorrect.”

Volunteers in environmental programs participate for educational, volunteerism, and leisure oriented motivations and are specifically motivated to seek knowledge, participate in learning activities, engage in social interactions, understand ecosystems, express one’s values, enjoy the outdoors, and help the environment (Van Den Berg et al. 2009). Participant motivation for scientific data collection may be less when the data collection are for impersonal risks (e.g., risks threatening the environment) than for issues directly affecting the participants themselves (Kahlor et al. 2006). Perceived social pressure to be informed about, and engaged in, activities addressing invasive species may play an important role and the establishment of online social networks and incentives for data quantity and quality may also improve volunteer motivation and retention (Longan 2007). Ryan et al. (2001) found that social factors and sound project organization are significant predictors of future volunteer commitment. My results indicate that the mode of communication used for tutorials and trainings may not be all that useful to foster future motivation and participation; tutorials are best served to develop skills rather than motivate. From a volunteer coordinator perspective, my results indicate that easier to create static tutorials may be as effective as more sophisticated multimedia approaches and that online tutorials in general ought to be reserved for more conceptual topics such as why invasive species are a problem rather than the more hands-on topics of species identification and Global Positioning System use. If multimedia tutorials are to be created, more interactive quiz-like features need to be included to fully maximize the benefits of these technologies.

4.7 Conclusions & Recommendations

Although Parker (2009) indicates that tutorial construction may be relatively easy, I found that the development of multimedia tutorials was difficult and time consuming. Synchronizing voice-overs with animations in Adobe Captivate was challenging and there was increased time involved to embed flash tutorials within standard web pages to improve usability. Because the two tutorial approaches appear to yield similar results for most skills, and because all indications point to the difficulty in creating effective multimedia tutorials, I recommend that volunteer coordinators focus on developing strong content presented in more traditional approaches using standard Hyper Text Markup language text and images. However, if resources are available, offering two versions of the same tutorials for volunteers to choose from may accommodate different learning styles (Mestre 2006) likely encountered among diverse and geographically widespread volunteers. The best strategy would be to offer training materials in as many learning styles as possible: in person, online using traditional static tutorials, online using multimedia tutorials, and even online using live video. As one participant stated, "[although] the in-person training [may have] been more detailed … I like the flexibility of the online training." More research is needed to compare both static and multimedia tutorials to in-person trainings. Additional research is also needed to evaluate synchronous and a synchronous live video trainings. Efforts should be made by volunteer coordinators to provide volunteers with as many training approaches as possible.

CHAPTER 5 CONCLUSIONS

> *"A National Science Foundation Workshop on Envisioning a National Geoinformatics System for the United States foresaw '…a future in which someone can sit at a terminal and have easy access to vast stores of data of almost any kind, with the easy ability to visualize, analyze and model those data.'."*
>
> *~ National Science Foundation (2007)*

Do we have easy access to vast stores of data and can we easily visualize, analyze, and model these data? Have we made this vision a reality? The cyber-infrastructure system developed for my dissertation research supported a total of 141 professional and citizen-based projects that collectively contributed 222,942 'visits' recording 3,128 unique taxonomic identifications comprising 322,719 organism data records having 518,582 associated attributes as of April 3, 2010. The top ten species recorded (Figure 5-1) include: Tamarisk (*Tamarix*; 57,775 occurrences), Dalmatian Toadflax (*Linaria dalmatica*; 46,902 occurrences), Giantreed (*Arundo donax*; 24, 639 occurrences), Canada Thistle (*Cirsium arvense*; 14,183 occurrences), Cheatgrass (*Bromus tectorum*; 12,955 occurrences), Brazil peppertree (*Schinus terebinthifolius*; 11,916 occurrences), Musk Thistle (*Carduus nutans*; 4,610 occurences), Japanese honeysuckle (*Lonicera japonica*; 3,926 occurrences), Russian Olive (*Elaeagnus* *angustifolia*; 3,893 occurrences), and Buffelgrass (*Pennisetum ciliare*; 3,264 occurrences).

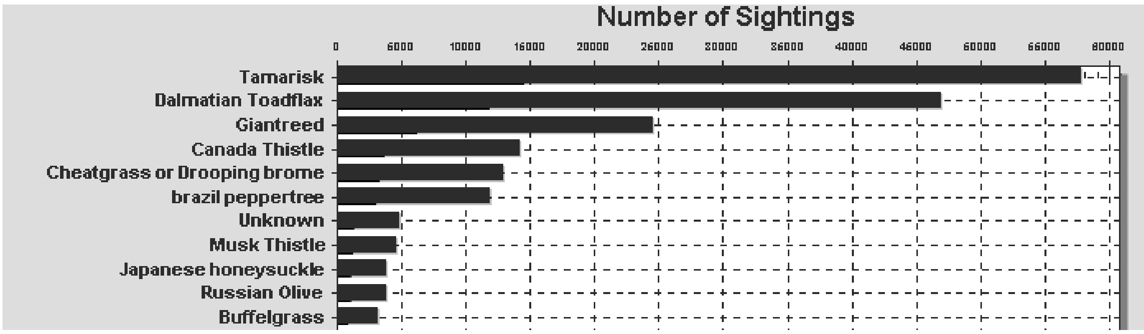

Figure 5-1. Top ten species reported through the cyber-infrastructure as of Aril 3, 2010. This figure was created online automatically using the cyber-infrastructure itself - one example of easily analyzed and reported real-time information.

Although citizen science data combined with professional data increases data availability, it exacerbates the need for cyber-infrastructure systems capable of storing, standardizing, retrieving, assessing, classifying, manipulating, analyzing, communicating, disseminating, and synthesizing data (Gray et al. 2005). Based on my dissertation research, I provide recommendations for each of these aspects of cyber-infrastructure systems (Table 5-1).

Table 5-1 - Recommendations for future cyber-infrastructure development

Role	Recommendation	**Existing**[*]	**Planned**[**]
Storage			
	Ensure long-term hardware and software support		X
	Ensure regular database backups	X	
	Build human resource information technology capacity		X
	Incorporate foresight, planning, indexing, and scalability		
Standardization			
	Use standard protocols	X	
	Use controlled vocabularies[***]	X	
	Obtain buy-in from professional organizations		X
	Use scientific notation but build features for conversion	X	
	Allow for emergent controlled vocabularies where appropriate		X
Retrieval			
	Use standardized web service protocols for data exchange	X	
	Assess quality of retrieved data before ingest		X

Role	Recommendation	Existing*	Planned**
	Retrieve only required data for cyber-infrastructure domain	X	
Assessment			
	Check for Latitude >90 or <-90, Longitude >180 or <-180	X	
	Check for UTM Easting >500000 or Northing > 50000000	X	
	Provide error checking for all form variables		X
	Use pick lists for controlled vocabularies	X	
Classification			
	Use standard classification schemes***	X	
	Cross-walk different schemes into common schemes***		X
Manipulation			
	Offer features for data conversion between units	X	
	Offer features for data conversion between file formats		X
	Provide tools for feature extraction against base layers*****	X	
Analysis			
	Develop online spreadsheet features	XX	
	Create simple logical operators for new data field to be created		X
Communication			
	Develop automated newsletter features for programs		X
	Facilitate email among project members		X
	Use existing APIs for social networking features		X
Dissemination			
	Create automated report features		X
	Share data with other systems using web service protocols	X	
Synthesis			
	Provide summary statistics across merged datasets	X	X
	Deliver Really Simple Syndication feeds of summary statistics		X

* X=Existing; A=Existing through administrative backend.
** Planned future feature based on feedback and recommendations from citizen scientists.
*** Examples: National Land Cover Dataset values and Federal Information Processing Standards.
**** Examples: State A, B, and C noxious weed lists versus Red, Yellow, and Green lists.
***** The system use MaxEnt for this purpose for online modeling capabilities (Phillips et al. 2006).

As more data are collected, improved data storage capabilities are needed (Gray et al. 2005) to meet the challenges associated with data over-abundance common to disciplines as diverse as neuroscience (Hasson et al. 2008) and astronomy (Nieto-Santisteban et al. 2005). Data storage requires the ability to archive and store large amounts of legacy and new data collections through centralized or cached, distributed (federated), or hybrid approaches (Graham et al. 2009). Successful approaches possess long-term hardware and software support, adapt to technological changes, use appropriate technology, and adopt new innovations (Table 5-1). They incorporate foresight, planning, indexing, metadata, and scalability (Gray et al. 2005). My experiences indicate that developing cyber-infrastructure systems that include some minimal quality assurance / quality control features such as requiring location accuracy to be entered for all sightings submitted improve the ability of those reusing citizen science data and improve the quality of data available for reuse. For example, of the 5,196 species occurrences submitted to the cyber-infrastructure thus far, 35% (1,840) have associated location accuracy information recorded with them greater than zero. A majority (94%) of these citizen contributed data has location accuracy values that are not null in the database; many are recorded as incorrect zero values. However, of the professional data in the system, only 1% has associated location accuracy information greater than zero and 94% are not null; many of which are also incorrect zero values. Many of these professional data values are derived from legacy datasets my research team obtained and contributed. Thus, the use of online quality assurance / quality control features appears to be promoting quality data – even of these data are submitted by citizens.

Adherence to widespread and accepted data standards creates inter-operable systems (Cargill 1997, Lake and Farley 2007, Haklay and Weber 2008) that together represent the emerging geospatial web – the global collection of discoverable web services and data supporting the use of geographic information in a range of domain applications (Lake and Farley 2007). The use of standardized controlled vocabularies improves data integration, analysis, and meta-analysis (Table 5-1) and may mitigate performance limitations of distributed systems requiring federated searches, the semantic web, and ontology-based knowledge discovery systems (Graham et al. 2009). For example, using standard classification schemes such as the National Land Cover Dataset values, the North American Amphibian Monitoring Program's Call Index values, and Federal Information Processing Standards values will decrease the amount of post-processing required for exchanged data. Seamless download and use of real time data will improve workflow efficiency. Effective cyber-infrastructure systems will inform the information enterprise as data are changed so those using data may update old datasets and any subsequent data that may have been derived from them. The true utility of such a web 2.0 framework hinges upon these data standards, interoperability, and standardized Application Programming Interfaces (Lake and Farley 2007, Haklay and Weber 2008).

Current visions for future cyber-infrastructure include Collaborative GIS, "… a collection of tools, theories, and practices [that] directly support multi-stakeholder participation in the planning and management of geographically distributed resources" (Balram et al. 2009). These so-called Group Spatial Decision Support Systems integrate spatially enabled tools, theories, and technologies, structure human participation, and articulate issues of concern in local and distributed spatial planning processes (Balram et al. 2009). They are envisioned to include analysis features that allow end users to sort, manipulate, and interact with online data sets collaboratively and that augment a user's intellect rather than increase their intellectual burden (Gray et al. 2005). They use multimodal interfaces for participant interactions (MacEachren et al. 2005) and spatial databases to provide baseline data and store new emergent information (Balram et al. 2009).

Online analysis of data sets will decrease the time necessary for scientific data collection through data analysis; web-enabled, modular, information science-based systems will allow for flexibility and expand analysis capabilities as new and improved techniques are developed. A preliminary needs assessment (Newman, unpublished data) indicates that citizen scientists want online analysis features such as real-time calculation of histograms, group means, minimum values, maximum values, average values, and visualizations such as graphs, bar charts, and pie charts. For example, 93% of respondents (n=42) desired bar charts, 55% desired pie charts, 76% desired line graphs, and 45% wanted scatter plots. Online statistics desired most included minimum, maximum, mean, and variance.

Thus, web delivery of real time data, knowledge, information, and wisdom will provide improved mechanisms to disseminate information and make it easy to discover data. Multi-scale spatial and temporal visualization tools will allow stakeholders to customize data visualization to suit their specific needs. Advanced 3D visualization capabilities that automatically update as the data sources are updated improves visualization, understanding, and science literacy. Improved science communication approaches will be needed to reach broader audiences, inform stakeholders of risks (Bier 2001, McComas 2006), and communicate uncertainty (Janssen et al. 2005).

These envisioned capabilities will require science and technology education and improved spatial literacy. They will also require successful diffusion of innovations to often ill-prepared stakeholders. The diffusion of innovations theory hinges upon the innovation-decision process which involves phases of knowledge, persuasion, decision, implementation, and confirmation (Figure 5-2; Rogers 2003). The knowledge phase refers to when an individual becomes aware of the new innovation. Persuasion refers to when individuals form favorable or unfavorable attitudes towards the innovation.

Decision refers to when individuals engage in activities leading to their choice to either adopt or reject the innovation. Implementation refers to when individuals within a social system actually put the innovation to use, and confirmation refers to when individuals seek reinforcement to their innovation-decision made in the decision phase (Rogers 2003).

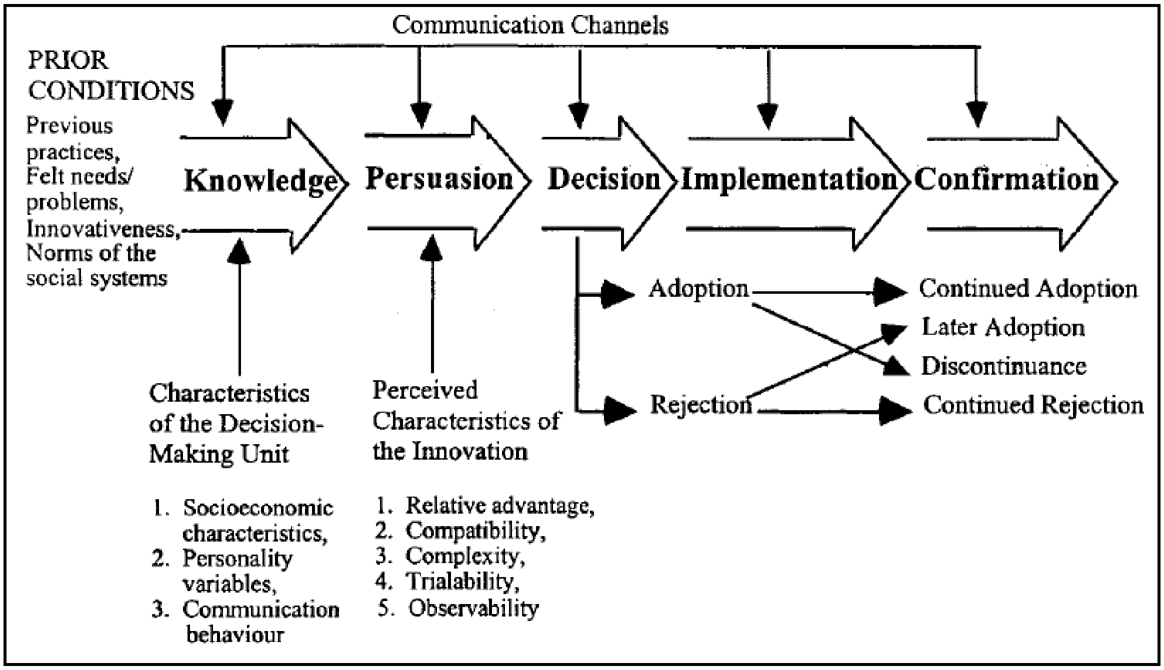

Figure 5-2 - The innovation-decision process (adapted from Rogers 2003)

Each of these phases will be important to the future use (or lack of use) of cyber-infrastructure systems in support of citizen science programs. Future research regarding these diffusion-adoption phases will iteratively improve the design, development, and deployment of cyber-infrastructure systems. Improving these systems, integrating them with citizen science programs, and augmenting traditional science models through cyber-infrastructure will continue to prove challenging. However, accomplishing these goals will improve our information science capacity and yield systems better matched to our current environmental problems, concerns, and decision-making needs.

5.1 Reflections

My dissertation research caused me to think deeply about several philosophical conundrums, including the tensions between the have's and the have not's and the benefits and drawbacks of open web systems versus those that may be participatory, but that use gatekeepers to control data quality. There are many reasons to encourage participation such as improving volunteer motivations (Van Den Berg et al. 2009), but often scientists required a certain level of data accuracy and precision to be able to make science-based decisions. Can these both exist? A middle ground might hold the key. My experiences show that contributors really do care about the correctness of their contributions. However, malicious activities are an unfortunate reality and may take too much time to clean up if checks and balances are not in place. Small non-governmental organizations are in no place to spend precious time constantly dealing with data uploaded just because some kid thought it was funny. Thus, it may be that quality assurance / quality control procedures are required to prevent malicious or incorrect data entry while still allowing those with permissions the ability to participate freely. I fall somewhere in between purely open systems such as Open Street Map and purely closed systems such as governmental intranet systems that do not allow public participation and acknowledge that these different approaches may best be suited to different situations.

My dissertation research represents the culmination of over eight years of investment in developing applied web-based tools for ecological data management and citizen science. I have been developing web mapping applications to support the data management needs of ecologists throughout my employment as a research associate at the Natural Resource Ecology Laboratory. Traditional dissertation research is judged primarily by the quality and quantity of peer reviewed journal articles it produces. I hope that my dissertation research is also judged on the quality and quantity of the applied products (tools, websites) it produced. There are now 27 citizen science projects consisting of 166 active citizen science volunteers using the CitSci.org website and cyber-infrastructure. I receive new contacts from interested stakeholders regularly. Supporting the needs of these diverse stakeholders is something I do on a regular basis and openly love; it brings me great joy to see the fruits of my labor used and enjoyed by many to ease the complicated tasks they all too often face when managing their ecological data. Most of the progress made in developing the cyber-infrastructure was made prior to the more formal research experiments discussed herein began. It is unfortunate that "researching and evaluating cyber-infrastructure systems in support of multi-scale citizen science" has led to the stagnation (and perhaps decline) of the very system being evaluated. Researching products requires a very different focus than creating, managing, and maintaining them. Throughout the research process, I found myself having to put off development of tutorials and website features in lieu of developing rigorous statistical "treatment groups" to statistically compare the effectiveness of different tutorial versions, for example. This led to the development of two versions of each tutorial rather than perhaps one improved version. Nevertheless, through the research process, I have had the opportunity to learn about the effectiveness of different communication approaches and usability issues. The research process forced me to create tutorials using different communication approaches. This led to more tutorials being available to more volunteers in a variety of approaches. Even if each tutorial may be of slightly less detail given the pressures of creating multiple versions, those who prefer to learn with traditional static versions now have these available and those who prefer multimedia approaches also have resources available to them. I now aim to spend more time developing improved tutorials and additional website features to better support citizen science organizations. It is my hope that the combination of the products developed and the research results gained from this endeavor advances our ability to effectively create cyber-infrastructure systems in support of multi-scale citizen science and allow better integration of these data with professional data to construct a more comprehensive view of the integrity of our beloved natural resources we so desperately need to monitor and sustain.

APPENDICES

APPENDIX A

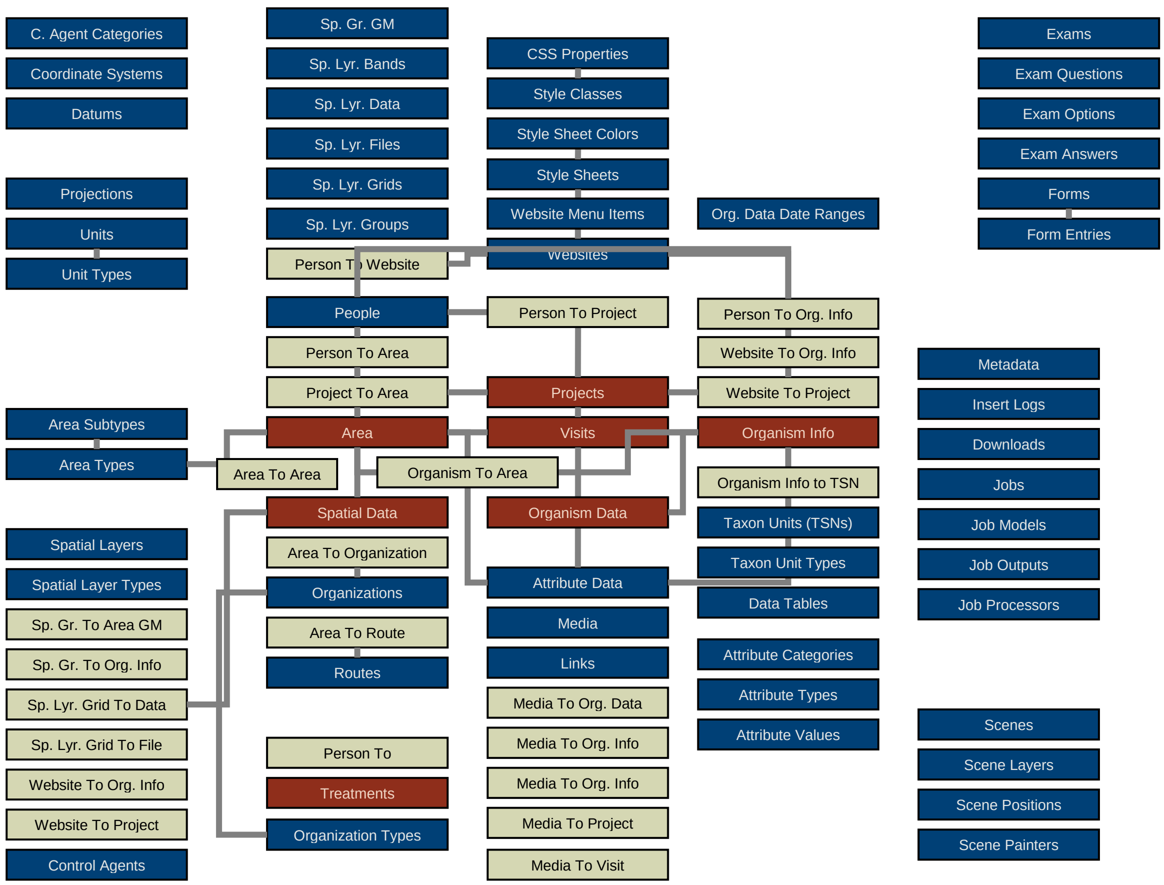

Figure A-1. Entity Relational Diagram for the cyber-infrastructure in support of multi-scale citizen science. Note: not all tables and relationships are shown for clarity.

Figure A-2. A screen shot of the citizen science website (www.citsci.org) created through the cyber-infrastructure system.

APPENDIX B

Table B-1. Reliability Analyses for usability concepts identified by factor analyses

Items used for Measured Concepts	Item Total Correlation	Alpha if Item Deleted	Cronbach Alpha
Perceived Ease of Use			.89
I was satisfied with my experience using the website	.67	.88	
The words on the screen were legible (easy to see)	.63	.89	
The site layout was easy to follow	.66	.88	
I felt overwhelmed when using the site	.73	.87	
The pages loaded quickly	.49	.89	
I found the site very easy to use	.85	.87	
I found the site easy to read	.66	.88	
I was not frustrated when using the site	.77	.87	
I could easily find the information I needed	.60	.88	
Content			.79
I found the information easy to understand	.57	.77	
I found the site to be well-written	.62	.77	
I prefer to print and then read Web pages	.74	.67	
I prefer reading information online rather than downloading .pdf files and then reading the printed file	.69	.70	
Aesthetics / Engagement			.82
The colors are pleasing	.68	.78	
The site design is attractive	.85	.67	
The graphics were meaningful	.52	.83	
The website was engaging	.63	.78	

Table B-2: Problems and associated task completion times and rates (%) by scenario

	Scenario 1**		Scenario 2**		Scenario 3**	
Problem (Task Concept Measured)	Time*	%	Time*	%	Time*	%
Difficulty locating register, login, and logout	3:49	0%	2:41	100%	2:44	100%
Overlooked ‘Early Warnings’	2:44	33%				
Early Warnings	1:08	0%				
Overlooked ‘Locations of Interest’	1:50	0%				
Join Project (register for project) – 1 and 2	3:22	33%	3:02	100%		
Join Project (register for project) - 2			1:14	67%		
Join Project as Reviewer					3:26	75%
Invasive Species Information	1:00	100%	1:32	100%	1:05	75%
3 species; find projects for them – 1 and 2	2:55	33%	1:09	67%	1:00	100%
3 species; find projects for them – 2			1:05	100%	0:52	100%
Find Honey Bee and show on map – 1 and 2	2:38	67%	1:07	67%		
Find Honey Bee and show on map & print – 2			1:19	33%		
Find Tamarisk – 1					1:28	100%
Find Tamarisk – 2					2:46	100%
Help and map tools help	1:20	0%	2:59	67%	3:36	100%
Add leafy spurge occurrences on map	2:18	33%	1:46	67%		
Retrieving a saved map confusing	1:26	33%	0:45	67%*		
Load and print map	0:30	33%	1:26	33%*		
Request Instigator (apply)	2:03	67%	2:11	67%		

* Minutes

**See Appendix B, Tables B-7, B-8, B-9, and B-10 for specific tasks for each scenario.

Table B-3. Mean evaluation for each usability concept

Usability Concept	Mean*	Standard deviation
Ease of Use	5.18	0.97
Content Satisfaction	4.25	1.03
Aesthetics	5.70	1.00

*Based on a sample size of 16 (n=16).

Table B-4. Computer Experience

	Years of Experience		Level of Experience*	
Technology Skill	Mean #	S.D.	Level	S.D.
Using a personal computer	17	4.4	6	1.3
Using the World Wide Web	11	2.6	6	1.2
Personally downloading Acrobat software	6	2.3	5	1.5
Downloading .pdf files for information	6	2.4	5	1.7
Installing software	9	6.5	5	2.0
Installing hardware	8	7.3	3	1.7
Filling out applications/forms online	8	3.6	6	1.0

*Respondents answered using a 1 to 7 scale where 1 = None and 7 = A Great Deal.

Table B-5. Separate pair-wise comparisons between three usability concepts

Usability Concept Comparisons	*t*-value	*p*-value*
Ease of Use - Content	3.52	.003
Ease of Use - Aesthetics	1.76	.098
Aesthetics - Content	5.63	<.001

* Note: The significance level for significant differences between means for each pair-wise concept comparison based on a Bonferroni correction is 0.017 (0.05/3 comparisons).

Table B-6. Comparison between prior technology experience and usability concepts

	Ease of Use			Content			Aesthetics		
Technology Experience*	Mean	*t*	*p*-value	Mean	*t*	*p*-value	Mean	*t*	*p*-value
Prior PC experience		.43	.68		.67	.52		.02	.99
Low	5.06			4.04			5.68		
High	5.29			4.42			5.69		
Prior www experience		.88	.40		.79	.45		.63	.54
Low	4.97			4.04			5.84		
High	5.43			4.48			5.50		
Prior forms experience		1.3	.23		.99	.35		.72	.48
Low	5.53			4.55			5.90		
High	4.89			3.98			5.50		

* The low and high technology experience groups were determined by using the mean value for each experience index calculated by the respondent's self reported number of years of experience * their self reported experience level on a scale of 1 (None) to 7 (A Great Deal). Those respondents with indexes below the mean index score were considered low and those with indexes above the mean index score were considered high.

Table B7. Scenario 1 tasks and their average task completion time and rate (N=3)

Task #	Task	Time*	Completion Rate (%)
1	1. Go to the Citizen Scientist Website by clicking on the CitSci icon and register as a Citizen Scientist. Next, check the I Accept box and click on Submit. Log out of the site and close the browser.	3:49	0%
2	2. Once you've registered, you realize that you forgot to set your ***Early Warning Alert*** on**.** Log back in and turn your email alert ***on***.	2:44	33%
2a	3. How can the ***Early Warning Alert*** help you with your project?	1:08	0%
3	4. To receive information about projects in your area, you decide to set your ***Locations of Interest. Add*** the following two locations of interest in Colorado, ***Rocky Mountain National Park*** and ***Larimer County.***	1:50	0%
4	5. You have looked through the project list and are interested in the ***Honey Bee*** project. Register for the ***Honey Bee*** project. Go back to ***My Profile*** and join the ***Honey Bee*** project as a contributor.	3:22	33%
5	6. From the ***Home page,*** find information on why Invasive Species are a problem?	1:00	100%
6	7. Using the Website, name **3 Species** considered to be Invasive Species? Pick a species from the ***All Species*** list. Are there any projects you can join for that species?	2:55	33%
7	8. Assume that you'd like to find data about the invasive species ***Honey Bee*** (*Apis mellifera*). From the ***Home page*** where would you find that information? You decide to look at the map showing the invasive species distribution of the ***Honey Bee*** in North America. Go to the map and ***print*** the map.	2:38	67%
8	9. You're not sure what functions the icons on the map page provide. Using the Help feature name the Map Tools and Map Functions and briefly describe what they do.	1:20	0%

9	10. From the **map page**, assume you're also interested in the occurrences of the ***Leafy Spurge*** (*Euphorbia esula*) invasive species. ***Add*** those occurrences to your map.	2:18	33%
10	11. Assume you decide you want to keep the map you just created for future reference. Save the map and name it ***CitSci Project***. ***Log out*** of the site.	1:26	33%
11	12. You decide after you **log out** of the site that you'd like a copy of the map you created. ***Login*** to the site using the ***Citizen Scientist* icon**, go back to ***My Maps*** and ***retrieve*** and ***print*** the map.	0:30	33%
12	13. Assume you've been a citizen scientist for three years and now you'd like to become more involved in Invasive Species projects. You read the Website and learn that you can do so by becoming a project instigator. Go to ***My Profiles*** and **apply** for a project instigator level for ***Cheatgrass*** (*Bromus tectorum*).	2:03	67%

* Average time in minutes to complete task

Table B-8. Scenario 2 tasks and their average task completion time and rate (N=3)

Task #	Task	Time*	Completion Rate (%)
1	1. Go to the Citizen Scientist Website by ***clicking*** on the ***CitSci icon***, ***expand*** the screen to a ***full screen*** and ***register*** as a Citizen Scientist using the following information. ***Next***, check the ***I Accept*** box (ignore the Got Data?) and ***click*** on ***Submit. Log out*** of the site and ***close*** the browser.	2:41	100%
4a	2 You have looked through the ***Project List*** and are interested in the ***Honey Bee*** project. Register for the ***Honey Bee*** project.	3:02	100%
4b	3. Go back to My Profile and join the project as a contributor	1:14	67%
5	4. From the ***Home page,*** find information on why ***Invasive Species*** are a problem?	1:32	100%
6a	5. Using the Website, name **3 Species** considered to be ***Invasive Species***?	1:09	67%
6b	6. Pick a species from the ***All Species*** list. Are there any projects you can join for that species?	1:05	100%
7a	7. Assume that you'd like to find data about the ***Invasive Species Honey Bee*** (*Apis mellifera*). From the ***Home page*** where would you find that information?	1:07	67%
7b	8. You decide to look at the map showing the Invasive Species distribution of the ***Honey Bee*** in North America. Go to the map and print the map.	1:19	3%
8	9. You're not sure what functions the ***icons*** on the map page provide. Using the ***Help*** feature, ***name*** the ***Map Tools*** and ***Map Functions*** and briefly ***describe*** what they do.	2:59	67%
9	10. From the ***Home page***, assume you're also interested in the occurrences of the ***Leafy Spurge*** (*Euphorbia esula*) invasive species. ***Add*** those occurrences to your map.	1:46	67%

10	11. Assume you decide you want to keep the map you just created for future reference. Save the map and name it ***CitSci Project***. ***Log out*** of the site.	0:45	67%
11	12. You decide after you **log out** of the site that you'd like a copy of the map you created. ***Login*** to the site using the ***Citizen Scientist*** **icon**, go back to ***My Maps*** and ***retrieve*** and ***print*** the map.	1:26	33%
12	13. Assume you've been a citizen scientist for three years and now you'd like to become more involved in Invasive Species projects. You read the Website and learn that you can do so by becoming a project instigator. Go to ***My Profiles*** and ***apply*** for a project ***Instigator Level*** for ***Cheatgrass.***	2:11	67%

* Average time in minutes to complete task

Table B-9. Scenario 3 tasks and their average task completion time and rate (N=4)

Task #	Task	Time*	Completion Rate (%)
1	1. Go to the Citizen Scientist Website by ***clicking*** on the ***CitSci icon***, ***expand*** the screen to a ***full screen*** and ***register*** as a Citizen Scientist using the following information. ***Next***, check the ***I Accept*** box (ignore the Got Data?) and ***click*** on ***Submit. Log out*** of the site and ***close*** the browser.	2:44	100%
2	2 Assume you have looked through the ***Project List*** and are interested in the ***Honey Bee*** project. ***Join*** the ***Honey Bee*** project as a ***Reviewer***.	3:26	75%
3	3. From the ***Home page***, find information on why ***Invasive Species*** are a problem?	1:05	75%
4a	4. From the ***Home page***, name **3 Species** considered to be ***Invasive Species***?	1:00	100%
4b	5. Pick a species from the ***All Species*** list. Are there any projects you can join for that species?	0:52	100%
5a	6. Assume that you're interested in finding out if you have the ***Invasive Species Tamarisk*** (*Tamarix sp.*) is in your garden. From the ***Home page*** where would you find that information?	1:28	100%
5b	7. You decide to look at the map showing the Invasive Species distribution of *Tamarix sp.* in North America. Go to the map and print the map.	2:46	100%
6	8. You're not sure what functions the ***icons*** on the map page provide. Using the ***Help*** feature, ***name*** the ***Map Tools*** and ***Map Functions*** and briefly ***describe*** what they do.	3:36	100%
7	9. From the ***Home page***, assume you're also interested in the occurrences of the ***Leafy Spurge*** (*Euphorbia esula*) invasive species. ***Add*** those occurrences to your map	1:53	75%
8	10. Assume you decide you want to keep the map you just created for future reference. Save the map and name it ***CitSci Project***. ***Log out*** of the site.	0:56	100%

9	11. You decide after you **log out** of the site that you'd like a copy of the map you created. ***Login*** to the site using the ***Citizen Scientist*** **icon**, go back to ***My Maps*** and ***retrieve*** and ***print*** the map.	1:43	75%
10	13. Assume you've been a citizen scientist for three years and now you'd like to become more involved in Invasive Species projects. You read the Website and learn that you can do so by becoming a project instigator. Go to ***My Profiles*** and change your ***User Level*** to an ***Instigator Level.***	1:06	100%

* Average time in minutes to complete task

Table B-10. Scenario 4 tasks and their average task completion time and rate (N=4)

Task #	Task	Time*	Completion Rate (%)
1	1. Go to the Citizen Scientist Website and register as a Citizen Scientist using the following information.	2:28	100%
2	2 Assume you have looked through the ***Project List*** and are interested in the ***Honey Bee*** project. ***Join*** the ***Honey Bee*** project as a ***Reviewer***.	2:54	75%
3	3. After looking at the ***Species List***, you decide you want to make a map of the ***Leafy Spurge*** *(Euphorbis esula)* distribution. Create a map of ***Leafy Spurge*** *(Euphorbis esula)* occurrences	2:39	100%
4	4. You don't like the color of the ***Leafy Spurge*** *(Euphorbis esula)* on the map, so you decide to make the ***Leafy Spurge*** *(Euphorbis esula)* appear bright green. Remove the default color of the occurrences and add ***Leafy Spurge*** *(Euphorbis esula)* with outline and fill colors in bright green.	3:26	25%
5	5. Assume you're going to use the map in a presentation and want the map legend to convey the "common name" ***Leafy Spurge*** instead of the scientific name ***Euphorbia esula.*** Edit the map and change the legend name from ***Euphorbia esula*** to ***Leafy Spurge.***	1:00	75%
6	6. ***Zoom*** to create a map of ***Leafy Spurge*** *(Euphorbis esula)* in Colorado. ***Print*** and ***save*** the map. ***Log out*** of the site.	2:00	75%
7	13. ***Login*** and ***retrieve*** the saved map. ***Zoom out*** to create a map that includes the 4 Corner states.**.**	1:36	50%

Note: * the average time and percentage is based on three of four participants. One participant skipped Tasks 5, 6, and 7.

Table B-11. Website overall usability questionnaire.

Questions *	Scale: Strongly Disagree						Strongly Agree	
I was satisfied with my experience using the website	1	2	3	4	5	6	7	NA
I found the links between pages hard to understand *	1	2	3	4	5	6	7	NA
I could easily correct any errors I made while using the website	1	2	3	4	5	6	7	NA
The diagrams and graphics enhanced the information in the text	1	2	3	4	5	6	7	NA
The text has too much information – it makes it hard to understand the topic *	1	2	3	4	5	6	7	NA
The site's left-hand navigation was helpful	1	2	3	4	5	6	7	NA
The words on the screen were legible (easy to see)	1	2	3	4	5	6	7	NA
I found the site confusing to use *	1	2	3	4	5	6	7	NA
I found the information easy to understand	1	2	3	4	5	6	7	NA
The site layout was easy to follow	1	2	3	4	5	6	7	NA
I never felt lost when using the site	1	2	3	4	5	6	7	NA
I felt overwhelmed when using the site *	1	2	3	4	5	6	7	NA
I made few errors when using the site	1	2	3	4	5	6	7	NA
The pages loaded quickly	1	2	3	4	5	6	7	NA
I found the site very easy to use	1	2	3	4	5	6	7	NA
I found the site easy to read	1	2	3	4	5	6	7	NA
I was not frustrated when using the site	1	2	3	4	5	6	7	NA
I found the site to be well written	1	2	3	4	5	6	7	NA
The site was not interesting to use *	1	2	3	4	5	6	7	NA
The site has too much information in .pdf files	1	2	3	4	5	6	7	NA
I prefer to print and then read Web pages	1	2	3	4	5	6	7	NA
I found the links to be inconsistent	1	2	3	4	5	6	7	NA
The font (typeface) was hard to read	1	2	3	4	5	6	7	NA
The font (typeface) was too small to read	1	2	3	4	5	6	7	NA
I could easily find the information I needed	1	2	3	4	5	6	7	NA
The site design is attractive	1	2	3	4	5	6	7	NA
The colors are pleasing	1	2	3	4	5	6	7	NA
I prefer reading information online rather than downloading .pdf files and then reading the printed file *	1	2	3	4	5	6	7	NA
The graphics were meaningful	1	2	3	4	5	6	7	NA
The website was engaging	1	2	3	4	5	6	7	NA

* Items were reverse coded.

Table B-12. Computer experience questionnaire.

Questions *	Years	Scale							Variable
		None						A Great Deal	
Using a personal computer	_____	1	2	3	4	5	6	7	p4a_CE_Index
Using the World Wide Web	_____	1	2	3	4	5	6	7	p4b_CE_Index
Personally downloading Adobe's Acrobat Reader software	_____	1	2	3	4	5	6	7	p4c_CE_Index
Downloading .pdf files for information	_____	1	2	3	4	5	6	7	p4d_CE_Index
Installing software	_____	1	2	3	4	5	6	7	p4e_CE_Index
Installing hardware	_____	1	2	3	4	5	6	7	p4f_CE_Index
Filling out applications/forms online	_____	1	2	3	4	5	6	7	p4g_CE_Index

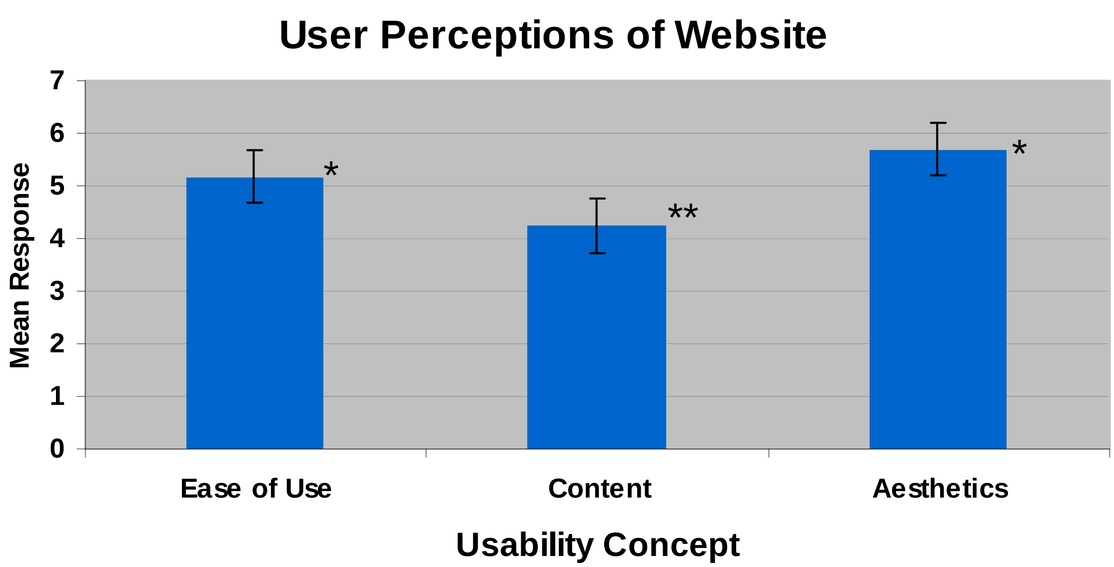

Figure B-1. Mean evaluation response for each usability concept analyzed. Responses were coded on a 7 point scale: 1= strongly disagree and 7=strongly agree. Error bars represent standard deviations. Means with different symbols (*, **) differ in paired *t*-tests (p<.05). Mean response values were based on a sample size of 16 respondents.

APPENDIX C

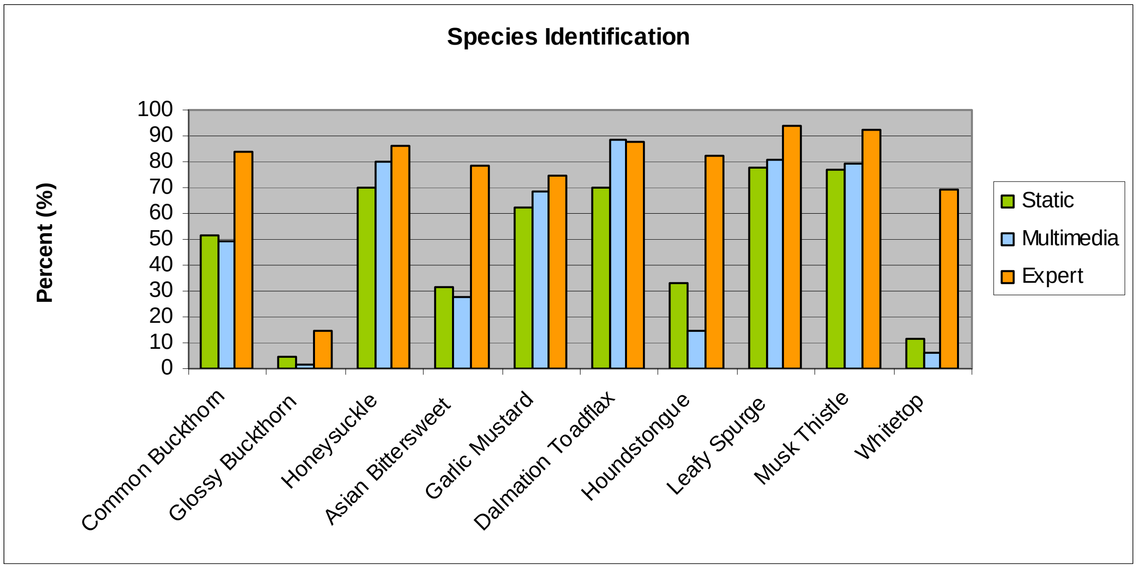

Figure C-1. Mean correct species identifications (%) of participants trained using static and multimedia tutorials and of experts receiving no training for the ten species evaluated in Colorado and Wisconsin.

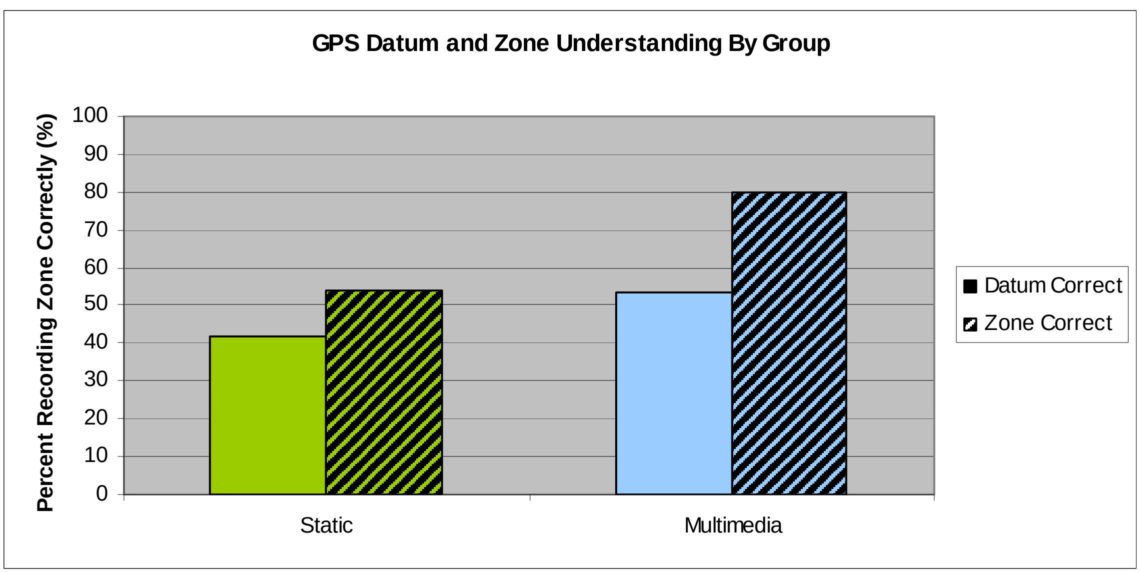

Figure C-2. Mean abilities (%) of participants trained using static and multimedia tutorials to correctly identify the datum (dashed bars) and Universal Transverse Mercator Zone of their eTrex Legend Global Positioning System device.

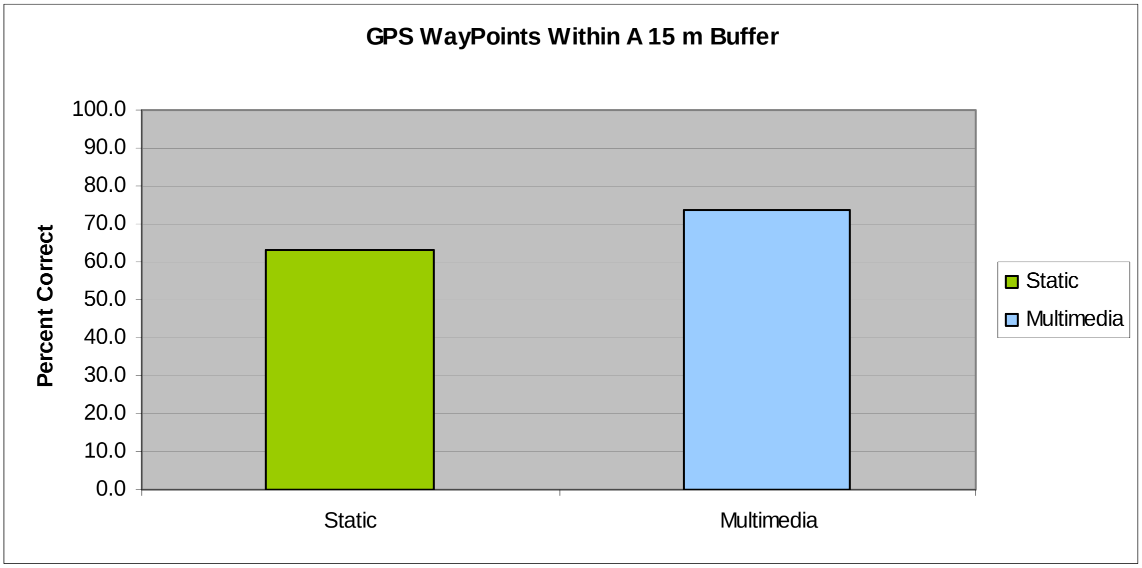

Figure C-3. Mean abilities (%) of participants to correctly record a waypoint of five replicate locations within a 15 meter buffer using an eTrex Legend Global Positioning System device.

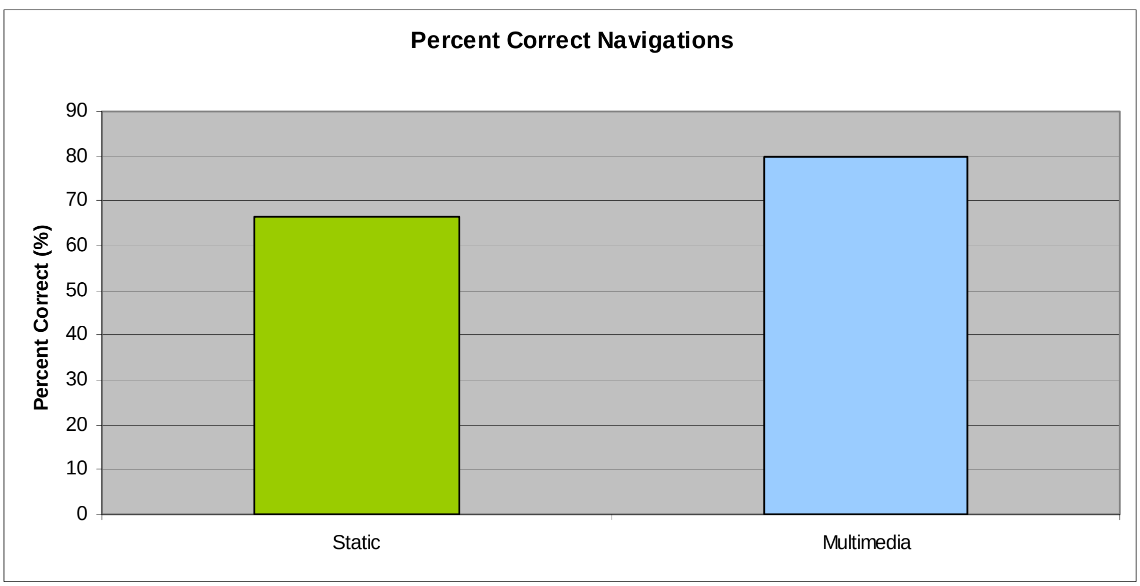

Figure C-4. Mean abilities (%) of participants trained using static and multimedia tutorials correctly navigate to five replicate pre-defined waypoints using a Global Positioning System device (eTrex Legend).

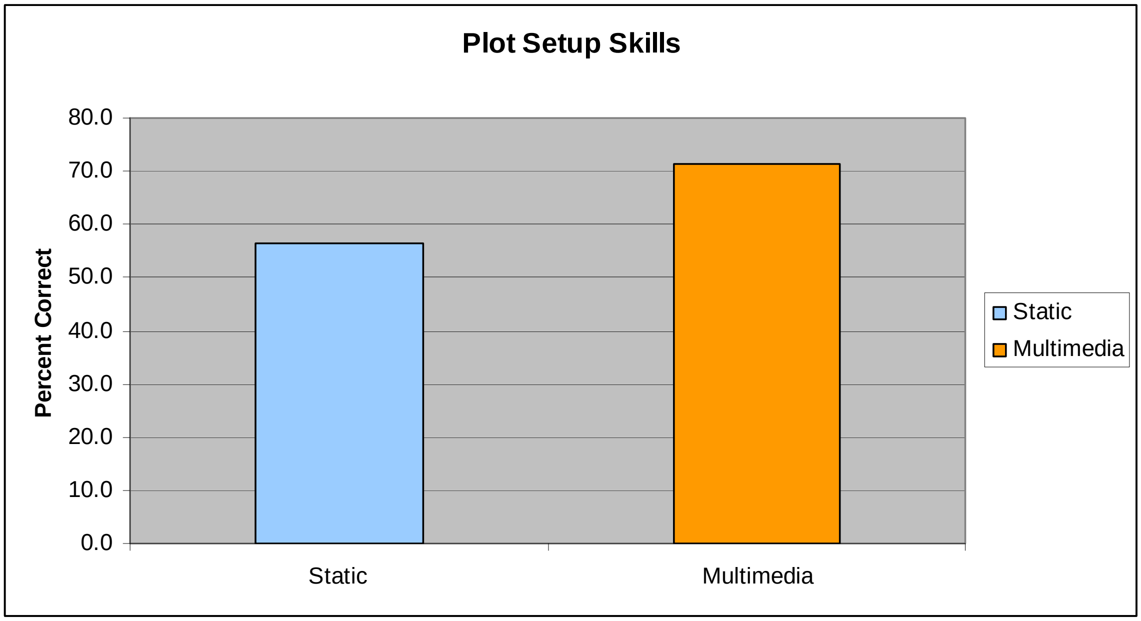

Figure C-4. Mean plot setup abilities (%) of participants trained using static and multimedia tutorials to correctly establish a Forest Inventory and Analysis vegetation monitoring plot.

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