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Designing for Online Collaborations and Local Environmental Action In Citizen Science: A Multiple Case Study

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Designing for Online Collaborations and Local Environmental Action In Citizen Science: A Multiple Case Study

By Ruth Kermish-Allen

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Abstract

Traditional citizen science projects have been based on the scientific community's need to gather vast quantities of high quality data, neglecting to ask what the project participants get in return. How can participants be seen more as collaborative partners in citizen science projects? Online communities for citizen science are expanding rapidly, giving participants the opportunity to take part in a wide range of activities, from monitoring invasive species to identifying far-off galaxies. These communities can bring together the virtual and physical worlds in new ways that are egalitarian, collaborative, applied, localized and globalized to solve real environmental problems.

There are a small number of citizen science projects that leverage the affordances of an online community to connect, engage, and empower participants to make local change happen. This multiple case study applies a conceptual framework rooted in sociocultural learning theory, Non-Hierarchical Online Learning Communities (NHOLCs), to three online citizen communities that have successfully fostered online collaboration and on-the-ground environmental actions. The purpose of the study is to identify the range and variation of the online and programmatic functions available in each project. The findings lead to recommendations for designing these innovative communities, specifically the technological and programmatic components of online citizen science communities that support environmental actions in our backyards.

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Chapter 1: Introduction

Access to the tools of the digital age are expanding at an unprecedented rate (UNESCO, 2013), connecting the citizens of the world in ways that generations past would never have dreamt possible. The ease with which people can generate and share their own content with a world-wide audience is staggering (Haythornthwaite, 2005). Mobile devices enable learners to collaborate, create new knowledge, and share this immediately on the Internet, all within real-world contexts (Inkpen, 1999). All of these innovations are beginning to change the way we interact, the way we learn, the way we act, and the way we define our identities (Coulter, 2011). How can this love affair with all things digital be directed toward positive outcomes, such as healthier and more sustainable communities and individuals? This dissertation aims to provide a few initial answers to this question through the exploration of citizen science projects that leverage the digital connectivity available around the globe.

Citizen science originated as a way for the general public to assist scientists in collecting data for their research, as well as a vehicle to communicate aspects of science to the general public (Bonney, Ballard, Jordan, & McCallie, 2009). But the level of citizen participation no longer needs to stop there. The involvement of local people in all aspects of scientific inquiry through citizen science can lead to faster and more reliable data collection (Newman, Crall, Laituri, Graham, Stohlgran, Moore, Kodrich, Holfelder, 2010). This, in turn, can inform environmental decision-making at a much faster rate than more traditional scientific approaches (Mueller & Tippins, 2012). Citizen science can be more than just a service that the public provides for scientists. It can also be a tool for communities and individuals to ask their own scientific questions as they work toward building healthier and more sustainable communities. Citizen science initiatives are using the connectivity available to communities today to empower learners with tools they can use to understand their environments better, share those understandings with a broad audience, and exponentially amplify connections across the globe (Dickinson, Bonney, Fitzpatrick, Louv, 2012). This dissertation seeks to understand some of the different models and structures the growing citizen science movement is using to marry global connectivity with the emerging scientific questions of local communities.

A first step in understanding what that marriage looks like is to document projects that have come closest to realizing this vision. To that end, this dissertation uses a multiple case study approach to examine three citizen science projects that use online learning communities to promote collaboration and foster local action. This study seeks to answer the question:

What are the essential design elements, practices, and structures of online learning communities used in citizen science projects that foster and result in local environmental actions?

Defining Action

"Action" in this sense does not refer to modifying specific individual behaviors like recycling or saving water, but instead to engage learners in planning and taking action on community-level environmental issues they find relevant (Schusler, Krasny, Peters, & Decker, 2009). Results of these types of action can be seen in policy changes such as land use regulations to conserve or restore sensitive habitats; efforts to eradicate invasive species; sociological changes that promote car pooling or public transportation use; and activities such as planting butterfly gardens. Participants learn to critically analyze information, make informed decisions, and take an active role in accomplishing tasks to enable those actions. The key components of the action of interest in this study are solutions that the citizen scientists produced to address the problems they identified. This study does not analyze the actions in any way: it simply documents the types of actions resulting from the projects and the design elements and practices present in the project that supported its development.

Defining Citizen Science

Citizen science is not a new phenomenon. In fact, it has been explored in different ways in the public domain for over a century (Bonney, Ballard, Jordan, & McCallie, 2009). Volunteer bird surveys in Europe and America have been ongoing for over 100 years, creating some of the longest-term ecological data sets we have to understand global environmental change (Shirk, Ballard, Wilderman, Phillips, Wiggins, Jordan, Bonney, 2012).

As the field of citizen science has evolved, the methodologies for conducting citizen science have, as well. In 2009, a report from the Center for Advancement in Informal Science Education (CAISE) brought together the leading researchers and practitioners in citizen science and tasked them with describing the different forms of public participation in scientific research (PPSR) – or citizen science. Out of this report, three commonly accepted types of citizen science emerged, which vary according to the level of citizen engagement.

1) *Contributory* citizen science projects ask members of the public to contribute data to various scientific research projects. Contributory projects are designed by research scientists and place an emphasis on the need for high quality data. Contributory projects usually do not provide any information back to the public other than acknowledgement of their contributions. In most cases, this form of citizen science is best employed when a research project needs a very large amount of data from a wider geographic range. The data collection protocols are very simple, specific, and allow for extremely high data quality. Project Bud Burst or the Christmas Bird Count is an example of a contributory project.

2) *Collaborative* citizen science projects provide additional opportunities for public engagement, including the contribution of data, analysis of data, assistance in disseminating findings, or other methods for the public to use the data for their own purposes. The research questions, design, and data collection protocols originate solely with the scientific community.

3) *Co-created* projects originate and grow from start to finish with partnerships between scientists and members of the public. This form of citizen science engages public participants through participation in most or all steps of the scientific process, and in some cases the project development process as well. Co-created projects start from the

ground up, often originating from a public concern, and are typically very small in nature, due to the focused intent to investigate a very specific concern or occurrence.

Online communities are used in all of the variants of citizen science discussed above, especially in contributory projects (Newman et al., 2010). The focus of this dissertation attempts to shift the scale of the use of online communities towards co-created and collaborative citizen science projects. Therefore, the projects included in this study fall somewhere along the continuum of collaborative and co-created variants of citizen science projects.

Dissertation Structure

This dissertation is in a manuscript-style format; each chapter of the dissertation is formatted for submission to a peer-reviewed journal. Each chapter must stand on its own and represent a small section of the entirety of the dissertation. Due to this format, there is some repetition in the introduction sections of each chapter.

This dissertation is framed as a two-part multiple case study. The first part developed a new conceptual framework, based on sociocultural learning theory, to understand online citizen science communities. Chapter 1 discusses this process and defines the new framework – the Non-Hierarchical Online Learning Community (NHOLC). The chapter then describes the findings of this researchers Q methodology (McKeown & Thomas, 2013) study, which highlights the key components of the NHOLC framework that participants in three case study projects believed to be important to fostering collaboration online.

The second part of the study digs deeper into participants' experiences to identify how they engaged with the online community, specifically the technological functions of the site, to collaborate and foster environmental action. To tell this story Chapter 2 shares the results from the analysis of semi-structured interviews and online observation protocols. The findings from Chapter 2 lead to a list of recommendations for designing the technological and programmatic components of online citizen science communities that foster collaboration and support local environmental actions.

Chapter 3 organizes the findings into core themes that have implications for the design of tools and practices of online citizen science communities. The tone of Chapter 3 is intended to bridge research and practice, providing practitioners with easy-to-understand guidelines for the future development of successful co-created and collaborative citizen science online communities.

This study adds to a growing body of literature focused on citizen science (Cronje, Rohlinger, Crall, & Newman, 2011; Druschke & Seltzer, 2012; Newman et al., 2010). It specifically addresses for the first time how the structure and role of collaboration in online communities can help achieve project goals. The design principles and NHOLC conceptual framework presented here provide a research-based starting point that other researchers and program designers can learn and build from. With the guidance presented here, citizen science projects no longer need to re-invent the wheel to leverage the affordances of digital connectivity. This study shares sufficient evidence of the tremendous potential for creating online citizen science communities that result in environmental action in our backyards.

Locating Myself in the Study

In this section I offer some insight for the reader into my life, interests, and evolution as an educator and researcher and how those paths have informed my journey throughout this dissertation.

Ever since I was a very young child I knew I wanted my love of science and the natural world to play a major role in my life and career. But the route to my dissertation research has been rather indirect and meandering across a variety of fields including forest ecology, community organizing, science education, informal learning, emerging technologies, and the learning sciences. When I began my master's degree in forest ecosystem sciences I wanted my life's work to move our society closer to a sustainable relationship with our planet. I originally thought that understanding and developing sustainable forestry practices would accomplish that goal. But as I entered into the final stages of that degree I realized that I spent the majority of my time behind a computer screen crunching numbers and I was not sharing what I was learning with anyone. I felt isolated and purposeless. I was not sharing the findings of my work with foresters; I was not sharing it with community members that live near these forests, no one. I had no means of communicating to others how what I had learned could move us toward a more sustainable society.

That realization resulted in a sharp left turn into a field that would provide a sizeable population to work with, K-12 education. While studying pedagogical strategies and educational psychology in a science and environmental education master's program…I found myself. I found a mechanism that builds on my love of learning, natural talent for listening, empathic personality, never ending questioning, and love of science and the natural world. I dove head first into teaching. In my first year after graduation with an M.Ed., I joyfully lead the nature and outdoor leadership program at a summer camp, began my first year as a high school earth and environmental science teacher, and taught an environmental history course as an adjunct professor. I loved my interactions with young people, I enjoyed sharing my passions with them, and I found that they enjoyed my interactive teaching style.

At this point, I was a purist in place-based pedagogy and did not see an appropriate role for technology in the science classroom other than typing up papers or research. I saw students that were disengaged with school become leaders as we canoed local streams, designed native plant gardens, and researched the impacts of local industrial expansions. I loved teaching, but unfortunately the administration of the high school where I first taught was not as comfortable with these active approaches to learning. I was forced out of my position. In hindsight, that was probably the best thing that could have happened to me at that time.

I ended up teaching all of the math and science courses for 6 months in a very small un-bridged island school, the North Haven Community School. The administration here was extremely supportive of place-based pedagogies. While working in this environment I saw the type of educational experiences that were possible when an entire school culture is grounded in experiential place-based education. I stretched my wings, experimented, and pushed the boundaries of what could be accomplished in a classroom. Unfortunately, this was only a short term position, but one that would launch me into my current interests.

I wanted to share the experiences I had at North Haven with teachers around the state. I wanted to find ways to support teachers that are experiencing push-back from their administration, I wanted to support teachers in over coming the boundaries that make place-based education difficult, I wanted to provide teachers with the support that I didn't receive when I had begun teaching. It was while exploring how to overcome boundaries to place-based education that the incorporation of technology began to enter into my practice.

I moved from classroom teaching to the non-profit sector as education director for the Island Institute. In this position I designed professional development opportunities for teachers from Maine's most isolated communities, un-bridged islands. As I began to understand the hurdles and challenges that island teachers experienced I started looking to different technologies to address those needs. Students wanted to compare their experiences with other island students, teachers wanted to connect to other teachers to share strategies. At this time the information communications technology sector was just starting to take off and new opportunities to overcome isolation were emerging everyday.

I began connecting my love of environmental and science education with information technology of all kinds. Geographic information systems enabled students to map and understand their place by layering existing data sets with their own. For example, when students partnered with a lobster hatchery the students became the digital mapping experts as they provided maps of where the hatchery should release the young lobsters for the best survivability rates. These student recommendations were based on existing ocean current, bottom type, and water temperature data sets. Students started designing websites to share what they had learned during research projects with the world. I began to see what an amazing resource the information technologies could be for both learning and community change. The technologies provided new tools and resources that could assist students and their communities in finding solutions to the questions they had. Questions related to natural resources, questions related to historical preservation, questions related to environmental justice, questions related to community decision making and governance, and many others.

As the Internet and mobile phones began to grow in popularity and access I began to see how the online world could be a transformational space for learning and connecting with new resources that individuals would have never had access to in the past. As stated by Hughes (2005) and Pea (1985) *transformational* uses of technology in education provide the opportunity for changing learning and teaching practices, roles, content, cognitive processes, and problem solving (Hughes, 2005; Pea, 1985) so that new opportunities are made available that would not have been provided without the technology. Examples could include online learning communities that share and discuss environmental topics, data, and potential solutions to environmental problems. Another example might be augmented reality games that provide information relevant to a user's surroundings that could assist them in learning a topic. The key defining factors of transformational learning experiences are 1) whether the use of technology provides access to learning or situations that would have otherwise not been available and 2) the dynamics of the roles of teachers and students change from the traditional top-down model (Hughes, 2005).

I wanted to understand the intricacies of how and why individuals use these technologies to learn and act. I had many questions that I did not have the tools to answer. I knew how to design an educational program or learning environment, but I built them on what my intuition told me. My projects were not grounded in theory or built off of what the education field already knew from decades of educational research. I was unclear of what could be answered through research and what could not. I did not understand the methods by which researchers could answer the questions I had. So, with all of my questions and passions I began down the path of transforming my practitioner mind into one that could easily bridge over to a researcher mind.

My research interests originally focused on the use of technology to empower young students in formal educational settings. But as I began to explore potentially transformative uses of technology for education I became enthralled with the connectivity online learning communities provided. I found and personally witnessed exciting initiatives for positive environmental change that occurred when online communities brought together individuals that would otherwise have never connected.

I started a pilot project that developed curriculum for students from very remote island communities to observe and record weather data. The project placed high quality weather stations on each school building. Within a few weeks of starting the project students wanted to know what the other students from the other island communities were observing and recording. At the same time, fishermen that lived and fished off of these remote communities would call over to the school to find out what direction the wind was blowing to determine if they should fish in a certain harbor or not. The hyper-local real-time weather data the stations provided became a resource that students could share with the community.

In response to this unanticipated public interest in what the students were learning we quickly set up a publicly available online spreadsheet that each school would post their observations on everyday. Community members, fishermen, and other schools would visit the site to compare data. Then they wanted to see representations of the weather, so the project set up a simple share site to post pictures of the school house, flag, and other local interests to show how foggy it was, the direction the wind was blowing, how high the snow had gotten, and other fun weather facts. In summary, the project caught fire and the communities involved wanted more. Fishermen realized that they could do something similar to share interesting creatures they pull up in their traps. Students and teachers wanted more ways to connect with each other. And scientists, wanted access to the hyper-local data.

This experience and the interest of the scientific community led me to look into the field of citizen science. There I found a variety of approaches for building databases online to share data, but the scientists and not grassroots efforts originating in community interests specified most of them. This realization of a significant gap in the field reinforced my interest in online learning communities as a mechanism for potentially transformative learning experiences. Therefore, I wrote a grant to build a new form of online learning community, specifically for co-created community led citizen science initiatives. The WeatherBlur project was funded by the National Science Foundation's Cyberlearning program to support coastal communities in understanding the local impacts of climate change. It brought together students, fishermen, and research scientists of many different disciplines, teachers, and other interested community members.

As my team and I built the online community and began to see the amazing outcomes of the online community I had more questions than answers. What was special about the online space to allow often-adversarial groups, like fishermen and scientists, to network and work together to answer common questions? What role, if any, did the online community play in moving from a community investigation about green crab populations to statewide policy to control the invasive population decimating the native clamming industry? Was the population WeatherBlur worked with unique to outcomes like this, or could online communities enable this type of action in other contexts with different populations? Which brings the dissertation study at hand to light.

With these questions in mind paired with the first two years of doctoral course work in research methods and theory I dove headfirst into the multiple case study research found here. I proposed the possibility of a multiple case study of online citizen science communities that exhibit the characteristics of a non-hierarchical online community to answer the questions I wondered about above. The National Science Foundation awarded an EAGER award to support this research because they also see the potential transformative educational experiences of online citizen science communities. This grant launched me into the research presented in this dissertation.

Chapter 2: Towards a Framework for the development of online learning communities in citizen science

Realizing a modern vision of citizen science

People want to learn with technology, with one another, in their own time, in their own place, and do things that matter (Fadel & Lemke, 2006). To meet this demand new digital opportunities have quickly worked their way into educational contexts. People around the globe are using new tools to understand their environments better and share those understandings as they exponentially amplify connections across the globe (Dickinson, Bonney, Fitzpatrick, & Louv, 2012). For example, community activists in Peru are connecting with scientists in Pennsylvania via online communities to learn about new methods to determine the amount of lead and other chemicals in drinking water near resource gas extraction sites. Indigenous students in Alaska are connecting with climate scientists to document changes in the sea ice at villages where their families have lived for generations.

Citizen science is a fast growing sector of informal science education that is working hard to leverage global connectivity and improve the health and sustainability of communities. Citizen science originated as a way for the general public to assist scientists in collecting data for their research, as well as a vehicle to communicate aspects of science to the general public (Bonney et al., 2009). But what do the citizens get in return? How can the citizen and his/her community be seen more as a partner and beneficiary in citizen science projects? Citizen science projects have the potential to go beyond *learning* about the monarch butterfly, for example. Instead it can bring people together to understand how their region relates to the butterfly's migration routes and life cycle, as well as what they can do in their every day lives to address the problems facing the monarch and the ecosystems upon which it depends.

Learning theory plays a very important role in the realization of the vision for citizen science described above. Timothy Kochmann (1996) coined the term computer-supported collaborative learning (CSCL), to define a new educational paradigm which focuses on the use of technology as a tool within collaborative methods of instruction. As stated by Dennen & Hoadley (2013, pg. 392),

> *"The design of CSCL is not to define a specific learning theory or content domain to be covered and the optimal way to cover it...instead CSCL instructional theories often specify roles, norms, values, or other process oriented aspects of the learning environment. The CSCL designer gives up control of many instructional choices that would be normal in the traditional design of non-collaborative environments - in exchange the designer can tap into powerful (if unpredictable) social processes to help drive learning."*

In this spirit of adventure, the purpose of this paper is to identify themes in educational theory (cognitive and instructional) that could inform the use and development of highly collaborative online learning communities for citizen science. To accomplish this goal the paper will first provide an exploration of the tenets of Vygotsky's sociocultural learning theory as well as more contemporary perspectives. Then the paper delves into the applications of sociocultural theory in related instructional theories such as, Wenger's Communities of Practice (CoP), Scardamalia and Beretier's Knowledge Building Theory, Gonzalez and Moll's Funds of Knowledge, and Sobel's Place-based education. Third, to bring the conversation back to online learning communities for citizen science, the paper explores how each theoretical component can be woven together into a new conceptual framework - Non-Hierarchical Online Learning Communities (NHOLC) - for citizen science. "Non-hierarchical," in this sense, is defined as a collaborative learning forum in which traditional experts, such as scientists are no longer perceived as the sole owners and creators of knowledge. Instead, all participants are generators of content and knowledge as well as active learners; the boundaries between scientist and citizen, young and old are blurred into one cohesive community of actively engaged learners. In the final sections of this paper, the findings of a Q methodology study that looks across three citizen science projects are shared. This study refines the NHOLC conceptual framework and sheds light on potential design principles for future research and projects.

Linking Sociocultural Education Theory with Citizen Science

Collaborative and co-created variants (Bonney, Ballard, Jordan, McCallie, Phillips, Shirk & Wilderman, 2009) of citizen science align well with sociocultural learning theory due to the strong recognition and value of cultural and historical perspectives that individual participants can bring to the study. Vygotskian sociocultural approaches are based on the concept that human activities take place in *cultural* contexts, and are mediated by tools, language, and other symbols, which can be best understood when investigated in their cultural and historical settings (Kozulin, Gindis, Ageyev, & Miller, 2003). Sociocultural perspectives on learning have many common threads including 1) the importance of tools, both socially and culturally constructed; 2) the need for a diverse social circle, including lesser and more experienced individuals; and 3) pedagogies and contexts that respect cultural and historical perspectives (John-Steiner & Mahn, 1996).

Sociocultural learning theory moves away from the norm of learning as an individual enterprise and instead places emphasis on the social processes of the co-construction of knowledge (Tobin, 2014). From a sociocultural perspective, an individual is always closely related to the social spheres and groups within which he/she functions, thus the goals of an individual are closely related to the group's motives and purpose (Tobin, 2012). Therefore, productive learning environments foster opportunities for individuals who act not only for themselves, but also promote their own achievement to expand the learning of others (Tobin, 2014). This approach to learning favors a co-production model that is characterized by a redistribution of the traditional roles of participation in the production of scientific knowledge (Cook, 2015). An example of this is clearly seen in the definition of non-hierarchical provided above which stresses traditional experts, such as scientists, no longer perceived as the sole owners and creators of knowledge.

Co-created and collaborative forms of citizen science build upon sociocultural learning theory as projects ask participants to not only gather data but also revise data collection protocols (in partnership with scientists) to fit within cultural norms. In some instances, projects provide the opportunity for participants to ask their own questions related to the local contexts in which participants live. When projects take this approach they are gaining the benefit of local social and historical contexts to make the overall project goal relevant to the learner and his/her community. For example, a sociocultural perspective would challenge individuals involved in study with the goal of increasing the frequency of the identification of new or invasive species in a key fishery's ecosystem to work closely with the communities that depend on that fishery – valuing and respecting their cultural norms, incorporating their values and traditional knowledge into data collection methods, and asking them for assistance in the interpretation of findings and recommendations for increasing populations.

Sociocultural theory also provides insight into the design and use of technology-mediated learning environments, such as online contexts. Using a socio-cultural approach to develop online learning communities provides a lens for investigating the interconnectedness between the individual and social spheres mediated by modern technology (Bencze & Alsop, 2014). Applying these understandings provides a platform to build on what we already know about how people learn and collaborate to guide the development of effective online citizen science communities. Empowering communities and individuals to ask their own scientific questions, using new tools to understand their environments better, sharing those understandings with a broad audience, and amplifying connections across the globe (Mueller, Tippins & Bryan, 2012) as those involved build healthier and more sustainable communities (Jenkins, 2011).

This paper explores four variants of sociocultural learning theories that provide solid ground upon which to build a new framework for collaborative online learning in citizen science, the Non-Hierarchical Online Learning Community (NHOLC). Communities of practice theory, knowledge building theory, place-based education theory, and funds of knowledge theory are all discussed in detail. This section will first introduce each theory, then describe theory-driven design principles for online communities, and finally rework the initial design principles to integrate concepts from all four theories into an interwoven conceptual framework.

Communities of Practice Theory

Communities of Practice (CoP), as defined by Lave and Wenger (2000), is any group of individuals working in relation with each other and the world through a shared set of practices to accomplish a shared enterprise or goal (Lave & Wenger, 1991). The theory's main assumption is that learning occurs through social participation (Wenger, 2000a). Participation in this sense refers not just to being engaged in local events with specific people, but to a more all encompassing process of becoming active participants in the *practices* of social communities and construction of identities in relation to those communities (Wenger, 2000b). Kisiel (2010) expanded on these ideas with the introduction of intersecting CoPs, which brings together various CoPs to develop new goals together utilizing a combination of each CoPs original shared practices. There are many questions in science that cannot be answered by one CoP alone.

Citizen science projects have the potential to leverage both the CoP and intersecting CoP models to advance scientific and educational goals. As the problems our communities face become more complex, the assumption that individuals can solve a problem alone, or the "expert as savior" mentality, has melted away. It is becoming clearer that we need

CoPs that are continually building knowledge together to learn from the past mistakes of others to share all possible resources to combat the problems at hand. Examples of this are often seen in understanding and mitigating the impacts of climate change on fishing communities, for instance. Scientists have realized that they need the traditional knowledge, expertise, and access that generational fisherman have to the populations and fishing grounds. At the same time, fishermen acknowledge that the marine ecosystem they know and love is changing and they need the partnership of the scientific community to understand these changes and develop their industry around sustainable practices that will ensure their livelihoods.

Some basic design principles emerge from this exploration and critique of CoP that could be built upon to develop online learning communities – they are shared below:

1. Online learning communities (OLC) should connect individuals who have a *shared repertoire* – use the same resources (same tools, artifacts, experiences, definitions) to accomplish the shared goals of the community (Hoadley & Kilner, 2005)
2. The goals and/or requirements of the online learning community should be defined and negotiated informally by members of the OLC – an example of *Joint enterprise* (Hoadley & Kilner, 2005)
3. The overlapping purpose or *joint enterprise* of the citizen science OLC should unite, motivate, and, in part, validate the activities of the OLC as significant. (Barab & Duffy, 2000)

4. Having a defined central purpose of the OLC can provide a starting ground from where members can begin to develop relationships and take on roles within the OLC (Hoadley & Kilner, 2005)

5. OLCs should provide tools and associated practices that the community needs to solve an authentic, real-world problem (Jonassen & Land, 2012)

6. Both novices and experts should be valued in the OLC (Barab & Duffy, 2000).

7. OLCs can provide opportunities for *mutual engagement,* referring to actions and especially interactions which members of the community share (Wenger, 2000b).

8. OLCs should provide a shared repository of information resources that are used by the community in its practices (Roschelle, Pea, Hoadley, Gordin, & Means, 2000).

CoP as an instructional theory, provides a magnificent basis upon which to build online learning communities for citizen science, but it does not go far enough. For example, CoP theory refers to learning as a linear process that moves along a continuum from novice to expert, as in the apprenticeship model from which CoP theory emerged. This is an important aspect of learning, but it does not value multi-directional learning in which the apprentice can also provide learning experiences for the mentor. A citizen science example of multi-directional learning could be when a local fisherman shares knowledge of where a specific species of interest can normally be found with a scientist known as an expert in the species. Furthermore, CoP theory only places emphasis on groups that already have a shared repertoire as they use the same resources (same tools, artifacts, experiences, definitions) to accomplish the shared goals of the community. CoP theory does not discuss the rich learning experiences that occur when groups of people that do not have a shared repertoire come together and work toward a common goal. The recognition of this gap is an outstanding opportunity to advance CoP theory. Researchers such as Kisiel (2010) are beginning to enter into this gap to offer alternatives such as intersecting CoPs which value bringing together multiple CoPs to solve a problem across a variety of shared repertoires.

Lastly, in the CoP model, theorists state that most CoPs have a shared repository of the knowledge for that community. This component, of course, is necessary to a successful CoP as seen in indigenous or traditional cultures that use multiple methods to store and share traditional knowledge. This concept is not new and has been shared from generation to generation over millennia. Shared repositories are not static, but ever changing as evolving members of the CoP critique, refine, and use the knowledge of the CoP in new and more productive ways. Through the technological capabilities we have available to us today we can modernize this concept and share these forms of knowledge with communities across the globe. These expansions of CoP theory provide the groundwork for a new genre of learning community – the NHOLC - which builds off of the strengths and potential new applications of CoPs. Knowledge building theory, which is a variant of CoPs, provides greater emphasis on the actual mechanics of how knowledge is created rather than how it is shared.

Knowledge Building Theory

Knowledge building—the creation of knowledge as a social product—is something that scientists, scholars, and employees of highly innovative companies do for a living

(Bereiter, 2005). Knowledge Building (KB) theory, defined by Scardamalia and Bereiter (1994), is a particular kind of community of practice that has the explicit goal of developing individual and collective understanding (Hoadley & Kilner, 2005). KB should not be confused with knowledge dissemination, which is defined as the transfer of knowledge across settings. There is an area of overlap between knowledge dissemination and KB, but that distinction is not central to the purpose of this paper and KB's role. In short, knowledge dissemination is the process of sharing knowledge from an individual entity to others. KB is built upon 1) a shared commitment of the community to generate new knowledge; 2) the importance of discourse; 3) the ability to build upon past knowledge, ideas, and artifacts; 4) shared responsibilities across the community for collaboration and decision-making; and 5) the importance of new and emerging sub-goals (Zhang, Scardamalia, Reeve, & Messina, 2009). Knowledge building, represents an attempt to re-invent formal education to initiate students into a knowledge creating culture. Involving learners not only developing knowledge building competencies but also coming to see themselves and their work as part of the civilization wide effort to advance knowledge (Scardamalia & Bereiter, 2006). Scardamalia and her colleagues (Hewitt & Scardamalia, 1998; Oshima, Scardamalia, & Bereiter, 1996; Zhang et al., 2009) have gone on to further define four essential design principles, or opportunities for engagement, that must be present in knowledge building communities for them to function:

1. *Collective Cognitive Responsibility* requires taking responsibility for the state of public knowledge (Zhang et al., 2009), anticipating and identifying challenges and solving problems, and collectively defining knowledge goals as they emerge throughout the process.

2. *Awareness of Contribution*s implies that there is a collective responsibility to knowing the from where and from whom information, actions, and goals have emerged, as well as understanding the changing goals, situations, actions, and connections in a community (Zhang et al., 2009).

3. *Complementary Contributions* (Zhang, 2009*)* respond to and build upon one another's ideas (Palincsar, Anderson, & David, 1993) and contribute non-redundant and important information that advances the pursuit of knowledge as a whole.

4. *Distributed Engagement* (Zhang et al, 2009) provides a framework for high-level operations such as community coordination, goal setting, and decision making to be completed across the entire community with minimal hierarchical control.

Knowledge building has strong core principles defining how knowledge is built in a CoP and is rooted in the power and ability of learners (specifically students) to truly advance knowledge in society. But it does not explain the interactions between overlapping communities, such as exchanges among inter-generational or multiple stakeholder-based communities. This opens up the opportunity for a new form of knowledge building community, one that reaches outside the boundaries of the classroom to include members of the greater community in knowledge building. This essential theme of bringing groups together to build knowledge is paramount in the realm of citizen science. Citizen science hopes to partner the goals and research questions of the scientific community with the large numbers and interests of the general public. Additionally, citizen science aims to answer scientific questions that cannot be answered by one discipline alone, but depend upon the coming together of many areas of expertise and ways of knowing. Therefore, the question becomes, how can design principles for online communities in citizen science foster and value multiple stakeholder perspectives? To address this question, an interwoven conceptual framework should build upon learning theories that place particular emphasis on the expertise of the learners themselves and how their life experiences can be extremely valuable assets to a learning community.

Funds of Knowledge

Funds of Knowledge (FoK) theory places emphasis on historically accumulated and culturally developed bodies of knowledge and skills essential for survival, success, and well-being (Gonzalez, Moll, & Amanti, 2005; Moll, Amanti, Neff, & Gonzalez, 1992). In Moll's (1992) investigations into knowledge exchange in immigrant communities she found that each household held accumulated bodies of knowledge based on the family members' life experiences, including agricultural, socio-political, and historical knowledge. The methods for knowledge transfer in the home and community setting was in stark contrast to the experiences of the community's youth in the formal classroom. FoK theory investigates how this accumulated knowledge from life experiences can provide value and meaning for formal and informal learning experiences (Gonzalez et al., 2005). The findings of Moll and her colleagues identified strategies for how families develop social networks that interconnect them with their social environments and how those relationships share and build new knowledge, information and resources related to a households' ability to survive and thrive in sometimes very difficult situations (Moll et al., 1992). These same strategies could prove very useful in the exchange of information and knowledge building between diverse stakeholder groups, such as those in citizen science. In these settings, sharing individuals' funds of knowledge can accomplish the shared goal of the group. Moll's core concepts provide valuable insight for potential design elements in online learning communities for citizen science:

1. Place value on each individual's historically accumulated and culturally developed body of knowledge and skills – fund of knowledge (Gonzalez et al., 2005).
2. Provide opportunities for community member to interact in adaptive, flexible, multi-dimensional ways to encourage multiple forms of relationships between individuals (Moll et al., 1992).
3. Provide opportunities for connections between members to become reciprocal and build trust over time instead of becoming buried at the end of an activity feed (Moll et al., 1992).

Citizen science projects are asking participants to share components of their individual fund of knowledge based on where they live and what they see around them every day. Such as India's *People's Biodiversity Register,* which asks residents to share historical and current information on dwindling numbers of the Siberian crane or the Vital Signs project's request for local gardeners to share their historical understanding and current knowledge of invasive plant species in their region. FoK theory can provide insight into design elements that illicit local traditional knowledge from individuals who may not necessarily see that know-how as important or beneficial to the scientific community. When in fact, that information can be more powerful than any expensive monitoring device. In addition, the questions posed by citizen science projects are usually inter-disciplinary in nature. Therefore, citizen science communities will be comprised of individuals or stakeholder groups that may not naturally seek each other out. FoK theory can contribute greatly to the development of both design and instructional elements for citizen science projects. The marriage of ideas between citizen science and FoK could prove useful in accomplishing the goals of the citizen science field, especially locally driven initiatives.

Place-based Education

The application of funds of knowledge usually occur in a specific place, for example the knowledge built up over generations about how to respond to periods of drought in local farming regions. The construct of place is very important when contextualizing this type of knowledge. Place-base education theory provides guidance for how to structure learning experiences grounded in questions of place. Place-based Education (PBE) promotes interdisciplinary learning that is rooted in the local community to accomplish both academic- and civic- engagement goals, while at the same time providing learners with the experiences and confidence to believe that they can influence positive change in their communities (Gruenewald & Smith, 2008; Smith & Sobel, 2010; Sobel, 2005). Designers of successful classroom interventions must make sure they are engaging enough to seduce learners into the world of learning (Brown, 1992). PBE takes this advice to heart by engaging most actively in topics that are framed with a high level of personal relevance and authenticity (Sobel, 2005). PBE begins locally and answers questions that are relevant to that community. Learning environments present core concepts through a locally-framed lens, leading to high levels of ownership and engagement (Chawla & Cushing, 2007a). Accomplishing the civic and academic goals of PBE requires a great deal of skill development, specifically around problem solving, communication, and collaboration. It is not enough for learners to learn beliefs and values about what they *should do*, they need opportunities to learn what they *can do* (Chawla & Cushing, 2007b). The key to PBE is that participants are learning about how they can influence their own community and see the change that they are capable of bringing about through partnerships with other groups in the community.

PBE fits squarely within a socio-cultural paradigm as it provides guidance for how to apply learning concepts in a locally relevant way. Duffin and colleagues (2008) reviewed educational literature and reported six core qualities essential to PBE, which can serve as design principles for online learning communities in citizen science:

1) Focus on topics that are relevant to learners;
2) Involve experiential and hands-on activities;
3) Promote understanding of concepts;
4) Use the local environment as a context for learning;
5) Learners work individually and in groups; and
6) Incorporate project-based work;

The focus on influencing locally relevant problems and questions fits perfectly with citizen science, since one of the goals of citizen science is to gain access to local data across a very large geographical span with the aid of locally trained volunteers. PBE, by nature is small in scale and locally contained. An opportunity for growth within PBE lies in partnering the power of online environments with the power of local questions. Many of today's environmental challenges have the potential to unite learners from around the world, if they have access to each other. Studies of invasive species, for example, or farming in drought conditions, provide the opportunity to connect with others trying to find solutions to similar problems. But, this in only possible if the online communication tools we have available to us today are brought to the forefront. Together individuals in online communities learn how to combat the issue in question through sharing experiences of their own place. In many situations, such as climate change, solutions to the problems being faced by local communities cannot be understood or solved, without the complex coordination of many different communities (and places) sharing what they are experiencing and what their strategies for solutions are. Online communities for citizen science may provide a vehicle with which to meet this goal of starting with the local and reaching out across a much wider distributed population. In addition, incorporating PBE with online communities will provide new opportunities for learners to get out into their world and gain access to new places across the globe that they would not have experienced otherwise.

Summarizing the NHOLC Conceptual Framework

The section above provides an understanding of each of the core theories that may be useful in their application to online learning communities in citizen science. This frame can be used to weave the concepts together into new conceptual framework. As such, the NHOLC framework provides a powerful starting point for designing and studying online spaces. Communities of Practice (CoP), focuses on how a group of individuals work and learn together. Integration of CoP theory helps inform how an online community might function. Place-based education (PBE) links the work of the community to the relevant interests and place of the participants. Knowledge Building (KB) guides the community with the intention to build new knowledge together related to the citizen science question mind. Funds of Knowledge (FoK) provide the framework with guidance for how to value diverse lived experiences and not just the "usually suspected" forms of expertise.

This conceptual framework incorporates diverse participant groups, real-world investigations rooted in place (local contexts), valuing lived experience as essential to building new knowledge, a recognition that knowledge generation is not a top-down process but instead a dynamic multi-directional process between participants, and finally leveraging the power of a digital culture to build a knowledge-building community that transcends geographic limitations of traditional place-based education to answer questions people care about.

Limitations of the NHOLC Framework

The NHOLC conceptual framework is by no means a panacea to the multiple challenges today's communities and the individuals that live there face every day as they strive toward a more sustainable future. There are many limitations inherent in the design of the NHOLC framework. First, there is the issue of access. If an individual does not have access to the Internet via a computer or smartphone they cannot access the online community. Wireless communication is expanding quickly, especially in third world nations, but it is still not everywhere. Even small town mountain and island villages in the United States still have difficulty accessing high-speed digital connectivity. Then there is the barrier of having access to the actual hardware, such as a smartphone, laptop, or desktop computer. Smartphones prices are dropping quickly but a good percentage of the world's population still cannot access these devices. Laptops and desktops are far more difficult to procure and afford. Even if an individual does not own their own device, there are many local community centers or libraries that can provide access to computers to access online learning communities. Perhaps the greatest limitation is the fact that any online learning community is only as good as the members that participate. Due to the sociocultural focus of the NHOLC framework, this limitation can make or break an online community no matter how good the technological components are.

Strengths of the NHOLC Framework

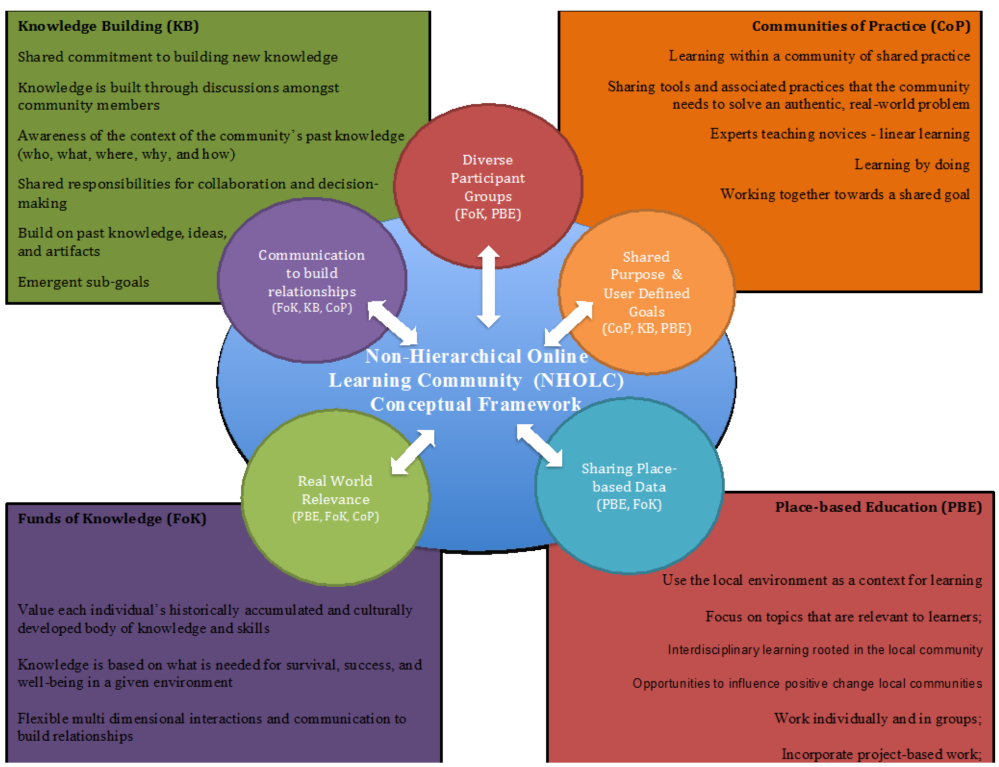


Image 1: Visual representation of the theoretical frame of NHOLC conceptual framework

This interwoven framework places emphasis on:

1) Bringing together diverse participant groups from widely differing areas of expertise to enable multi-directional learning opportunities in which everyone that joins the community has something they can offer and teach others within the community

2) Enabling participant-driven real-world investigations that are personally relevant to participants' lives

3) Sharing project purpose and goals

4) Enabling communication structures to build relationships and roles amongst a diversity of participants

5) Sharing place-based data across geographic boundaries

Image 1 above highlights how the core concepts of each guiding theory have been woven together into the five focus areas of the NHOLC conceptual framework.

As the strengths of these theories weave together to create a new genre for collaborative online learning – the NHOLC – the question we now must ask is, which components of this new framework are most important for fostering collaboration in online learning communities. Understanding which components are most important to online collaboration can begin to define design principles for successful applications of the NHOLC framework. As described at the start of this paper the realm of citizen science provides a valuable context or the use of the NHOLC framework. To test this proposition, the sections below detail a Q Methodology study that addressed the research questions of *what are the essential theory-based design elements of online learning communities for citizen science projects that resulted in environmental actions*.

A Q Methodology Study Applying the NHOLC Framework

To answer this question the most appropriate strategy is to find best-case scenario examples of projects that have characteristics of the NHOLC framework embedded in its design. With this in mind, a multiple-case study design is the best methodological fit to understand the implementation and design of an innovation (Yin, 2014) –characteristics of the NHOLC framework embedded into online learning communities for citizen science.

There are a wide variety of citizen science projects that use online learning communities. But, not all are locally focused or personally relevant for the individual participant. For example, Galaxy Zoo asks members to classify distant galaxies from images captured by the Hubble telescope and the Sloan Digital Sky Survey. Others, such as the 1000 Genome project, asks for help from the general public to identify novel genetic variants in examples of Y chromosomes from across Europe to track the historical migrations of humans. These are exciting ways to engage in citizen science and scientific questions, but it does not necessarily relate to a participant's everyday life. To zero in on projects that are best possible examples of embedded NHOLC characteristics this research chose to only include projects that have shown success in implementing local environmental actions, as suggested in the NHOLC framework vision discussed above.

The site selection requirements can be found in Box A (below). To tease out the most important, or essential, components of these online communities a Q-methodology is used to assess participants' priorities about an issue. The issue in this case is – what are the most important components of the NHOLC framework that foster collaboration and environmental action in online learning communities for citizen science.

Site Selection Criteria

1. The citizen science project uses an online space to:
    a. Bring multiple stakeholders together to answer questions relevant to the project (diverse ages and areas of expertise – for example, teachers, students, scientists, interested citizens, etc.)
    b. Bring together geographically diverse individuals to share place-based data
    c. Upload and share data via mobile and/or desktop technology with all users
    d. Analyze data
    e. Identify new areas of inquiry
    f. Provide an opportunity for users to connect with each other via a variety of means (discussion posts, messages, etc.)
2. The online space has:
    a. Been in use for 6 months or more
    b. Has funding to remain active through June 2016
    c. The ability to record and capture discussions online between users
3. The overall citizen science project:
    a. Have evidence of environmental actions implemented by participants due in part to the project
    b. Be committed to working with individuals of different ages and expertise (e.g., youth and adults; students; civic and science professionals)
    c. Be willing to share activity log data with this researcher
    d. Be willing to reach out to project participants for surveying and interviewing purposes
    e. Be willing to support staff time and opportunities to participate in researcher interviews and observations

Box A: Site selection criteria

Q-methodology was originally developed by William Stephenson (Stephenson, 1935) in order to assess individuals' priorities about an issue. It is designed to recognize the different value systems of different constituents (Brown, 1980). This approach can also illustrate underlying patterns between groups or individuals that have broad shared values, and can capture 'the way in which meaning is organized and patterned' (Brewerton & Millward, 2001). The basic difference between Q-methodology and standard survey analysis is its design to establish patterns within and across individuals rather than patterns across individual traits, such as age, class, etc. (Barry & Proops, 1999). In this study, Q-methodology uncovers the most important components of the NHOLC framework – the underlying essential design elements for collaboration and local environmental action common across individual's experiences of online learning communities for citizen science.

A total of 30 citizen science participants took part in the study. The sample includes project coordinators/founders and various types of participants including scientists, teachers, local community organizers, and the general public. These individuals came from across the country including Maine, California, New York City, New Orleans, and everywhere in between. All participants are active on one of the online communities. The sample includes all the major types of stakeholders involved in each of the case's learning communities. Fifteen participants, five from each of the three cases comprise this Q-sort. Each case includes one project founder/coordinator, two scientists or technical experts, and two members of the general public at varying levels of participation.

Descriptions for Case Study Sites

Public Lab is both an online community and a non-profit that grew out of a grassroots initiative during the Deepwater Horizon BP Oil Spill to enable communities impacted by the spill to access data from "community satellites" - helium balloons, kites with mounted inexpensive digital cameras - about where and how much the oil was spreading. Public Lab participants can learn how to investigate environmental concerns of interest to them using inexpensive Do-It-Yourself (DIY) techniques. Today, Public Lab is an international community with participants active in every hemisphere. The types of environmental monitoring range from water quality, to air pollution, and others as the community defines its interests. The online community is an open network of educators, technologists, scientists, and researchers working to create, share, and use low cost solutions to solving local environmental problems. This community has supported environmental actions ranging from aerial mapping for monitoring purposes (measuring waterway pollutants, drought conditions, plant health, invasive species, industrial pollution, etc.) to water quality testing to air quality monitoring—with opportunities to engage in local actions related to the research.

Vital Signs is a project of the Gulf of Maine Research Institute that has the goal of identifying and documenting invasive plants in the Northeast United States. The project originated as a citizen science project focused for the K-12 classroom, but has since grown to include adults at environmental organizations like land trusts, master gardeners, and others. The online community provides a venue to learn about which species others are finding in the region, participate in "missions" to find specific invasive species, and then a space to upload their findings. Participating scientists, or species experts, confirm or deny species identification of user data. Recently, Vital Signs has added a "design your own mission" function that allows participants to design their own investigations into local environmental questions. Many participants have engaged in action by hosting community events to educate the public about the presence, spread, and concerns connected with specific invasive species. Others have conducted removal or remediation of invasive species.

WeatherBlur is a project of the Maine Math and Science Alliance, which brings together scientists, fishermen, and K-8 students and teachers to explore the local impacts of shifting weather and climate change via an online community. The WB learning community uses online technologies to provide users with the opportunity to participate in an evolving set of "co-created" citizen science projects. The projects are rooted in place-based weather and climate data and questions that matter to citizens and provide highly valued data to scientists. During the pilot phase of this project, a bycatch study used lobster traps to investigate organisms that live amongst lobsters. Members asked questions about each other's data and provided suggestions for more accurate data collection. In August of 2014, a task force on green crabs solicited a summary of the WeatherBlur investigation. This report played an important role in developing new regulations to minimize threats posed by the crabs.

Each of the cases described above provide an online space for diverse stakeholders - scientists, youth, teachers, interested community members such as representatives from natural resource based economies - to ask questions, share and analyze data, collaboratively solve personally relevant scientific questions, and build new knowledge together. The goal behind all of these projects is to increase the participatory involvement of local people in environmental monitoring that can lead to highly accelerated research findings and policy changes to tackle environmental challenges.

Development of Q- Statements

Q-methodology typically includes a concourse stage. During this stage statements are generated to capture the full range of subjective experiences on the study topic. The most representative statements constitute the Q-sample (McKeown & Thomas, 2013). The Q-statements for this study were designed to highlight two different contexts. First, a series of statements reflect the core ideas of the original four socio-cultural learning theories - community of practice, knowledge building, place-based education, and funds of knowledge. There are 45 of these statements. Second, a series of statements reflect the emerging ideas of interwoven NHOLC conceptual framework. There are 55 of these statements. Each of the statements were then culled to limit repetition, increase clarity, and to reach a manageable number of unique statements that reflected the range of literatures reviewed. In accordance with the recommendations of McKeown & Thomas (2013), the final set of statements were limited to no more than 50 statements. The final 49 statements included in the Q sample are presented in Table 1 in the findings section. The first column of the table denotes the origination of each statement – original theoretical frame or NHOLC conceptual frame. Any statement with a NHOLC represents the new interwoven framework.

Data Collection

The Q-sort template for this study was forced-choice and arranged in a quasi-normal pattern (Figure 2). Statements were sorted on a nine-point scale, ranging from -4 (Least Important) to +4 (Most

Prompt Used During Q-sorts with Participants

"We are interested in learning about the pieces of the _______ project that were most successful at helping participants work together on the project to meet goals. Please think about the _______ project and sort the statements below to identify those that are most and least important for collaboration online with other participants to reach the goals of the project."

Important), as shown in Figure 1. Each of the three case study projects – WeatherBlur, Public Lab, and Vital Signs – were all equally represented with 10 participants each. To ensure equal representation only adult participants from the United States were included in this study. In addition, the different participant groups from each project were equally represented in the sample of 10 individuals from each project including research scientists/technical experts, project coordinators, teachers, local activists, and general participants.

Q-sorts were completed using online video conferencing and screen sharing. Each interview was approximately 60 minutes. The remote participants completed the Q-sort online using Flash-Q software (Hackert & Braehler, 2007). The interview began with an introduction to how the online flash version Q sort functioned. The participant would manually sort each statement with his or her own mouse. All 30 participants were presented with the statements in random order, and asked to arrange them initially into one of three piles (important, neutral, not important). Next, participants were asked to sort their cards according to the template below by placing cards in one of the nine columns – forced choice placement (see Figure 2). After completing the sort, participants were interviewed to document the reasons they selected statements as most or least important and to gather their perceptions of the overall themes for the kinds of statements that were most and least important to productive collaboration in an online citizen science community. Each Q-sort and associated interview took no more than 75 minutes per person total and was completed in one session.

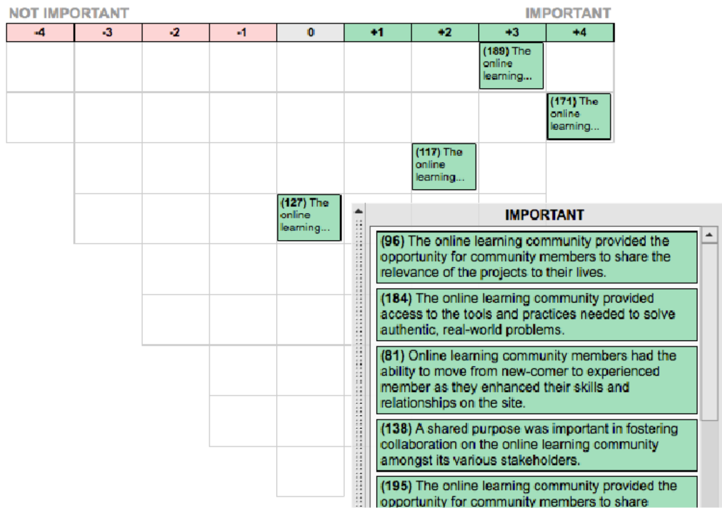


Figure 2

Q-sort Distribution for 49 Q Statements

Defining Factors: Perspectives on what was most important for online collaboration and on-the-ground action

The Q-sort data were analyzed using PQMethod software (Schmolck, 2002), which conducts a Principle Components (Factor) Analysis with a Varimax rotation. Following the criteria set by Green and Salkind (Green & Salkind, 2010), the three-factor solution was chosen to interpret the range of perspectives captured. The three-factor solution with the equitable representation across projects accounts for all individuals in the sample, and explains 49% of the total variance.

Table 1 (below) shares the findings of the Q sort. Column 1, *theoretical frame,* denotes whether the statement originated from one of the four original theories alone (CoP, KB, FoK, or PBE) or if it is a statement describing the new interwoven NHOLC conceptual framework (XXX/NHOLC). Column 2, *statement,* simply restates each of the statements that participants ranked during the Q sort. Columns 3, 4, and 5 *Factor #,* provides the average ranking for each statement from the individuals that were grouped together into each factor. Column 6 simply restates which factor each statement fit best within based on the amount of agreement amongst the individuals in that factor. For example, the first 11 statements in the table are statements that all members of factor 1 agree with. The statements that have a "1,2,3" in this column are statements that could fit into each of the separate factors, but each factor had a different perspective on how important or unimportant it was. The statements that have an "NA" in this column are statements that did not fit into any factor. The statements that have a "consensus" in column 6 are statements that everyone in the entire sample shared agreement on.

See Table 1 for the factor rankings of Q-sort statements, including consensus rankings.

Table 1: Factor ranking of Q-sort statements and consensus statements

Theoretical frame	**Statement**	**Factor 1**	**Factor 2**	**Factor 3**	**Three Factor Solution**
KB	The online learning community provided a structure to encourage the sharing of responsibilities and decision-making.	-3	0	-1	1
CoP/NHOLC	The online learning community connected individuals who have similar interests, but did not use the same resources for work (the same language, tools, experiences, definitions).	-2	0	0	1
CoP/NHOLC	The different perspectives of online learning community members assisted in developing individuals' roles on the online learning community.	-3	-1	-1	1
CoP/NHOLC	The online learning community encouraged members to value the variety of expertise present in the community.	-1	1	1	1
CoP/NHOLC	The different perspectives of online learning community members aided in developing relationships with others in the community.	-2	0	1	1
FoK/NHOLC	The online learning community encouraged members with historic and cultural knowledge relevant to the project to share that knowledge with others.	-2	1	0	1

KB/NHOLC	The online learning community brought together the diverse stakeholders needed to achieve the project's goals.	0	2	2	1
CoP	The online learning community's overall shared purpose motivated members of the community.	3	-2	-1	1
KB	online learning community members had a commitment to the same overall goals.	3	-3	-2	1
KB/NHOLC	The online learning community had a mechanism that provided the opportunity to critique and help shape new ideas that emerge from the members of the community.	1	-3	-2	1
KB	online learning community members had a commitment to building knowledge that could be used by the whole community.	1	-1	0	1
CoP/NHOLC	The online learning community attracted new members by showing the relevance of the project to potential member's lives and interests.	-1	1	-2	2
CoP	The online learning community provided a starting point for conversation.	1	3	1	2
KB/NHOLC	The online learning community encouraged any community member (no matter his/her age, expertise, or perspective) to propose new questions or investigations on the site.	0	2	0	2
KB/NHOLC	The online learning community provided the opportunity for members from multiple perspectives to respond to and build on the ideas of others to advance a project.	1	4	0	2
CoP	The online learning community's overall shared purpose united members of the community.	0	-4	0	2
CoP	Online learning community members felt like they were working toward the common goal of building new knowledge together.	2	-4	2	2
KB/NHOLC	Members joined the online learning community because they wanted to build knowledge related to the shared goals of the project.	2	-3	2	2
CoP/NHOLC	A shared purpose was important in fostering collaboration on the online learning community amongst its various stakeholders.	1	-1	1	2
CoP	online learning community members had the ability to move from new-comer to experienced members as they enhanced their skills and relationships on the site.	-1	0	3	3
CoP	The online learning community provided members with the freedom to express opinions and offer suggestions without fear of how the other members would judge it.	-1	-2	2	3
KB	The online learning community provided all members with a way to track and understand how and why a project changed over time.	0	0	-4	3
KB	The online learning community provided the opportunity to develop investigations that represented evolving ideas in the community.	1	0	-1	NA
CoP/NHOLC	The OLC provided a starting point for discussion with stakeholder groups that otherwise not connect to share	0	2	1	NA

	ideas.				
CoP	The online learning community provided the opportunity for community members to develop roles on the site.	-4	-2	-4	NA
CoP/NHOLC	The online learning community brought together people with different levels of expertise and/or experience.	1	2	3	NA
KB/NHOLC	All members of the online learning community had the potential to influence the direction and focus of projects.	0	3	-1	1, 2, 3
CoP	The online learning community provided a place to put resources that were used by the community.	3	1	-1	1, 2, 3
CoP	The online learning community had a structure for notifying members of where information came from and how it had been used in the past.	-1	1	-3	1, 2, 3
KB/NHOLC	The online learning community provided the opportunity for members to propose emerging project/investigation ideas that were relevant to their interests.	2	3	0	1, 2, 3
CoP	The online learning community encouraged community members to apply information on the site to their own situations and questions.	0	3	-3	1, 2, 3
KB/NHOLC	The online learning community highlighted and made clear the different groups / stakeholder perspectives involved in the project.	-3	1	-1	1, 2, 3
CoP/NHOLC	The online learning community provided the opportunity for community members to share the relevance of the projects to their lives.	-2	2	0	1, 2, 3
CoP	The online learning community's overall shared purpose helped the project feel significant.	4	-3	1	1, 2, 3
FoK/NHOLC	The online learning community provided members with the opportunity to share their knowledge of where they live and what they have experienced in their life.	-4	-1	2	1, 2, 3
CoP	Projects on the online learning community solved authentic, real-world problems.	4	1	4	1, 2, 3
FoK	Each member of the online learning community brought knowledge to the community based on where they live and what they have experienced in their life.	-2	0	3	1, 2, 3
KB/NHOLC	The online learning community provided the opportunity to connect with members who had the expertise needed for an investigation.	2	-1	4	1, 2, 3
CoP	The online learning community brought people together from different locations.	1	0	3	1, 2, 3
CoP	The online learning community provided the opportunity for community members to develop relationships with other members on the site.	-1	-2	-2	Consensus
CoP	The goals of the online learning community are defined and refined by members.	-3	-2	-2	Consensus
CoP	The online learning community connected individuals who use similar resources for work (same language, tools, experiences, definitions).	-1	-1	-3	Consensus
KB/NHOLC	The online learning community provided members with various ways to connect with any member of the community.	-2	-2	-2	Consensus

CoP/NHOLC	The online learning community helped community members connect to and work with members who had submitted information in the past.	0	-1	-1	Consensus
CoP/NHOLC	Starting with a shared purpose was important in generating trust amongst the various stakeholders.	-1	-1	0	Consensus
CoP	The online learning community helped foster relationships and built trust among community members.	0	-1	1	Consensus
CoP	The online learning community provided the opportunity for community members to share information with one another.	2	2	1	Consensus
CoP/NHOLC	The different types of expertise present on the online learning community were a factor in making members feel like they were working toward the common goal of building knowledge together.	2	1	2	Consensus
CoP	The online learning community provided access to the tools and practices needed to solve authentic, real-world problems.	3	4	3	Consensus

The NHOLC statements that defined each factor was of interest, as those characteristics had the potential to bridge the existing models of collaborative learning in the sociocultural learning theory literatures explored with the new emerging genre of the NHOLC experiences. The characteristics of each factor, consensus statements, and interview data were used to create descriptive titles and narratives of each perspective/factor. Using a participatory approach, the project coordinators of each case study were presented with and asked to give feedback and refinements on the factor descriptions and optimal Q-sorts during a one-hour long video-conference focus group. During the focus group participants were invited to share their interpretation of the factors as well and assist in further refining the factor titles, narratives, and implications for design principles. Their feedback is included in the factor descriptions and discussion sections below.

The factor analysis teased out three primary factors/perspectives that represent three distinct groups of participants from across the projects. Each group has their own distinct perspective on what is important to collaboration online for citizen science projects. The descriptions below explain how each distinct group viewed what was and was not important in their experiences of collaboration online in the citizen science project they participated in.

Factor 1: Clarity of purpose is important, but not members' backgrounds

A shared purpose and a focus on real world problems foster collaboration online, while knowing community members' backgrounds is not important.

Demographic information: Factor 1 has 7 significantly loading participants and it explains 19% of the study variance. The participants in this factor represent participants in all case study sites, including 4 teachers, 1 scientist, and 2 general participants.

Factor Interpretation: A clear understanding of and commitment to the project's shared goal (114: +3) generates motivation (76: +3) for collaboration online. Collaboration online can be fostered by projects that solve authentic, real world problems (145: +4). A shared purpose of the collaboration can make the work of the project feel significant to participants (117: +4). Collaboration in an online learning community happens when participants have a commitment to building new knowledge that can be used by the whole community (180: +1) and a mechanism to critique and shape those new ideas that emerge from the community (114: +3). A structure within the online community to share responsibilities and decision-making (11: -3) was not of importance to online collaboration within the experiences of individuals in this factor. Bringing together diverse stakeholders (109: 0) or valuing the variety of expertise present in the community (111: -1) was not a driver to online collaboration or the development of roles in the online community (83: -3). Role development was not an ingredient for collaboration online. In addition, the ability to share historical and cultural knowledge (194: -2) or knowledge of where they live and what they have experienced in life (118: -4) relevant to the project with others was not part of this factor's experience in fostering collaboration online.

Factor 2: Diversity of perspectives and stakeholders matter, but shared goals are not needed

Projects that are relevant to participants' place and lived experience, as well as diverse participants that range across multiple perspectives are important to fostering online collaboration, while it is not as important for everyone to have one shared goal since everyone comes to the project for a somewhat different purpose.

Demographic information: Factor 2 has 4 significantly loading participants and it explains 13% of the study variance. The participants are from Public Lab and WeatherBlur, including 1 project coordinator and 3 active participants (a fisherman and 2 local organizers).

Factor Interpretation: Providing an opportunity for participants from multiple perspectives to build on the ideas of others to advance a project (174: +4) and encouraging diverse stakeholders no matter his/her age, expertise, or perspective to propose new questions (107: +2) is important in fostering online collaboration. To foster collaboration the online space attracted individuals to participate in and propose projects that are relevant to their everyday lives and interests (14: +1 and 57: +3). Knowing the different stakeholder groups involved in a project encouraged collaboration online (79: +1). Encouraging community members to apply information on the site to their own situations and questions fostered collaboration online (60: +3). The online space was a starting point for conversations amongst the various stakeholders (38: +3). Having shared goals/purpose or working toward building new knowledge together was neither a starting point, nor a uniting or motivating factor for collaboration online in the experience of these participants (186 & 92: -4 and 95: -3 and 138: -1).

Factor 3: Building skills and trust amongst diverse stakeholders is important to collaboration, historical context of the collaboration is not

This group believes that collaboration can move forward by sharing lived experiences and making new connections across boundaries. The ability to connect with individuals that had a diverse array of expertise and geographies in a safe supportive environment was important to online collaboration, whereas building on past historical knowledge of the community is not as important.

Demographic information: Factor 3 has 5 significantly loading participants and it explains 17% of the study variance. The participants are active in both WeatherBlur and Vital Signs, including 1 teacher, 2 project coordinators, and 2 scientist participants.

Factor Interpretation: Solving authentic real world problems (146: +4) and the ability or each member to share knowledge based on where they live and what they have experienced in their life (165: +3) fostered collaboration online. To foster collaboration it was important that the online space provided the opportunity for members to connect with others that had the expertise needed for an investigation (187: +4) and were from different locations (191: +3). To foster collaboration it was important that the online community provided the opportunity for members to move from new-comer to experienced members as they enhanced their skills and relationships on the site (81: +3) and that they felt freedom to express opinions and offer suggestions without fear of how the other members would judge it (127: +3). In the experience of these individuals the ability to track and understand how and why a project changed over time (28: -4), notifying members of where information came from and how it had been used in the past, or applying information on the site to their own situations and questions (60: -3) were not important in fostering collaboration.

Consensus Statements

Given that the goal of this study is to explore whether there are characteristics that participants considered essential design elements for collaboration in online learning communities, the statements that are considered *important* or *not important* across all participants are equally relevant (if not more so) than the factors themselves.

Three statements were ranked as *important* by all factors, and are considered foundational in defining design principles for collaboration in online learning communities. The strongest consensus amongst the participants is the importance of the online space providing the access to tools (data collection protocols, research notes, maps, data analysis) and practices (user suggested improvements on how to collect data, how-to guides) needed to solve authentic, real-world problems. In addition, all participants identify the importance of being able to share information online with a wide array of expertise present in order to build knowledge together.

Four statements were ranked as *not important* by all perspectives, and thus not considered imperative components for collaboration online. First and foremost, goals in the online community that are defined and refined by its members are not important to online collaboration. Connecting members who have similar skillsets, interests, experiences, and practices is not important to collaboration online. In addition, based on the interviewees' experiences to date, 1) providing multiple ways to connect and 2) developing relationships with others on the site is not important to online collaboration.

Implications for Designing Online Learning Communities Using the NHOLC Framework

It is encouraging to see representation from each of the three cases in each factor. This cross-factor representation shows that there is enough consistency in each participant's experience of the various online citizen science programs to uncover potential design principles that can work for all projects. The consensus statements indicate that all participants think that authentic, real-world problems and the tools necessary to solve them are essential for establishing online collaboration.

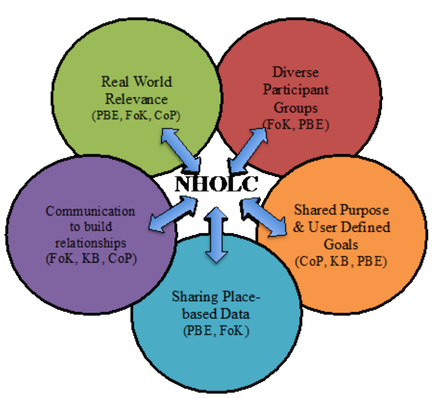
A somewhat unexpected, but eagerly welcomed, emergent design principle is the importance of having an online community that brings together individuals from diverse stakeholder groups with vast areas of expertise (lived experience, skill sets, ages, jobs, etc.). Such as bringing representatives from a rural mining community together with technologists who can design low cost water monitoring equipment and electro-chemical engineers. Together this cast of unlikely characters that can only connect via an online community can define an potential in the rural community, develop a means for data collection when high end scientific equipment is not an option, analyze the data to understand what hard metals are in the water, and define a solution to mitigate the polluted water.

In addition, consensus statements highlight that access to others with a similar skillset or interest to one's own does not foster collaboration; this suggests that many areas of expertise and experience are necessary to solve the relevant real-world problems on which these projects focus. This finding emphasizes one component of the NHOLC framework - bringing together diverse stakeholders with a variety of expertise and lived experiences.

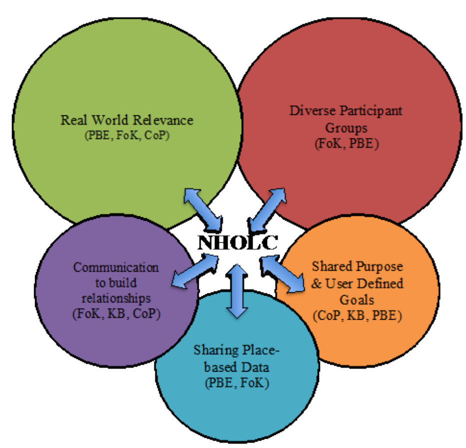
Building on the community's past knowledge is also a component of the original theoretical framework that varies across the factors. Factor 3 did not see building on the community's prior knowledge as important, while the other factors were neutral about this component of the theoretical framework. These findings can be based on the fact that each of the case studies has a different level of prior knowledge available for participants to use. For example, the WeatherBlur project is new and does not have a large store of past data. Public Lab, on the other hand, has a glut of past knowledge about regional environmental monitoring projects and low-tech tools to use for data collection. Vital Signs has a valuable store of past knowledge and data but participants do not necessarily need to use it to complete their projects. Based on the findings of this study, building on past knowledge is not a key design principle of online collaboration but is worthy of further study.

Participant-driven inquiry and decision making is a component of the original theoretical framework that was hotly contested amongst the factors. Statements related to shared goals, user-driven inquiry, shared responsibilities and decision-making fell all over the map. As Factor 1 highlights, a clear understanding and commitment to the shared goal of the project and user-driven inquiry is extremely important. Factor 2 can be interpreted to believe that it is not important for everyone to have one shared goal since everyone comes to the project for a somewhat different purpose and individual goal in mind. In juxtaposition, factor 3 considers shared goals and user-driven inquiry of neutral importance. This might be for a variety of reasons. Although each of the cases studied offer the ability for users to create new inquiries and define new goals, not every participant took advantage of that ability. Many participants expressed interest in doing more user-driven inquiry, but for a variety of reasons including time and low-confidence in their ability to do so, they did not take advantage of this design element in the online community. This low-confidence in participants' abilities to do user-driven inquiry, but a high level of interest highlights a gap in the field that new citizen science initiatives should begin to address with professional development and added supports for user-driven inquiry. Within two of the cases, the democratization of science as driven by the public was a core founding philosophy while one of the cases did not start out with that ideal but has been moving toward user-driven inquiry in recent years. For all of these reasons, the theoretically driven design principle of user-driven inquiry and the evolution of shared goals should remain an important and highly valued design principle for online collaboration in citizen science but how they are operationalized in online environments needs further exploration and explanation.

Reflecting on the findings of this study it is clear that the original NHOLC conceptual framework should be revisited and revised. The findings from the Q sort seem to suggest that emphasis should be heavily placed on the diverse participant groups component of the framework. The fact that participants can collaborate with individuals - who have new information relevant to their interests - that they may never have had the opportunity to connect with if it were not for the online community is an important and powerful driver in these communities.



Original



Revised

Image 3: Original Versus Revised NHOLC Conceptual Framework

The findings also suggest that authentic real-world problems that are relevant for learners needs to be a highly prioritized component of successful online communities for citizen science. Across all of the projects and factors that emerged, real-world relevance was core to each individual's experience. This emphasized component of the framework brings a new question into focus. Namely, how does an individual define or determine relevancy and real-world applications. In reflecting upon how important this component was to individuals, but yet somewhat undefined, highlights the need for further study to answer this emergent question.

The three additional components – communication, sharing place-based data, and a shared purpose – were all very variable in levels of importance to collaboration in each factor. But each still played a key role in individual's experiences. Additional research is needed to better understand the role of each of these components and how they could be revised to increase the impact of the NHOLC conceptual framework.

Linking the NHOLC Conceptual Framework Back to the Future of Citizen Science

This paper explores how sociocultural learning theory can inform design principles for online citizen science learning communities in order to inspire local environmental action. To answer this question the paper defines a new conceptual framework that builds off of four key sociocultural learning theories - Wenger's (2000) Communities of Practice, Scardamalia and Beretier's (1994) Knowledge Building, Gonzalez and Moll's (1992) Funds of Knowledge, and Sobel's (2005) Place-based education. The research presented applied the new interwoven Non-hierarchical Online Learning Community

(NHOLC) framework to a multiple case study of 3 citizen science projects that use online learning communities as a core component of their program.

Past research in citizen science contexts has shown that individuals have greater motivation to engage and learn if the topics being explored are **relevant** to their everyday lives (Falk, 2001; Dierking, 2010). Past research also indicates that individuals gain additional motivation if they can directly **affect the learning** process, content, or outcomes/actions (Bonney et al. 2009; Falk 2001). And prior research also indicates the value of participants having the opportunity to ***do the work of scientists*** – and experience the same thrills of inquiry, debate, and new questioning that happens during true scientific inquiry relevant to their interests (Bonney et al., 2009). The findings of this study certainly align with this prior research, but it also adds some fresh new insights into how online spaces specifically can be structured to enable collaboration between participants in online communities for citizen science. The findings represented here present the theoretical foundations, conceptual framework, and essential design principles for online citizen science projects. The findings provide a starting point for researchers and practitioners to further develop this area of work. Findings from this study suggest, the design elements of the NHOLC framework that rise to the top as important design elements for use in online learning communities for citizen science are:

1) Access to tools (data collection protocols, research notes, maps, data analysis) and practices (user suggested improvements on how to collect data, how-to guides) needed to solve authentic, real-world problems; and

2) Diverse stakeholder groups from vast areas of expertise (both professional and lived experiences).

The other elements of the NHOLC framework are important to collaboration for specific participant types and are worthy of additional study related to how to foster or challenge collaboration online within specific contexts (e.g. targeted audiences). In addition, further research is needed to understand exactly what forms or tools and practices are needed to solve problems, as well as foster collaboration and local action. It is hoped that the findings of this study provide a framework that will contribute to the design of other citizen citizen-based online communities that want to leverage the power of our modern digitally connected society to solve local and even more global environmental problems.

Chapter 3: Designing for Online Collaborations and On-The Ground Action In Citizen Science: A Multiple Case Study

The Shifting Landscape of Citizen Science

The scientific community has eagerly embraced growing global connectivity to engage with the general public and ask for assistance in collecting data for their research (Bonney et al., 2009). The involvement of local people in all aspects of scientific inquiry through citizen science can lead to faster and more reliable data collection (Newman, Crall, Laituri, Graham, Stohlgran, Moore, Kodrich, Holfelder, 2010). This, in turn, can inform environmental decision-making at a much faster rate that more traditional scientific approaches (Mueller & Tippins, 2012).

But the level of citizen participation no longer needs to stop there. Citizen science projects have the potential to go beyond, for example, learning facts about the monarch butterfly. Projects can bring people together from different parts of the world via online communities to learn, in this instance, how their region relates to the butterflies migration routes and life cycle. Those same projects can empower participants with tools and strategies to address the threats facing the monarch and the ecosystems upon which it depends (Mueller, Tippins, & Bryan, 2012).

Citizen science can be more than just a service that the public provides for the scientists. It can also be a means for communities and individuals to ask their own scientific questions as they work toward building healthier and more sustainable communities (Jenkins, 2011). Leveraging new opportunities in citizen science, such as online communities, can empower the public with tools to understand their environments better, share those understandings with a broad audience, and exponentially amplify connections across the globe (Mueller et al., 2012).

There are a small number of citizen science projects that have realized this vision through the use of online communities (Tippins & Jensen, 2012). The purpose of this study is to understand the range and variation of the structures of these online communities and the programmatic drivers that foster collaboration and on-the-ground actions. To do this, the paper explores three online citizen science communities—WeatherBlur, Public Lab, and Vital Signs. The Non-Hierarchical Online Learning Community (NHOLC) conceptual framework (Kermish-Allen, in prep), grounded in sociocultural learning theory, is applied to each project to understand the characteristics and design of each project.

In this paper, the reader is first introduced to each of the projects included in the study. To frame the theoretical grounding of the study, a brief description of the NHOLC conceptual framework follows. The paper will then outline the methods used including semi-structured interviews. The findings then explore the range and variation of the NHOLC components by sharing participants' experiences of the projects. The findings pay special attention to the technological functions of the online community and how they supported the participant experience. Design principles to foster each component of the NHOLC framework then emerge from commonalities across the three projects. In the discussion, the author reflects on the role of these new design principles in future citizen projects and the new areas of research that still need to be addressed.

An Introduction to the Projects Explored

Public Lab

Public Lab is both an international online community and a non-profit that grew out of a grassroots initiative during the Deepwater Horizon BP oil spill in 2010. It enabled communities affected by the spill to access data about where and how much the oil was spreading. Public Lab developed and shared the design of "community satellites"—helium balloons and kites mounted with inexpensive digital cameras—with the greater community and asked people to use them to collect and share data online about the spill.

Today, Public Lab is an online community where participants can learn how to investigate a wide range of environmental concerns using inexpensive DIY techniques. The list of tools Public Lab uses has grown to include DIY spectroscopes, air particulate sensors, water quality tests, and many others. The online community is an open network of educators, technologists, scientists, and researchers working to create, share, and use low-cost environmental monitoring techniques in communities from New Zealand to New England. This community has supported environmental actions ranging from aerial mapping for monitoring purposes (measuring waterway pollutants, drought conditions, plant health, invasive species, industrial pollution, etc.) to water quality testing to air quality monitoring—with opportunities to engage in local actions related to the research.

Vital Signs

Vital Signs is a project of the Gulf of Maine Research Institute that identifies and documents invasive plants in the Northeast United States. It originated as a citizen science project for K-12 classrooms, and has since grown to include land trusts and master gardeners. The online community provides a venue to learn about which species are appearing in the region and to participate in "missions" to find specific invasive species, and a space to upload findings. Participating scientists and species experts confirm species identification. The Vital Signs community promotes communication online between citizen and species experts where they exchange comments about the accuracy and context of the data.

Recently, Vital Signs added a "design your own mission" function that allows participants to devise their own investigations. Many participants have engaged in action by hosting community events to educate the public about the presence, spread, and concerns connected with specific invasive species. Others have conducted removal or remediation of invasive species. Species experts provide guidance online, and in some cases in–person, to determine the most appropriate action to deal with the species in question.

WeatherBlur

WeatherBlur is a project of the Maine Math and Science Alliance funded by the National Science Foundation. It brings together scientists, fishermen, and K-8 students and teachers to explore the local impacts of shifting weather and climate change via an online community. The WB learning community uses online technologies to facilitate "co-created" citizen science projects. New questions about authentic real-world issues emerge from the participants themselves and are refined in partnership with participating scientists. These co-created projects are rooted in place-based weather and climate data and questions that matter to citizens and provide highly valued data to scientists.

The online community shares pictures, videos, and local news stories about topics of interest. During the pilot phase of this project, a bycatch study used lobster traps to investigate organisms that live amongst lobsters. It revealed a shocking number of these invasive European green crab (*Carcinus maenas).* Members asked questions about each other's data and provided suggestions for more accurate data collection. In August of 2014, a task force on green crabs solicited a summary of the WeatherBlur investigation. This report played an important role in developing new regulations to minimize threats posed by the crabs.

Typically, scientist-executed monitoring to inform management leads to implementation of policy decisions within three to nine years (Theobald, Ettinger, Burgess, DeBey, Schmidt, Froehlich, Parrish, 2015). In the case of WeatherBlur, this process took less than one year, as local stakeholder groups leveraged the power of online communities. All learners in this situation witnessed the impact their shared observations had on developing and implementing solutions to a local environmental challenge.

Each of the cases described above provides an online space for diverse stakeholders—scientists, youth, teachers, interested community members such as representatives from natural resource based economies—to ask questions, share and analyze data, collaboratively solve personally relevant scientific questions, and build new knowledge together. The goal behind all of these projects is to increase the participation of local people in environmental monitoring, which can lead to accelerated research findings and more rapid policy changes to tackle environmental challenges.

Building on Theory to Inform the NHOLC Conceptual Framework

What do we already know about how people learn and collaborate that can guide the development of effective online citizen science communities? Sociocultural learning theory is an ideal starting point, due to its emphasis on the value that people, place, and history can bring to the learning process.

Sociocultural learning theory is rooted in the interdependence of social and individual processes in the co-construction of knowledge (Kozulin, 2002). The individual is always closely related to the social spheres and groups within which he/she functions, thus the goals of an individual are closely related to the group's motives and purpose (Tobin, 2012). Using a socio-cultural approach to develop online learning communities provides a lens for investigating the interconnectedness between the individual and social spheres mediated by modern technology (Bencze & Alsop, 2014).

The NHOLC framework provides a powerful starting point for designing and studying online spaces. One expression of sociocultural learning theory, Communities of Practice (CoP), focuses on how a group of individuals work and learn together. Integration of CoP theory helps inform how an online community might function. Place-based education (PBE) links the work of the community to the relevant interests and place of the participants. Knowledge Building (KB) guides the community with the intention to build new knowledge together related to the citizen science question mind. Funds of Knowledge (FoK) provide the framework with guidance for how to value diverse lived experiences and not just the "usually suspected" forms of expertise. This interwoven framework places emphasis on:

1) Bringing together diverse participant groups from widely differing areas of expertise to enable multi-directional learning opportunities in which everyone that joins the community has something they can offer and teach others within the community

2) Enabling participant-driven real-world investigations that are personally relevant to participants' lives

3) Sharing project purpose and goals

4) Enabling communication structures to build relationships and roles amongst a diversity of participants

5) Sharing place-based data across geographic boundaries

Image 1 below highlights how the core concepts of each guiding theory have been woven together into the five focus areas of the NHOLC conceptual framework.

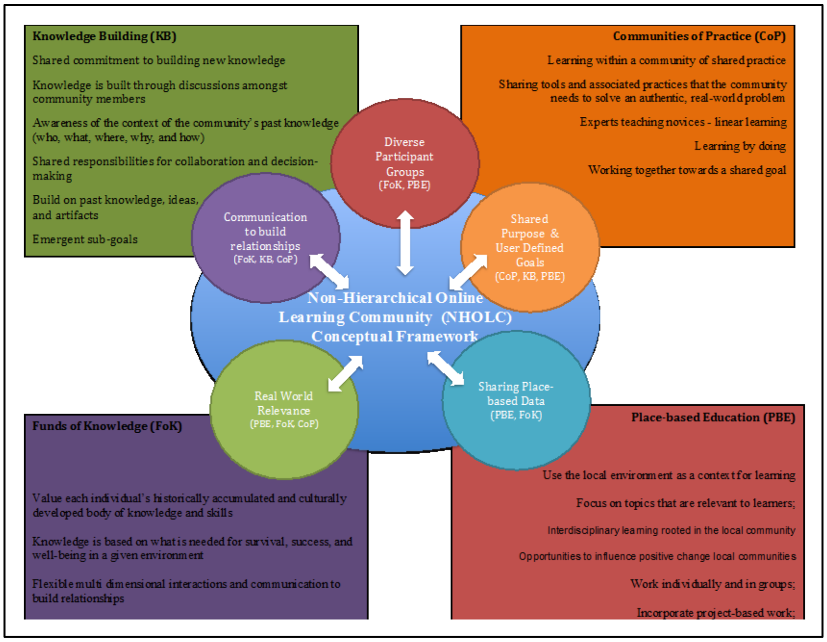


Image 4: The evolution of the NHOLC conceptual framework

Applying the NHOLC Framework to Understand Experiences of Community Members

This study employs a multiple case study design to determine the range and variation of the functions (technological and programmatic) available in each online community. The cases chosen were the best examples found that had shown success in using online citizen science communities to collaborate and make environmental actions happen in participants' backyards. The NHOLC conceptual framework is applied to three online communities for citizen science projects: Public Lab, Vital Signs, and WeatherBlur. A combination of online observation protocols, participant interviews, and focus groups are used to triangulate the different datasets and reveal how components of the NHOLC conceptual framework are present in each project.

A semi-structured interview protocol is used to understand: 1) What did the community members experience? 2) What compelled members to participate? 3) What kinds of actions (personal and project-level) resulted from their participation? 4) Which components of the NHOLC framework did the community member experience? and 5) Which functions of the site facilitated the community member's experience of each component of the framework?

Box B: Site Selection Criteria

Site Selection Criteria

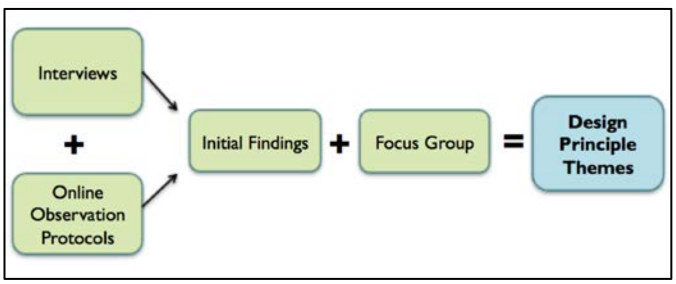
4. The citizen science project uses an online space to:
    a. bring multiple stakeholders together to answer questions relevant to the project (diverse ages and areas of expertise–for example, teachers, students, scientists, interested citizens, etc.);
    b. bring together geographically diverse individuals to share place-based data;
    c. upload and share data via mobile and/or desktop technology with all users;
    d. analyze data;
    e. identify new areas of inquiry;
    f. provide an opportunity for users to connect with each other via a variety of means (discussion posts, messages, etc.).
5. The online space has:
    a. been in use for six months or more;
    b. funding that remains active through June 2016;
    c. the ability to record and capture discussions online between users.
6. The overall citizen science project:
    a. has evidence of environmental actions implemented by participants due in part to the project;
    b. is committed to working with individuals of different ages and expertise (e.g., youth and adults; students; civic and science professionals);
    c. is willing to share activity log data with this researcher;
    d. is willing to reach out to project participants for surveying and interviewing purposes;
    e. is willing to support staff time and opportunities to participate in researcher interviews and observations.

A total of 20 interviewees are included in the study to represent the different types of groups that use each project, such as scientists or experts, project coordinators, and general citizen scientists including teachers, and community advocates. There are 5-7 individuals from each case study. Each interview was conducted via a *Zoom* video-conference and was approximately 60 minutes. The interview protocol is found in Appendix 1.

In addition, the study includes a semi-structured videoconference focus group of the coordinators of each project. They were asked to review findings described in this paper and confirm that what reported is consistent and reliable. The group was also asked to discuss the recommended design principles for each component of the framework and how it applies to their current and future work.

A simple online learning community observation protocol was used to provide further detail about how each online community is structured and functions. This protocol is used up to 3 times per site and is completed by the lead researcher. The protocol can be found in Appendix 2.

Image 5: Data Analysis via Selected Coding



The analysis of the interview data is completed using a convergent parallel mixed methods design (Creswell, 2014). Using a selected coding scheme that is grounded in the NHOLC conceptual framework the multiple data types collected, interview and online observations, are used to determine the range and variation of the essential design principles. These initial findings were then shared with the focus group for refinement and reliability.

Designing for NHOLC Components

In the sections below, the expression of each NHOLC component as seen in the projects is explored in detail. Overall themes and recommended design principles begin to emerge from the data. Special focus is placed on understanding how the technological and programmatic supports facilitated members' experiences of the NHOLC concepts in each project.

Incorporating Diverse Participant Groups

To answer the often inter-disciplinary questions that inspire citizen science projects, a variety of stakeholders need to come together, share their expertise, learn from each other, build new understandings, and design potential solutions (Barton, 2012). This form of citizen science may provide a non-threatening venue for communication between these often disparate groups that would otherwise not be willing to share information with each other (Mueller & Tippins, 2012).

Looking across the three case studies, there were a variety of programmatic and technological design principles that each program used to incorporate diverse user groups. While each project had varying degrees of success three design elements were common to all three projects as they incorporated diverse user groups.

1. Provide easy access to all members

Each of the cases used a variety of methods to help their members find others who could provide the expertise and insight needed for a project. Public Lab used topical and region-specific list-serves that fed directly into individuals' email inboxes. Vital Signs assigned species experts to each mission, directly connecting members with expertise in the given research project who could confirm or deny sightings of the targeted invasive species. And WeatherBlur used a variety of filtering functions to assist members in finding others that had the expertise and experiences they need to move their projects forward.

> *"If it wasn't for the site I would never have known that there was a technological issue with measuring hydrogen sulfide and I wouldn't be contributing. I'd be off here in the middle of NC and I wouldn't be connected with these people in Los Angeles, Peru, or India and places where they do the fracking…I wouldn't have access to the questions they are all interested in and I wouldn't be able to contribute. I would have never known about this new application of my area of expertise (electro-chemicals) to understanding hydrogen sulfide pollutants." – Public Lab member*

As illustrated by the quote above, the key feature was a way for members to find others that had information, expertise, or general experience in an area that applied in their own contexts. The technology was the tool that connected members across wide geographic and demographic distances. Only through the online connections were members able to build new knowledge together. This combination of online and on-the-ground relationships that developed between members led to the successes of each of the projects.

There is a lot of variation in the way that profile pages of members were structured and used in each of the projects. In Vital Signs, the public profiles of participants were not searchable and did not provide a great deal of information other than the town the participant lived in and the particular species of interest. This made it difficult for members to connect with each other and expand any collaborations or conversations around common topics. The only way a user could connect with another member was to comment on a data post from that person.

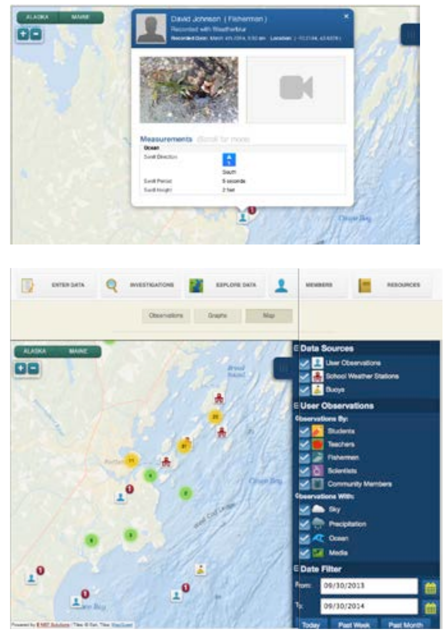
In Public Lab, public profiles contained a running list of all comments, research note edits, and other actions completed by the member. In addition, each member could share their area of interests and expertise, where they live, and other information about why they were participating in the community.

In WeatherBlur, profile pages included very similar, but less detailed, information about each member. WeatherBlur members could choose to view the personalized introductions of others, including the fishermen (highlighting where and what they fish and what they are excited about sharing with the community); the scientists (describing their areas of expertise and what topics they were looking for help and partnerships in); or participating schools (outlining interesting questions and past investigations that the school had worked on). However, the WeatherBlur profiles are not currently searchable in any way. For example, a member cannot search for a scientist, a fisherman, a student, or a school with a specific area of expertise to help solve a problem.

Image 6: Vital Signs Mapping feature

(retrieved from www.vitalsigns.org in the public domain)

Image 7: WeatherBlur Mapping feature



(retrieved from www.weatherblur.org in the public domain)

Maps played an important role in connecting with members on Vital Signs and WeatherBlur. In WeatherBlur, data and media posts were seen on a map that could be filtered by user type (fishermen, student, school, scientist, etc.), user location, and user data. By looking at the map, one could quickly see who was posting what. This feature helped users quickly find others interested in similar topics and data types. In Vital Signs, each data point was shown on a mission-specific map and could be a quick way to ascertain who else in a member's local area was posting data and which species they were looking for. Vital Signs members could filter the map by species, but not any other criteria.

A key feature unique to Public Lab was a recommendation list that appeared on a member's profile page. The recommendation list alerted members to individuals interested in similar topics, users starting new research notes about topics that relate to projects they were involved in, and other items related to the information that the user stated in their profile page. From there, users could visit the profile pages of anyone that came up on the recommendation list, visit the research notes related to the similar topics, and connect with others that they would otherwise have never known about.

2. Support community-led responses and a hands-off staff

The dynamics between community membership and program staff was quite different across the cases. However, it was clear in each project that productive online discussions evolved among diverse groups when program staff did not directly answer members' questions, but instead gently deflected questions back to the community.

Public Lab staff consistently did not answer user's questions directly. Rather, a staff member steered community members towards a list serve, interest group, wiki, or research note where they could find others who could assist them with their question. This design element may seem like a small thing, but in fact, it was a key reason why the online community was able to function as it did. When members were turned back to the general community to find the information they seek, they had to take a few risks and reach out to others. If the staff had just given an answer they would not have engaged with the rest of the community. In addition, the community shared the responsibility for bringing new individuals into the conversation. Public Lab also recruited "organizers" from existing users who were active on the site to help organize projects in their local region or in topics online where they had particular knowledge. The organizers created “welcome moments” for newcomers to Public Lab and encouraged newcomers to connect with more people to continue the conversation.

In WeatherBlur, program staff did not answer member’s questions, but instead asked the member a reflective question, such as “Have you connected with Dr. Lee, she might be able to help you address your question.” In Vital Signs, staff members addressed some general questions, but any questions related to the missions (invasive species projects) were addressed by the species expert for that mission. All of these approaches fostered conversations between the diverse participant groups in each project, although each met with varying degrees of success.

3. Fostering online communications facilitates on-the-ground activities

An interesting dynamic seen in all three cases is how both the online and on-the-ground worlds came together. For example, via the list serves in Public Lab, members posted local gatherings for developing new skills or just chatting in person. The gatherings brought diverse stakeholders together to learn a skill such as how to use a kite for aerial imagery, or simply discuss a hot topic for that region.

The online space played a different role for different members. For some, especially those that live in a more urban area, the online space was used to find others locally and then meet in person to work on a project. For many others, it provided a tool to find other people from around the world with a shared interest. In Public Lab, the site was used as a resource to invite people to in-person events, share ideas, and alert all users to happenings in each region.

In WeatherBlur, members designed their local investigations on the ground with a physical community of people, while the online community provided the support and expertise to actually carry out the investigation. For example, fishermen and students might identify an issue or question, but then go to the online community to connect with others to help define data collection protocols or interpret data.

In the Vital Signs example, the core projects were designed by scientists/species experts and then shared online with a greater community to complete the on-the-ground data collection. Without the structure of the online community, the species experts would have no access to citizens living in ecosystems at risk from the targeted invasive species. In addition, the citizens would not have access to the species experts who confirm or deny the invasive species' presence or absence. In summary, the online community can provide a space for communication that leads to on-the-ground environmental actions.

Reflecting on diverse participant groups and how to support them online

While each of the case studies incorporated diverse participant groups into their programs, they did so in various ways. Public Lab brought together and supported a very wide range of participants from across the world incorporating experts in designing environmental monitoring equipment and methods, community organizers, environmental activists, and many others interested in understanding their world better. Vital Signs had a more targeted approach to membership, as the project focused specifically on students, teachers, a few community members and organizations such as master gardeners, and species experts. WeatherBlur currently targets only coastal communities and a diverse membership of fishermen, students, teachers, and research scientists.

The online citizen science communities explored in this study employed a variety of strategies to support their diverse constituents. These design principles can be grouped into four themes that citizen science projects can build on to foster collaboration amongst diverse participant groups:

1. Providing easy access to all members
2. Supporting community-led responses and a hands-off staff
3. Fostering online communications to facilitate on-the-ground activities

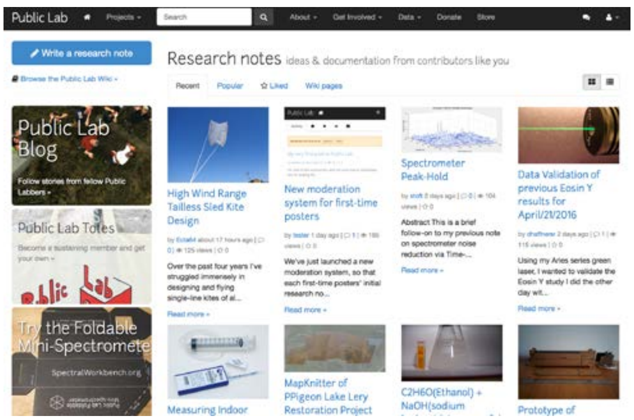
Sharing Place-based Data Across Geographic Boundaries

Accessing local data from a very large geographical span with the aid of locally trained volunteers is a core tenet of citizen science. This dynamic between online and on-the-ground worlds provided new opportunities for members of these communities. At the same time, scientists gained access to audiences and locations that they would never have reached through the traditional research processes. There are a variety of programmatic and technological design principles that each program used to share place-based data across geographic boundaries. While each project had varying degrees of success, there were five clear design elements that clearly led to success in sharing place-based data.

1. Full access to past and current projects

Each project provided the opportunity to view both ongoing and archived project data. With this design principle, the community always builds upon existing knowledge of the community.

Image 8: Public Lab Research Note Dashboard



(retrieved from www.publiclab.org in the public domain)

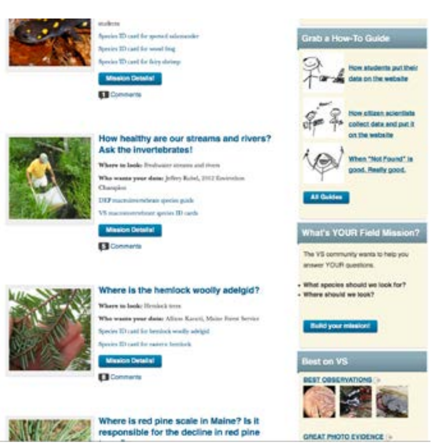
To accomplish this task, Public Lab used the research notes function (image 6) —editable, detailed posts that can include various forms of media, including pictures, videos, and data sets, external links. One community member created each research note and any other member could comment with questions, suggestions for improvement, etc. Community members used research notes to share information on *how* a local investigation was developing, progresses during implementation, what the findings were, and how that led to additional work. A research note could also detail the development of a new tool to be used to collect data.

The diverse participant groups in Public Lab created an interesting dynamic. Some members were highly focused on an issue in a specific region and shared research notes about ongoing projects, such as testing water quality in regions where fracking was active. Others were equally focused on a tool that could be used across different regions, such as a tail design to stabilize a kite during aerial photography sessions.

Research notes could be linked to a region, type of issue addressed, and other tags that caused it to show up on personal recommendation lists. Access to this type of information gave members the ability to gather their own data with tools designed by others in the community. They then could share data with the community and receive feedback on how to improve their methods or interpret the results.

WeatherBlur used a very similar method, called "investigations" instead of Public Lab's term "research notes," to share past and ongoing projects. Any member could start an investigation and all members could view and comment. One additional feature of WeatherBlur was the ability to upload numerical and categorical data to a searchable database, with data types tagged or linked to specific investigations.

Image 9: Vital Signs Mission Dashboard



(retrieved from www.vitalsigns.org in the public domain)

Within Vital Signs, the feature illustrating this theme was called a "mission". Member search for interesting missions to participate in on the dashboard seen to the left in image 7. Originally, members could only join a specific pre-identified mission: for example, a mission researching the invasive Asian green crab or purple loosestrife as members posted sightings across the state. Members posted a picture and associated data (where it was found, date, observer, context of sighting) with each sighting of an invasive species. Members could also search for the location where that species was found and who found it.

2. Access to data that are specific to each place and topic

All of the projects included various ways to link data to place and specific topics. Both WeatherBlur and Vital Signs used maps and databases that could be filtered by data type (precipitation, atmospheric, water, temperature, and other types), geo-location and time stamp data (data and place), user type (which diverse group), and media type (photo, video, other). Public Lab did not have a method or location for members to upload all of the data gathered from the various local projects. But

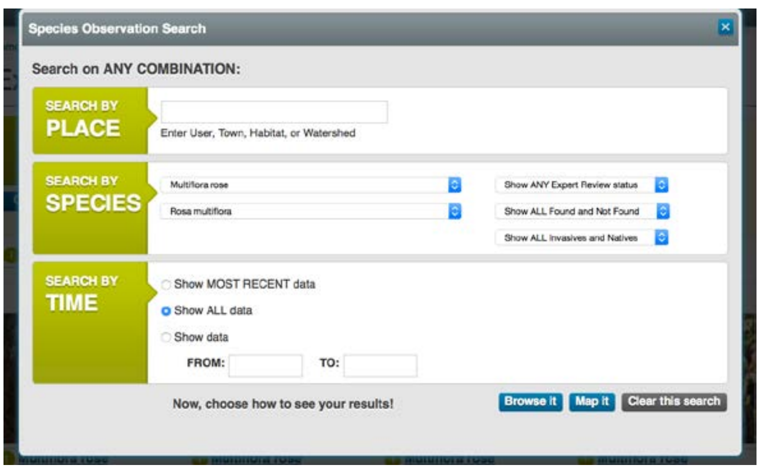


Image 10: Vital Signs Data Search Filter (retrieved from www.vitalsigns.org in the public domain)

through the personal recommendation list, members received constant updates on revisions to research notes related to their personal interests in specific regions and topics, including additional data sets, new findings, interpretations of data, or new methods for data collection.

In WeatherBlur, the activity feed on the front page highlighted the most recent activity on the site, including who had posted new data to an investigation, where that data was gathered, and all comments. This tool made it easy to see what the community was most interested in at any given time. It also provided a quick reference guide for any member to see who was sharing specific types of data from different regions.

Public Lab did not have running data sets for the entirety of the project, but they did provide a separate page for each initiative (water quality, air quality, etc.). Members shared their work on each of these projects, and the posts were tagged to topic and location. The search function in Public Lab has been problematic: many members stated that a more powerful search or filtering tool in these locations would help the community function better.

Many members from all of the projects suggested that it would be helpful for online communities to provide venues to share ongoing data streams related to place. Examples of this could include long-term weather data, historical data sets, or other publicly available datasets monitoring environmental conditions in the region.

3. Visual representation of data on a map

All of the projects utilized maps to share data, happenings, and build community both online and off-line. Both Vital Signs and WeatherBlur used a main map where members could see all of the activity happening across the community. Members could customize the maps via filters to focus on data type, region, sub-project (investigation or mission), and, in some cases, user. This feature gave members a quick picture of what is happening. For example, members could easily see the full geographic range of an invasive species. A number of Vital Signs members suggested that it would be valuable to understand not only where species are found, but also where they are not found and what other species are found in proximity to the invasive in question.

Public Lab took a different approach. They offered MapKnitter, which gave members the ability to generate maps of their visual data (pictures, aerial imagery, and others), share them with the community, get feedback, and hopefully be of some use to others investigating similar questions. Some examples of how this feature has been used include: stitching together aerial images taken via kites and balloons to show how drought conditions are affecting native and non-native plant species, or where oil pollution from a local business is contaminating a public water way. MapKnitter was less effective in aiding members interested in finding active projects in their region.

4. Venues to discuss data collection methods

All three projects had the capacity for members to build and design their own projects. Some communities utilized this tool a great deal more than others. Public Lab was unique, in that the data types collected by participants were solely the product of the tools and questions developed by the community.

This reflects the origins of Public Lab, which was formed when community members felt they were not getting enough information during the Deepwater Horizon BP oil spill in the Gulf of Mexico. Community members wanted to understand where the oil was, where it was heading, and its composition in order to evaluate the information released by officials. So, the community designed methods to collect their own data to get a better understanding of the geographic scale of the disaster. As stated by a Public Lab co-founder,

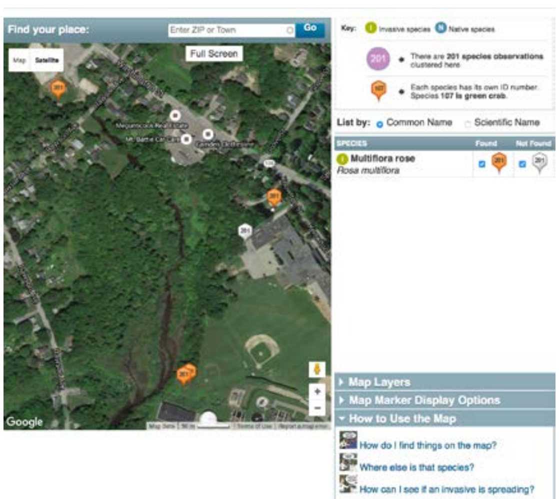
> *"If we wanted to find out what was really in the tar balls, we'd have to send it to a lab, but instead we found a simpler way to do that test onsite. Now people can build a simple oil pressing kit to look at different samples and basically break apart the color fingerprints to detect what the chemical make-up of that that sample is."*

In both WeatherBlur and Public Lab, members used a variety of discussion methods (posts to research notes or investigations and list serves) to determine what types of data should be collected to answer the research question at hand. The data collection methods were defined and refined via similar communication structures. The advantage of this approach is that the data collected is very responsive to the needs and interests of the community; however, data quality may suffer if scientific research experts do not weigh in on the decisions.

Vital Signs design favored better data quality, rather than responsiveness to members' interests. Scientists or invasive species experts decided upon the data collection methods prior to inviting the community to participate, an approach that is aligned with more traditional citizen science efforts. Vital Signs is beginning to explore a "create your own mission" function, but at this time it does not include any discussion from the community in identifying how or why specific data should be collected to answer the question at hand.

5. Provide an embed data analysis platform

All of the projects incorporated some form of data analysis function. Vital Signs included user-friendly filters including species observations (date, town, species, found or not found, etc.), habitat analysis (water quality, soil moisture, vectors, tides, etc.), species evidence (site photo, evidence, field work notes, etc.), species analysis (count, coverage, reproduction, size, etc.), general analysis (latitude, longitude, watershed, diversity of species, etc.), and details of how the data was gathered (species ID tools, water quality tools). These filters allowed for some initial data analysis, but any deeper analysis of the



place-based data had to be performed in a separate program outside of the online community. Members usually used Excel or another spreadsheet program to manipulate the data exported from Vital Signs to answer their own questions.

Image 11: Vital Signs Species Specific Data Analysis (retrieved from www.vitalsigns.org in the public domain)

Both Public Lab and WeatherBlur had analysis tools embedded in the site. WeatherBlur provided a simple graphing tool to give members the ability to compare precipitation and/or air temperature data (either in the same region or elsewhere) with regional NOAA data from 10-, 30-, and 60- year climatologies (graphs that show the historical average of max, min, and average data for a specific region). Using this tool, users saw how the data recorded by the community or themselves aligned with historical norms in any given place.

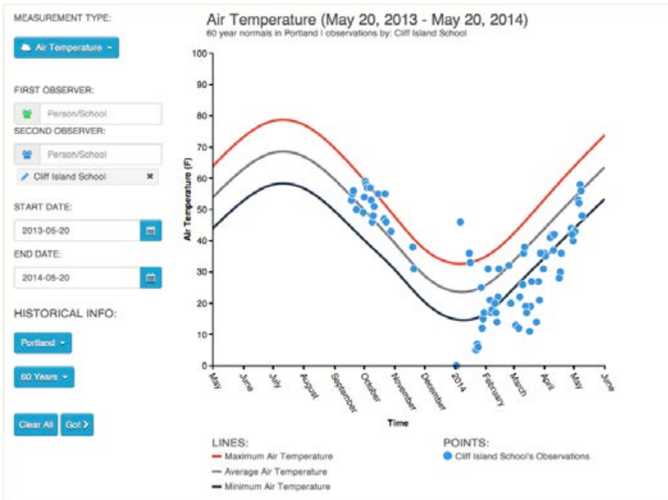


Image 12: WeatherBlur Data Analysis Platform in 2014-2015

(retrieved from www.weatherblur.com in the public domain)

Public Lab offered a variety of data analysis tools such as MapKnitter, Spectral Workbench, and Open Water. Spectral Workbench provides a space where members use the data captured with DIY methods, analyze and compare the spectra of that data, share them in an open database, and comment and collaborate with others. Open Water provides similar services for water quality data.

Reflecting on sharing place-based data and how to support it

All three case studies explored had a strong focus on place-based data. Each project had different methods for identifying who decides what data should be gathered, how that data was used, and tools for how it could be analyzed. At the same time, there are some general design principles for sharing place-based data that are common across all of the projects. The design principles discussed all build on the existing knowledge of the community through archiving, discussion, and personal connections. The features provide an added value for community members and eliminate the need to constantly "reinvent the wheel" as they figure out how to address the questions they have.

The online citizen science communities explored in this study employ a variety of strategies to support sharing place-based data, including:

1. Providing full access to past and current projects
2. Providing access to data specific to place and topic
3. Visual representation of data on a map
4. Venues to discuss data collection methods
5. Embedded data analysis platforms

Place-based data plays a significant role in catalyzing environmental action. The design principles involving sharing and gathering feedback from the community open the door to suggestions for what the data means and what to do about it.

Overall Shared Purpose and Member-defined Goals

The degree to which participants can define their own questions and projects is an often-contentious topic in citizen science (Theobald et al., 2015). The projects explored in this study are no exception. It quickly became clear that the concept of shared goals is more nuanced and differentiated that expected. While the overall purpose of an online community will draw a variety of groups and individuals in, they may have very different reasons for staying involved. The three design principles below describe the similar methods used to define each project's overall purpose and support members in defining and addressing their own sub-goals—keeping members engaged for the long term.

1. A clear overall purpose of the community

In their online sites, all of the projects explored used visual cues and artistic design features to give a clear idea of what each community was about. Pictures of members doing the type of work described throughout the community were very common on the front page. A simple background with large text conveying the actions members can take to get involved in the community was consistent across the projects. In addition, the overall purpose and intended outcomes of each community were clearly communicated up front in headers or a large central section on the front page.

The overarching goal of Public Lab as stated by one of the co-founders reads:

> *"to transform the ways that people view expertise and see their role in environmental projects. Everybody should have the ability to monitor their own environments…to be able to participate in the decisions that are being made about it…to speak robustly through using data and information in order to become part of decisions that are being made about their communities."*

Members of Public Lab most certainly agree with this overall theme. When asked about the overall purpose and goals of Public Lab, they discuss "empowering communities to get themselves out of environmental trouble," and "democratizing the research process to make scientific inquiry more accessible." These themes were present throughout the design and branding of the Public Lab site: on the front page, pictures show citizens gathering data outside (on a beach, in a wetland, on a boat) or working together to build one of the DIY tools for environmental monitoring.

The two overall goals of Vital Signs as stated by the program coordinator Voyer are: "1) to provide a venue for gathering a scientifically useable data set that is both useable and relevant, and 2) to foster science learning." Beyond the main page, the field mission page gave the specifics about the different ongoing data collection efforts (such as identifying Asian green crabs and invasive aquatic plant species). The field mission page also provided guidance about how to join the project, in what types of ecosystems the targeted species could be found, the scientists interested in the data, and what would be required to collect data for that project. The overall design, messaging, and marketing of the site provided visual cues that the project was about data and invasive species (although one needed to dig a deeper to see the targeted species and intended audience).

The WeatherBlur project had the overall goal of understanding the local impacts of climate change. The only place where that overall goal was voiced on the site was in a sentence at the top of the main page. New participants have noted that the design and messaging of the site did not clearly state what the project was about, which made it difficult to determine how or why to get involved.

2. Sharing stories of success and failure

As this study progressed, it quickly became clear that every individual is a member of each community for very different reasons. Individuals in this study come to an online citizen science community with their own set of questions, and their own goals and reasons for wanting to be involved in the project. For example, there were many Public Lab members that were only interested in designing new tools for aerial imagery, spectral analysis, or water quality analysis. They did not necessarily care how these tools are used for environmental monitoring on the ground. At the same time, other participants were involved in the online community to address a specific environmental question or concern in their own backyard.

The ability to read over past projects and see how they addressed members' individual goals and interests was a key driver in helping members determine if 1) they wanted to engage in the overall project at all, and 2) how they could use the community to address their own goals.

As a Public Lab member states, "People can ask a question about their real-world environmental problem and other people, like me, suggest ways to deal with it. People post their new tool that measures some environmental variable and other people at the site can see that and say, 'Oh, I could apply this to this particular environmental problem I have." It is through sharing how members attained their individual goals that community members learn from each other.

Different technological features of each community gave members the opportunity to find like-minded individuals with similar goals or find partners with the expertise to help them meet their goal. Public Lab accomplished this though list serves and research notes.

The list serve structure was specific by topic and region. For example, a member who hoped to connect with others in the Detroit region could find allies on the Detroit region list serve. Members interested in finding a better method for collecting data on the chemicals in a specific water sample would post questions and goals to the water quality list serve. List serves provided a direct link between members, delivered directly to their inboxes.

Research notes were a more formal method for members to share the progress toward a specific goal. For example, a member could use a research note to record the development of a new tool or to document a place-based data collection effort. These research notes are then shared with the community to help those with similar goals get started or overcome issues. All research notes have commenting features that provide the space for discussions around the evolution of a specific project.

As in the Public Lab example, WeatherBlur members joined with different goals in mind. Schools joined to integrate technology and place-based citizen science into the curriculum, fishermen joined to connect with each other and youth in coastal communities like their own, and scientists joined to gain access to data and networks of people interested in collecting data. The investigations space was where all of these different goals converged as members posted interesting questions and goals that they wanted to pursue. The investigation main page showed all of the different ongoing, completed, and newly developing investigations proposed by members. Each investigation listed who initiated the activity, who participated, and the goal of that specific investigation. This was made possible by the core functions of the site: 1) the commenting and discussion functions, and 2) the ability to share both photo and video evidence of what individuals were finding in each community.

In Vital Signs, the blog and "design your own mission" functions provided a venue where participants could declare their own goals and/or find others who shared those specific goals. At the time of this study, these functions were not widely used. When asked why, Vital Sign staff and members agreed, essentially, that defining their own questions was very hard and they were not quite sure how to go about it.

This concern is echoed across all of the projects. But it seemed that community members of Public Lab were able to overcome this hurdle. Members stated that were constantly exposed to others in the community struggling with the same concerns and challenges. Through the discussions on the site, members were able to see how others found ways to leverage resources (people, tools, and past projects) to ask their own questions and find answers. Perhaps a strong online community culture norm of defining, sharing, and addressing individuals' goals was the differentiating factor between Public Lab and Vital Signs in this case. This finding opens the door for new research in determining why some projects are successful in supporting user-defined inquiry and others still struggle.

3. Personal recommendation tools

Public Lab had a unique recommendation tool customized to each member's interests. For example, someone joins Public Lab with the goal of identifying the pollutants coming from a manufacturing plant's run-off into a local water supply. Then that individual starts reading research notes from another project that details the methods for how to identify specific chemicals in stream water. They decide to leave a few questions in the comments section to figure out how to apply this method to their region and water supply. The site tracks all of these activities and begins feeding this new community member other posts related to water quality testing. In a short period of time they are interacting with others online, asking questions, and applying what they are learning to answer the questions they have about the run-off.

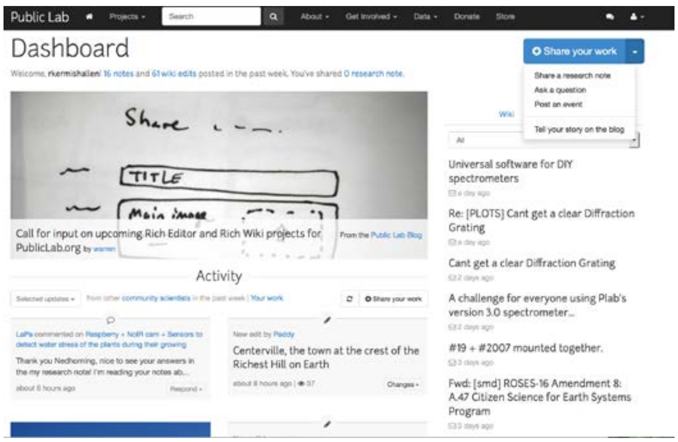


Image 13: Public Lab Personal Dashboard (recommendation list in the far right column)

(Retrieved from www.publiclab.org in the public domain)

Over time, a member's actions and clicks throughout the website builds a profile for that member. That profile contains information on the types of topics, tools, and regions the member is most interested in. The recommendation list function then begins to forward suggestions to the member of topics and other activities on the site that are similar to those they have been historically involved in. This function brings to a member's attention topics and people related to their interests that they may not have encountered without the recommendation function of the online community.

This function was not seen in the two other projects. But the need to connect the members and content throughout the community was seen as a high priority by everyone. The other projects were all working on tools that might be able to address this need, but at the time of the study did not have anything available to address it.

Reflecting on shared goals and supporting member-driven goals

This study has highlighted the need for projects to remain flexible to the needs and interests of members, while at the same time standing firm on the overall goal of the project. That goal brings members into the community, but the ability to address members' individual goals keeps them engaged. Accessible tools that support exploration of questions relevant to participants' interests and individual goals is paramount. The following design principles fostered this type of environment in the projects involved in the study:

1. A clear overall purpose of the community
2. Sharing stories of success and failure
3. Personal recommendation tools

Personal Real-World Relevance

The importance of learning in context is seen throughout all forms of sociocultural theory. Citizen science's focus on authentic real-world problems is a perfect fit for a sociocultural approach. The NHOLC conceptual framework brings a special emphasis on both place and traditional knowledge to the forefront. The projects explored in this study all worked toward bridging personal relevance, authentic real-world problems, and the tools/practices of citizen science to build new knowledge. The new knowledge created is specifically applied to the real-world topics that members of the community care about and have a personal stake in. The items below illustrate how the projects designed the online community to engage members in topics that have real-world relevance for them.

1. Methods to identify the value a member can bring

All of the projects had different methods for highlighting the different areas of expertise or special value each member brings to the community. Public Lab was clearly grounded in projects of personal real world relevance along two parallel tracks: 1) the actual local environmental issue, and 2) development of the tool to measure the impact of the environmental issue. For example, as a member of Public Lab that specializes in tool development explained,

> "*It is very important that the tools I am working on may be used for real problems. I am not going out and knocking on doors or rattling cages or digging holes where some big company has possibly dumped something, but at the same time I am offering the tools for people to go out and find that information. People can ask a question about their real-world*

> *environmental problem and other people, like me, suggest ways to deal with it."*

In Vital Signs and WeatherBlur, the teacher, student, and community participants all stressed the importance of knowing that they were collecting data that was both *needed* and extremely relevant to their lives. Simply receiving comments or confirmation of their post from a species expert quickly made the member feel like they were bringing something valuable to the community. As a WeatherBlur teacher participant stated, "When the kids got questions from scientists and the scientists wanted to know about a young person's observations—that got everyone talking." This was a major driver in initial and continued participation. On the other hand, when participants uploaded data and did not get any responses or feedback from members, they soon did not feel valued and often left the project.

2. Methods to quickly assess relevance of content to an individual's interests

In all of the projects, members had means to quickly gather information on a project and determine if it was relevant to their interests, whether under the investigations function in WeatherBlur, the mission function in Vital Signs, or the research notes function in Public Lab. These synopses of the specific member-driven sub-projects contained information about the research question, all participating regions, and all members that were adding data to the initiative.

These spaces usually also included easy access to an archive including all prior discussion threads between members over time, providing a searchable timeline for the evolution of the project from start to finish. With all of this information simply packaged, a member could quickly ascertain if the materials presented would be applicable and relevant to their own needs and goals. In addition, the member could easily identify the leaders of a specific project, and then reach out to them with questions about how the information presented could work in a different context. Public Lab and WeatherBlur had many examples of this interchange between members trying to figure out if a method that worked in one place could be used in a different place or context.

3. Linking online and offline opportunities

As the interviews progressed during this study, it quickly became apparent that members saw the relevance of these projects as they moved between the online and offline worlds. As expressed by a *WeatherBlur* participant and echoed by participants across each of the projects, "We crafted our investigations offline with members of the local community, but we grew the investigations together with online community members from everywhere."

Relationships and connections built in the online community do not exist in isolation. The work of the online community needs to be grounded in projects and connections made with the on-the-ground community to realize the goals of each project. Individuals moved back and forth as they looked for information in the online community and then applied it to real-world relevant topics. As they applied the insights in the offline world, they would return to the online community to share what they had experienced and learned, and ask questions to improve upon what they did.

This dynamic dance between the online and offline worlds is key to understanding how online communities and the topics they address are relevant to members. Unfortunately, this topic goes beyond the scope of this study. But it is clear that more research is necessary to understand better the dynamics between online and on-the-ground community building and action.

Reflecting on the personal real-world relevance of projects and how to support it

All of the projects explored focused on real-world relevant issues that the community—both online and on-the-ground—cared about. The online communities created an interesting dynamic between the online and the on-the-ground/offline worlds that is perhaps seen in the brightest light as we explore this concept of personal real-world relevance. In addition, the methods that the projects used to highlight that relevance did not just fall into themes as they did in the other sections of this paper. Instead, actual expressions of those themes were very similar across all of the different projects. To that end, the following design principles clearly provide guidance for supporting personal real-world relevance of online learning communities in citizen science:

1. Methods to identify the value a member can bring
2. Methods to quickly assess relevancy of content to an individual's interests
3. Linking online and offline opportunities

Communication to Build Relationships

Within the cases explored, there were many disparate groups of stakeholders. Building trust between members was of the utmost importance. Clear communication among members to understand what they were working towards and the current status of the community's knowledge was key. Within these online spaces, ubiquitous open free-form methods of communication and documentation ensured learning across groups. At the same time, members needed to feel safe as they shared new ideas or concepts that emerged.

This presents a risk however, since the interactions must take place within a very open structure. When dealing with children, adults, and sensitive place-based data, there are many risks to consider. In summary, the communication methods are the key to enabling the collaboration and resulting local action that happens in these online communities. The four design principles below illustrate how the projects in this study facilitated an effective communication structure to build the trust and cultural norms that culminated in the projects' successes.

1. Offer a few targeted communication methods

Public Lab had the widest range of communications technology available for members to use, including wikis, list serves, Google groups, means to comment on research notes, and more. However, newcomers to the site could find it difficult to know where to start. This Public Lab member summed up the feedback of many interviewees when he stated,

> *"There are lots of barriers to communication…As I said, the newcomers are scared. They don't know what to do, you have to decide whether to post a research note or edit a wiki or start a new wiki or just put something on the Google groups. It takes a long time to know how it all works. It's kind of a flaw in the system. Public Lab has used all of the available online tools or many of them to make it possible to communicate, but then it becomes a morass of which one to use and then if you want to go to Public Lab and find the answer to a question, where do you look?*"

On the other side of the spectrum, Vital Signs did not offer many opportunities for communication to build relationships. The only method available was commenting on data, which provided a platform for members to provide feedback, encouragement, and advice. It was also the only means of communication between species experts and the general citizen scientist. Due to the highly structured roles of the diverse groups, experts did not tend to reach out to other experts on topics of mutual interest due to the fact that there was not a venue for those discussions on the site.

On the other hand, a Vital Signs species expert noted, "Fluid real-time communication… removing any distance or time between what a person would see on the water and getting that information to someone technically minded that can address it is extremely valuable." The communication functions built into the site that made it quick and easy to share data for all to see, were well designed and achieved very effective communication.

This simple, streamlined approach may not build relationships, but it can lead to a quicker policy and action response.

WeatherBlur fell somewhere in the middle of this communication continuum. The core communication methods included commenting on data or discussion posts and personal messaging on members' profiles. At the same time, there were no communication limitations. The modes of communication were strategically designed for ease of sharing data and as much public discussion as possible. Full viewing and commenting features were available to every single member—there was no hierarchy of access dependent on age or role in the community. The majority of interactions were designed to take place via vertical commenting features associated with data posts, investigations, all forms of media, and analysis tools. Everyone could see and comment on everyone else's information and posts. This approach addressed the sort of concern expert members involved with Vital Signs expressed about not being able to access one other.

2. Fully open access, while remaining safe

In today's digital society, it can be a challenge to remain a fully open-access online community while maintaining the integrity of conversations and keeping members safe. The projects explored use a variety of methods and cultural norms to meet this need. In Public Lab, usernames accompanied most actions on the site, except for editing a wiki. This provided a means for members to "own" an idea and share it with the community. When members did this, they needed to be open to receiving feedback on those ideas. Public Lab members have continually and repeatedly mentioned feeling safe and unhindered in the online community, even when facing the thousands of members across the globe. A Public Lab member stated,

> *"I get the feeling people don't talk down to you in PL you know your idea can be somewhat silly but people won't talk down about it or anything like that so it really feels like it's more of a community of discovery. And even though what you may be doing could be done better, could be done more scientific, could be done with better methods…they appreciate the fact that you're out there doing it. And that's huge."*

When members were prompted to think about why they felt safe and supported, given the huge potential audience and unhindered communications, they suggested that it came down to two key advantages. First, the people that are drawn to Public Lab were genuinely interested in helping people. Second, due to the service ethic of the community, the community members supported and self-regulated the community together. When members saw behaviors they didn't agree with, there was a swift and fierce response. A Public Lab member suggests that,

> "*Communication is limited to a large extent by what people feel like communicating and I think that there's a certain anonymity to the Internet that encourages people to be more assertive than they would be if they could walk into the same people on the street."*

In the case of Vital Signs, the project designers paid special attention to communication structures, given the added risk of so many members being under the age of 13. The teacher participants served as gatekeeper to online communication. This created both positive and negative impacts. When teachers were engaged with the online space, they saw that students interacting online tended to participate in more online activities. On the other hand, if teachers were concerned about security or appropriate commenting etiquette amongst students in a public venue, they tended to significantly limit the time students spent online to just uploading data quickly and not allow commenting.

The very public nature of the communication structures of WeatherBlur created some hurdles for individuals who were not comfortable publicly asking questions or responding to questions. Initially, some teacher participants were wary of allowing their students free range and commenting access on the site. They feared that the content of a student discussion post would not be "professional" enough for the public. Although, after connecting with other teachers and seeing the other posts students were sharing with the community, teachers began to realize that,

> "*Kids loved going online and checking out what the other kids had posted—getting to know the other kids by their posts. You know we're kind of really isolated out here so kids getting to know other kids the same age as them they're doing the same thing. They're doing science and they're writing and it's always a nice thing to be able to compare it to somebody else's classroom." (WeatherBlur teacher participant).*

3. Personal recommendation lists

Communication to build meaningful relationships was fostered through the recommended match list on the Public Lab (mentioned in other sections above). The recommended match list suggested research notes and discussions that a member might be interested in, given other items they had searched for and read. This function served as a "best of" guide that helped members find conversations and other members that they may not have known to reach out to. A Public Lab member stated "The site is really instrumental in not only like you know wanting to post results and you know have a discussion or something but also in finding new things to do. That's what's interesting cause when you log on you never know what you're gonna see and some of it you will like and get really into." This feature was unique to Public Lab.

4. Encourage feedback

Trusting relationships are developed or lost via comments in these communities. As summarized by a Public Lab participant, "I publish a lot of research notes on the tools I develop and only 30% of them ever got any comments or any interaction at all and that's hard after you've worked hard on it…say you published two research notes at Public Lab and you get no responses or comments whatsoever. You may not publish any more unless you have an agenda to market something through your notes. You know people are looking at them but if you get no response, then what are you to think?"

This sentiment was strongly echoed by members of both WeatherBlur and Vital Signs. When a member was excited about sharing new information and then received no feedback from the community, it potentially had more of a negative effect than not posting at all. Based on these observations and statements, collaboration and communication seems to be most productive when the site drives members to new information and encourages them to provide feedback.

Reflecting on designs for communication to build relationships

Good communication is key to making online communities for citizen science work. With so many options for communication online, it is difficult to know which methods will work best for the intended audiences and outcomes. After reviewing the communication successes and challenges of the three projects included in this study, the findings reveal that there are four themes guiding successful design principles.

1. Offer only a few targeted communication methods
2. Provide a fully open access environment, while maintaining safety
3. Personal recommendation lists
4. Encourage feedback

Defining The Overall Design Principles for Online Communities in Citizen Science

In the sections above, this paper describes how each component of the NHOLC conceptual framework was represented in three online citizen science communities. The NHOLC conceptual framework was employed as a lens to understand what types of technical structures must be in place to support online collaboration and foster environmental action. To understand the participant experience, semi-structured interviews and online observations of interactions on the site were completed with an equal representation of user types across the projects. In addition, a focus group was convened to review the initial results and give feedback to validate and clarify each finding. *Image 2* below summarizes the design principles found for each component of the NHOLC conceptual framework.

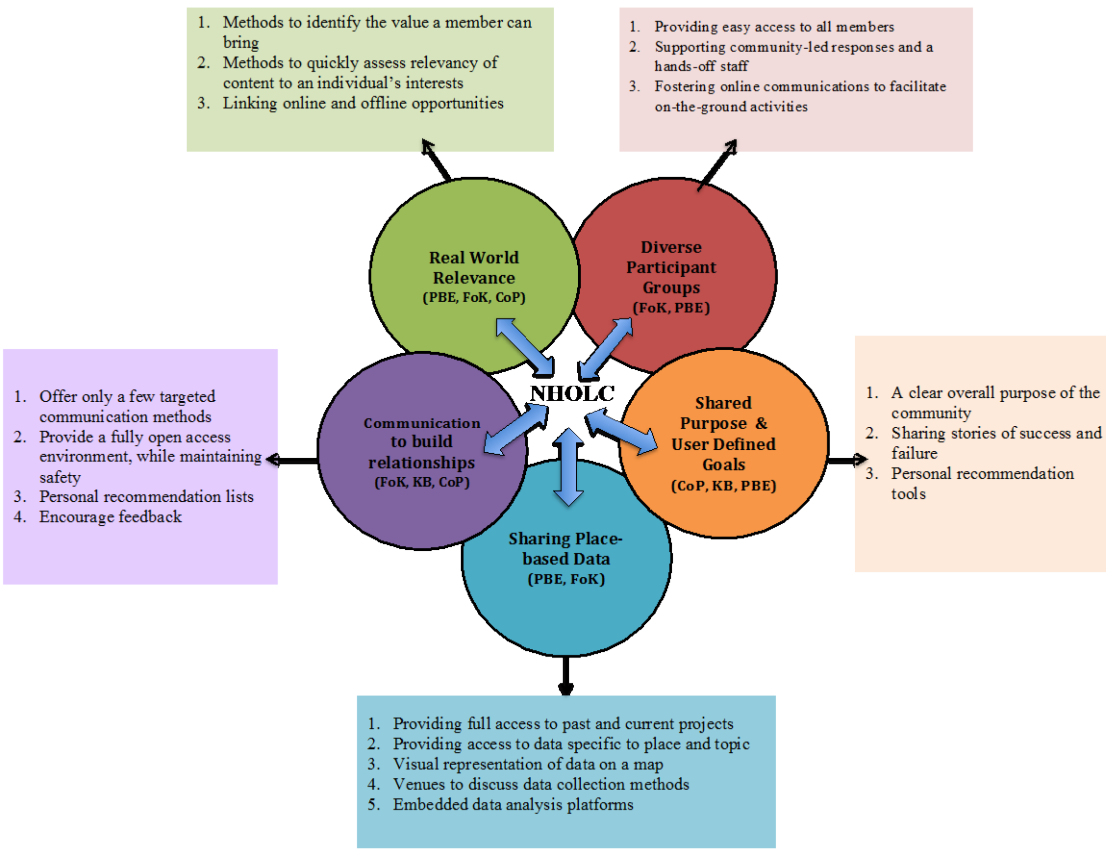


Image 14: Summary of the design principles identified for each NHOLC component

A surprising outcome of this work was that shared goals across the entire community are not as important to collaboration and enabling action as originally assumed in the NHOLC framework. In fact, the freedom to develop individual sub-goals that are relevant to members' interests was of much greater importance to the success of all of the projects. This theme is present across several components of the NHOLC framework, including diverse participant groups, personal relevance of real-world projects, and of course, the role of shared goals.

There is also strong evidence for the importance of personal connections for projects to succeed. The design principles that articulate how those connections can be made and fostered online provide a starting point for future research. Incorporating diverse participant groups was a strong theme throughout the entire study. This theme shines a spotlight on the types of learning experiences that become possible when unlikely allies are brought together around a common cause. In addition, the study uncovered new questions about the dynamics between online and offline activities and how they each build community in different ways.

In summary, to foster the types of collaboration and environmental action seen in the projects explored here, the following design principles should guide the development of online communities:

1. Provide access to knowledge from the community's past experiences (past studies, sub-projects or investigations, data collection methods, etc.)
2. Present information in a format that allows members to quickly determine if what is presented is relevant and usable for them
3. Connect members who have information and/or knowledge that others need
4. Alert members to activities (in person and online) related to their interests and goals
5. Offer a few accessible means of communication instead of offering too many options

These design principles can benefit the field of online citizen science, which is quickly spawning environments similar to those explored here. Unfortunately, there have been no frameworks, best practices, or design principles to guide the development of these online spaces. The time and financial investment required to build even the simplest online citizen science community is significant. Hopefully those investments can be more productive, given these design principles based on what worked in the three projects explored in this study.

As digital connectivity connects the farthest reaches of the physical world, citizen science projects that are designed with the NHOLC framework in mind can gather data that will shed light on large scale ecological processes and systems that impact communities across the globe. These projects can connect far-flung individuals to solve local environmental issues, and share stories of what others have been able to achieve.

Limitations of the Study

The design principles presented here could be viewed as "common sense" and nothing necessarily new to the field. Still, simply having a starting point that filters out the other potentially important design principles is an advancement that did not exist prior to this study. There are many researchers across the country asking similar questions and the design principles outlined here provides productive pathways to address these lines of inquiry. In addition, the findings presented here rely upon members of the community that have positive intentions as they populate the databases, comment, discuss, and share information. Without strong values in the online community and the drive to self-monitor content these online communities intended for positive community change and understanding could quickly devolve into unsafe learning contexts.

There are a number of additional limitations of this study. First, the case studies were all chosen based on whether or not the projects showcased the core characteristics of a NHOLC. This best-case scenario sampling method provides a focused lens to the study, but it also places limitations on the findings of the design principles. Therefore, one must keep an open mind to additional design principles that do not fall within the NHOLC framework. The study at hand emphasizes non-hierarchical models to understand how those specific environments function. Therefore it does not explore the ways that a more hierarchical model may contribute to online collaboration and local environmental action. It is the hope that additional research studies will simply use the findings of this study to ask additional research questions, perhaps by applying new theoretical and conceptual frameworks as lens to highlight design principles.

A second limitation of the study comes from the sampling of the interviewees. The sampling of project participants is not random. The study asked each project coordinator to suggest potential interviewees. The study incorporates individuals that had been some of the most active in the online communities and could hopefully provide the greatest insight into how and why it worked for them. Due to this method the findings of this study does not include the perspectives of individuals that joined the communities and dropped out, those that were not highly active, or those that did not want to participate in the interview process.

Applications and Next Steps

This study adds to a rapidly growing body of literature on the role and structure of citizen science in addressing outcomes related to environmental stewardship and action. There have not been any studies that look across online citizen science projects to understand how they are structured and function to reach their intended goals. There is no need to re-invent the wheel each time a citizen science project seeks to leverage the affordances of digital connectivity. Today, researchers and program designers can begin their planning one step ahead, with the design principles guided by the NHOLC conceptual framework presented in this paper.

There is a great deal of research yet to be done, ranging from developing a better understanding of the dynamics between online and offline relationships, to answering questions around identity development in these online communities, and understanding how information is translated from one place-based context to another as individuals learn and collaborate with each other online across vast geographic distances.

This instrumental case study combines the lessons learned across three innovative online citizen science projects that have all been successful in fostering localized environmental actions. The NHOLC framework serves as a lens with which to better understand the structural make up of the online functions and the experiences of the participants. In addition, the NHOLC framework and its associated design principles empower citizens with data, tools, and the necessary networks to find solutions to the environmental questions they have about their own communities.

Chapter 4: Designing Citizen Science to Build Community Online and Environmental Action in Our Backyards

Building Bridges Between Community, Science, and Action

As we learn to utilize the connectivity available to today's society, the definition of what we call "community" changes. It is no longer limited to those organizations and individuals in our neighborhoods, or specific locations. Online communities are becoming yet another way to engage in a variety of community activities from simple friendships to civic and political engagement (Lindros & Zolkos, 2006). Examples of this can be found in movements around the globe such as the *Arab Spring* and *The Occupy Movement.* Our society retains a sense of community that is tied to place, while at the same time expanding to include a new *global* community (Maibach, Leiserowitz, Roser-Renouf, & Mertz, 2011). Imagine the possibilities, not only for how quickly we can share, but how quickly we can learn and create change.

Citizen science originated as a way for the general public to assist scientists in collecting data for their research, as well as a vehicle to communicate aspects of science to the general public (Bonney et al., 2009). But the level of citizen participation no longer needs to stop there. The involvement of local people in all aspects of scientific inquiry through citizen science can lead to faster and more reliable data collection (Newman, Crall, Laituri, Graham, Stohlgran, Moore, Kodrich, Holfelder, 2010). This, in turn, can inform environmental decision-making at a much faster rate than more traditional scientific approaches (M. P. Mueller & Tippins, 2012). Citizen science can be more than just a service that the public provides for scientists. It can also be a tool for communities and individuals to ask their own scientific questions as they work toward building healthier and more sustainable communities.

Examples of Enabling Action Through Online Communities—Three Projects

There are a small number of citizen science projects that leverage the affordances of an online community to connect, engage, and empower community members in understanding and potential find solutions to questions they have about their place. The purpose of this study is to understand the range and variation of the structures of these online communities and the programmatic drivers that foster collaboration and on-the-ground actions. To do this, the paper explores three online citizen science communities—WeatherBlur, Public Lab, and Vital Signs—that achieved successes in online collaboration that led to environmental actions happening in local communities.

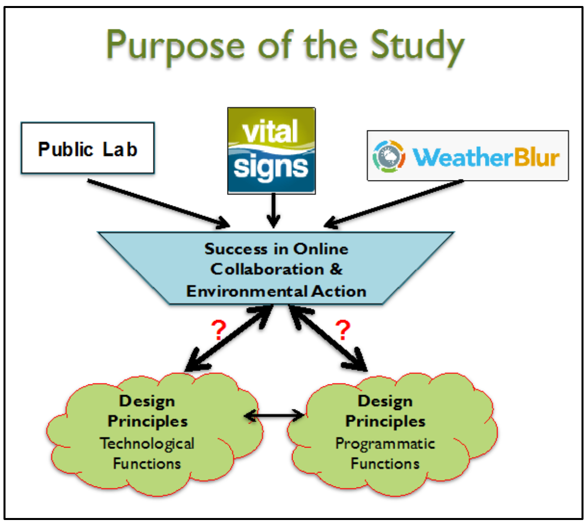


Image 15: Purpose of the study

WeatherBlur

WeatherBlur, funded by the National Science Foundation, is a multi-stage online citizen science community. Beginning in the summer of 2013, a fishermen-driven project under WeatherBlur used lobster traps to investigate organisms that live amongst lobsters. It revealed a shocking number of invasive green crabs (*Carcinus maenas)* wreaking havoc on native shellfish populations throughout Maine.

The WeatherBlur website, a central hub for all project information, became a green crab information exchange. Students from the local schools, fishermen, and community members shared the recent tallies of numbers of green crabs caught per trap, pictures, videos, and local news stories about green crabs. Research scientists asked questions about the data and provided suggestions for more accurate data collection and interpretations of data.

To combat the economic impact of the green crab, a task force was developed to determine how to deal with the green crab invasion in the state. In August of 2014, the task force solicited a summary of the WeatherBlur green crab investigation, which assisted in developing new regulations to minimize threats posed by the crabs. Typically, scientist-executed monitoring to inform management leads to implementation of policy decisions within three to nine years (Theobald, Ettinger, Burgess, DeBey, Schmidt, Froehlich, Parrish, 2015). In the case of WeatherBlur, this process took less than one year, as local stakeholder groups leveraged the power of online communities.

Public Lab

Public Lab is both an international online community and a non-profit that grew out of a grassroots initiative during the Deepwater Horizon BP Oil Spill in 2010. It enabled communities affected by the spill to access data about where and how much the oil was spreading. Public Lab developed and shared the design of "community satellites"—helium balloons and kites mounted with inexpensive digital cameras—with the greater community and asked people to use them to collect and share data online about the spill.

Today, Public Lab is an online community where participants can learn how to investigate a wide range of environmental concerns using inexpensive DIY techniques. The list of tools Public Lab uses has grown to include DIY spectroscopes, air particulate sensors, water quality tests, and many others. The online community is an open network of educators, technologists, scientists, and researchers working to create, share, and use low cost environmental monitoring techniques in communities from New Zealand to New England. This community has supported environmental actions ranging from aerial mapping for monitoring purposes (measuring waterway pollutants, drought conditions, plant health, invasive species, industrial pollution, etc.) to water quality testing to air quality monitoring—with opportunities to engage in local actions related to the research.

Vital Signs

Vital Signs, is a project of the Gulf of Maine Research Institute that identifies and documents invasive plants in the Northeast United States. The project originated as a citizen science project for K-12 classrooms, and has since grown to include land trusts and master gardeners. The online community provides a venue to learn about which species are appearing in the region, participate in "missions" to find specific invasive species, and a space to upload findings. Participating scientists and species experts confirm species identification. The Vital Signs community promotes communication online between citizen scientists and species experts where they exchange comments about the accuracy and context of the data.

Recently, Vital Signs added a "design your own mission" function that allows participants to devise their own investigations. Many participants have engaged in action by hosting community events to educate the public about the presence, spread, and concerns connected with specific invasive species. Others have conducted removal or remediation of invasive species. Species experts provide guidance online, and in some cases in–person, as they work in partnership with community members determine the most appropriate action to deal with the species in question.

Methods

A two-part study was conducted to understand what makes these kinds of online communities successful at transforming data collection into local action. In particular, the study focused on understanding the programmatic design elements and technological functions that support collaboration and environmental action in these projects.

To tease out the most essential components that enable collaboration in these online communities, a Q-methodology or QSort (Stephenson, 1935) is used to assess participants' priorities about an issue. To understand each participant's experience of the functions of the site and how it enabled or limited collaboration across the online community, a semi-structured interview protocol and online observation tool is used. (Appendix 2). The analysis of the interview data is completed using a convergent parallel mixed methods design (Creswell, 2014). Using a selected coding scheme that is grounded in the NHOLC conceptual framework the multiple data types collected, interview and online observations, are used to determine the range and variation of the essential design principles. These initial findings were then shared with the focus group for refinement and reliability.

The entirety of the study is grounded in Sociocultural Learning Theory, specifically drawing upon the instructional theories covered by Communities of Practice, Place-based Education (Sobel, 2005), Funds of Knowledge (Gonzalez, Moll, & Amanti, 2005), and Knowledge Building (Scardamalia & Bereiter, 2006). These sociocultural theories informed the development of the Non-Hierarchical Online Learning Community (NHOLC) conceptual framework that identifies some of the critical elements to creating an ideal online citizen science community committed to solving local and global environmental problems. (Kermish-Allen, *in prep*). Image 1 represents how the components of each theory lead to the five interwoven core concepts of the NHOLC framework.

All of the methods in this study looked specifically at how each project applies the core concepts of the NHOLC framework:

1) Bringing together diverse participant groups from widely differing areas of expertise to enable multi-directional learning opportunities in which everyone that joins the community has something they can offer and teach others within the community;

2) Enabling participant-driven real-world investigations that are personally relevant to participants' lives;

3) Sharing project purpose and goals;

4) Enabling communication structures to build relationships and roles amongst a diversity of participants; and

5) Sharing place-based data across geographic boundaries.

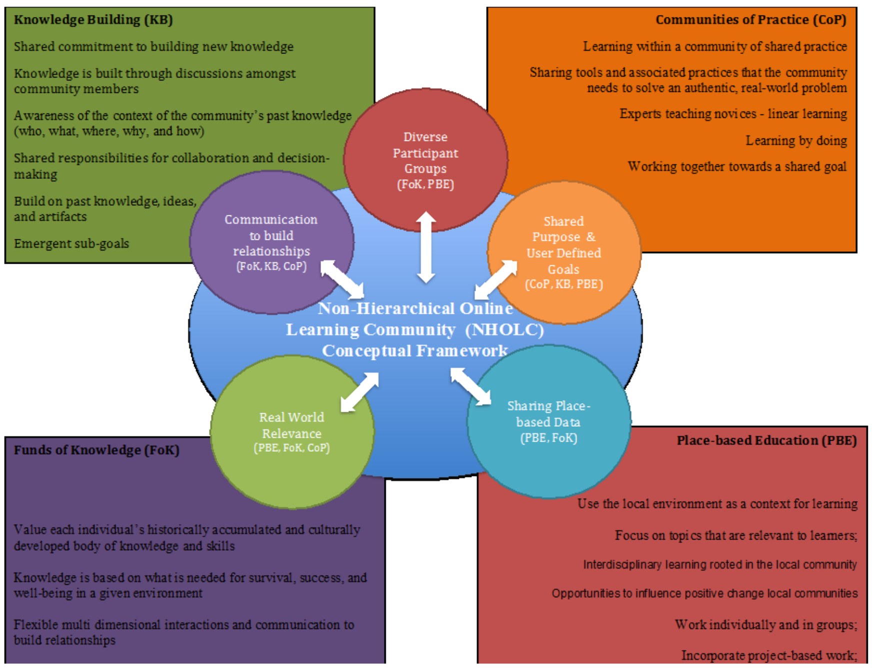


Image 16: *The Original NHOLC Framework*

The QSort asks participants to rank 49 statements that express variations of the characteristics expressed in the conceptual framework above. The statements can be found in Appendix 1. The statements are ranked by each participant along a QSort continuum from -4 (least important to fostering collaboration online) to +4 (most important to fostering collaboration online).

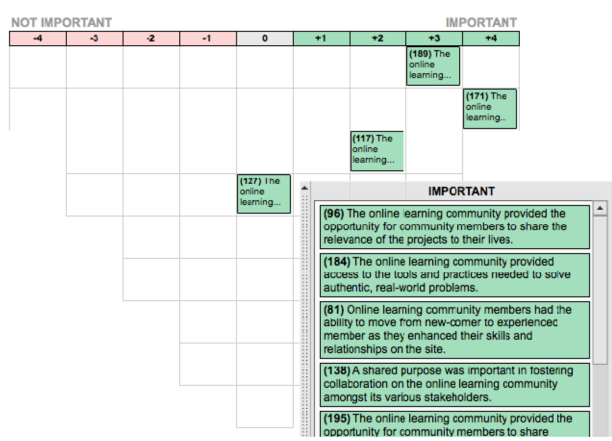


Image 17: Qsort ranking continuum

The findings emerge from 15 QSorts and 20 interviews with individuals across the three projects. Participants in this study were chosen to represent the different types of groups that use each project, such as scientists or experts, project coordinators, and general citizen scientists including teachers, and community advocates.

Learning From Success

Looking across the data of this study four themes emerge that seem to foster collaboration online to address local environmental issues. Based on the findings, the key design principles, driving the programmatic and technological structures of the online learning communities involved in this study include: 1) bringing together diverse groups from vast areas of expertise; 2) participant-driven real-world investigations that are relevant to participants' lives; 3) access to tools and stories about past successes and failures; 4) bridging online activities with on-the-ground activities. In the section below, each design principle will be explored based on the experiences of community members and how they used the functions of the online communities.

1. Bring together diverse participant groups from vast areas of expertise

In the QSort findings, participants across all of the projects agreed on a few statements. One of those statements was that "the different types of expertise present in the online learning community are a factor in making members feel like they are working toward the common goal of building knowledge together." At the same time, community members across all projects also unanimously agree "the online learning community does not need to connect individuals who use similar resources for work (same language, tools, experiences, definitions)."

Participants believe that projects are successful when they can connect members that have experiences, information, or know-how that is different from their own and can help them reach the goals they have in mind. A Public Lab participant sums it up nicely saying, "*If it wasn't for the site, I would never have known that there was a need for the expertise I have in these different contexts. I'd be off here in the middle of NC and I wouldn't be connected with these people in Los Angeles, Peru, or India and places where they do fracking…I wouldn't have access to the questions they are all interested in and I wouldn't be able to contribute."* Simply bringing together people with the same experiences and expertise will not create the type of rich productive communities present in the three projects examined.

2. Provide access to tools and stories about how others reached their goals.

Across all of the projects, everyone agrees "the online learning community needs to provide access to the tools and practices needed to solve authentic, real-world problems." There are two key ideas built into that statement: first, access to tools and practices to do the work of the project and, second, solving authentic real-world problems. This section addresses the first part of that statement; the link to real-world problems will be explored in the section below.

What does the term “tools and practices” mean? In this case, it means the methods of data collection, stories of local citizen science projects, sharing the lessons learned, methods of communication within the community, and generally how to do the work of the project. The tools and practices of each project were explored in detail during the interview.

Everyone who participated in this study agrees that the online learning community needs to provide the opportunity for community members to share information with one another. Many of the participants in all three cases value a format that allows them to determine quickly if material is relevant and usable. Whether that information is provided in narratives, databases, or maps, participants need to access the past knowledge of the online community to learn from it and apply it for their own purposes.

In some cases, finding the information a member needs to advance his/her ideas can be very difficult. To address this issue, the Public Lab project uses a “recommendation list” alert function. These online match functions connect individuals who can help each other meet their goals (i.e., connect an expert in freshwater algae with someone trying to understand how algal blooms in their local lake are influencing fish). The function also highlights information related to each member’s interests that are hidden in the community and very difficult to find otherwise (i.e. examples of how others gather data on algal blooms, what they found, and what they did about it). Interviewees from the other projects alluded to needing a function like this to foster more collaboration.

In addition, all of the project participants agree that an online community does not need to provide a variety of communication methods to connect members and build relationships. In fact, during the interviews, participants repeatedly mentioned that when there are too many options for communicating it becomes too overwhelming and actually hinders communications and relationship building. In the projects explored, it is clear that simpler is better. Providing a few targeted means of communication that are available to everyone, instead of offering too many options, is preferable when designing for collaboration and action.

In summary, to foster the types of collaboration and environmental action observed in the three projects, the following tools and practices are important:

1. provide access to knowledge from the community's past experiences (past studies, sub-projects or investigations, data collection methods, etc.);
2. present information in a format that allows members to quickly determine if what is presented is relevant and usable for them;
3. connect members who have information and/or knowledge that others need;
4. alert members to activities (in person and online) related to their interests and goals; and
5. offer a few accessible means of communication instead of offering too many options.

3. Create participant-driven, real-world investigations that are relevant to participants' lives.

This design principle addresses three key ideas. The first part speaks to local investigations and projects that are defined and led by the members of the community. The second part focuses those participant-driven investigations in the real world through relevant contexts for participants. The third, is that participants are excited about the value that their efforts can have for the work of scientists, providing real-world data that will inform rigorous scientific research and impact their local environments.

Relevance of the project to the community member emerges over and over again in the data. As a Public Lab member stated, "*People can work on things that are really important to them - it's the people who themselves decided that it was important to them - and they are the ones working to figure it out."* The collaborations that happen in all of the projects are driven by the fact that they could result in changes to improve life right in someone's backyard. A tool developer in Public Lab shared, "*People can ask a question about their real-world environmental problem and other people, like me, suggest ways to deal with it. People post their new tool that measures some environmental variable and other people at the site can see that and say, 'Oh, I could apply this to this particular environmental problem I have."*

Members of Vital Signs highlighted the importance they each saw in collecting data that they knew was extremely relevant and *needed* by scientists. This was a major driver in initial and continued participation that lead to new and exciting questions. As stated by a Vital Signs member,

> *"once you going out into the field to learn about invasive species then that opens up a whole doorway of learning about what are the regulations around this species, why is this a problem, why are some invasive species desirable, what makes something invasive versus just introduced…so it's a real-world problem that you're introducing participants to …and they can have an impact on the issue at hand."*

On the other hand, when participants are uploading data and then they do not get any responses from species experts to confirm or deny their findings they quickly do not feel valued. Many participants become quickly discouraged when there are not comments or discussions related to their posts from the community.

The methods that the projects use to highlight the potential relevance of their work to community members vary, but they all use mapping, narrative, and discourse in various formats. Essentially, both visual and narrative stories are shared to help community members ascertain whether the information and resources provided are relevant to their interests and the local real-world problems.

Originally, the NHOLC framework assumed that the *overall* goals of the online learning community needed to be defined and refined by members. Instead, as seen in the findings from this study, there was consensus that it is not important for an online citizen science community to define and redefine its goals. To understand this better, the interview questions probed the contrast between individual goals and the project's overall goals.

It became clear that each participant joins an online citizen science community to accomplish a personal goal. While one's personal goal aligns with the overall purpose of the project itself, the participants have specific outcomes in mind that they want to achieve. For example, an individual may join Public Lab because they want to find new uses for a tool that they have designed, while another member joins to find a tool that can address the local environmental questions they are concerned about. In WeatherBlur, a research scientist may join the community to gain access to a population of individuals interested in topics related to his research, while a fisherman may join to connect with other fishermen. And in Vital Signs, a student joins because his/her class are taking part in a mission to find local invasive species, but a scientist may join to mobilize a network of individuals from across the state to look for a newly introduced species.

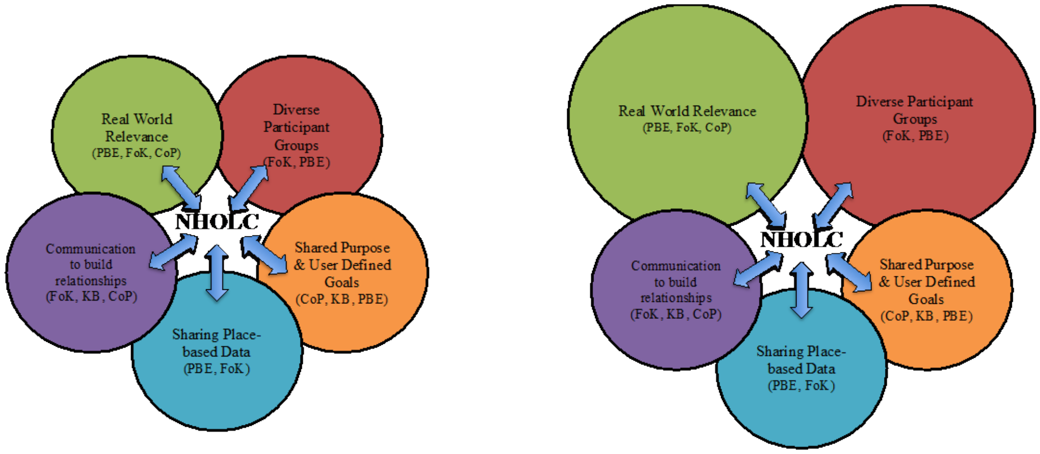
The overall goal of the project might draw them into the community, but members need to be able to identify, share, and address their own "sub-goals" or "sub-projects." When online communities provide examples or stories of how members use the community's resources to meet their own goals, new members report that they find it easier to understand how the community can help them meet their own personal goals.

4. Bridge online activities with off-line activities

One of the most intriguing findings highlights the importance of grounding online activities and collaboration with on-the-ground activities and relationships. As expressed by a *WeatherBlur* participant and echoed by participants across each of the projects, "*We crafted our investigations offline with members of the local community, but we grew the investigations together with online community members from everywhere.*" Relationships and connections built in the online community cannot exist in isolation. In Public Lab members often design and invite others online to attend in-person meetings to talk about an issue or learn a new skill. Successful projects found ways to use the online community to continue, and/or deepen conversations that began in-person or visa versa. More research is necessary to better understand the dynamics between online and on-the-ground community building and action.

Revising the NHOLC Framework

Reflecting on the findings of this study it is clear that the original NHOLC conceptual framework should be revisited and revised. The findings suggest that emphasis should be heavily placed on the diverse participant groups' component of the framework. The fact that participants can collaborate with individuals - who have new information relevant to their interests - that they may never have had the opportunity to connect with if it were not for the online community is an important and powerful driver in these communities.



Original

Revised

Image 18: Original Versus Revised NHOLC Conceptual Framework

The findings also suggest that authentic real-world problems that are relevant for learners needs to be a highly prioritized component of successful online communities for citizen science. Across all of the projects, real-world relevance was core to each individual's experience. This emphasized component of the framework brings a new question into focus. Namely, how does an individual define or determine relevancy and real-world applications? This component was important to individuals, but remains somewhat undefined, and is in need of further study .

The three additional components – communication, sharing place-based data, and a shared purpose – were all very variable in levels of importance to collaboration in each factor. But each still played a key role in each individual's experiences. Additional research is needed to better understand the role of each of these components and how they could be designed to increase the impact of online citizen science communities working towards local environmental actions.

As the digital world begins to connect the farthest reaches of the physical world, citizen science projects that are designed with the NHOLC framework in mind can leverage that connectivity for greater impacts on local environmental activities. Applying the design principles that emerge from this study leverages the power of online communities to gather, analyze, and share data that will shed light on ecological issues affecting communities across the globe. In addition, using these design principles in online citizen science projects can connect individuals across great distances to address those issues as they share stories of success and failure. The design principles discussed above summarize both the over-arching design elements for developers of online citizen science projects and the needed tools and practices to realize this vision.

This study adds to a growing body of literature focused on citizen science (Cronje et al., 2011; Druschke & Seltzer, 2012; Newman et al., 2010). It specifically addresses for the first time how the structure and role of collaboration in online communities can help achieve project goals, enhance science literacy, and nourish environmental stewardship and action. The design principles and NHOLC conceptual framework presented here provide a research-based starting point that other researchers and program designers can learn and build from. With the guidance presented here, citizen science projects no longer need to re-invent the wheel to leverage the affordances of digital connectivity.

There is a great deal of related research questions still to be addressed such as developing a better understanding of the dynamics between online and offline relationships in these types of projects. Also needed is a better understanding of how information is translated from one place-based context to another as individuals learn and collaborate with each other online across vast geographic distances. The design principles highlighted here hopefully serve as a starting point for others interested in designing engaging citizen science projects that build upon the power of both place and online collaboration to enable action in our own backyards.

Chapter 5: Conclusion

In a recent call to action, Wals, Brody, Dillon, and Stevenson challenged environmental educators to use mechanisms such as citizen science to create "opportunities for new forms of education that can lead to the engagement of seemingly unrelated actors and organizations in making new knowledge and in taking the actions necessary to address socioecological challenges" (2014; p.584). This dissertation is a direct response to that call. This study examined examples of such "new forms of education"—online learning communities—that can stimulate collaboration among "seemingly unrelated actors to make new knowledge." It is a first step in exploring how online learning communities in citizen science can build bridges across vast differences to make a real difference in local environmental outcomes.

Citizen science, per say, is not a new phenomenon. Volunteer bird surveys in Europe and America have been ongoing for over 100 years, creating some of the longest term ecological data sets we have to understand global environmental change (Dickinson and Bonney, 2012). The emerging area of work that this research focuses on is the use online databases and communities in citizen science. This type of integration of online components into citizen science originated with projects like the National Geographic Kids Network in the late 1980s. Karlan, Hubberman, and Middlebrooks (1997) detailed the great potential for engaging students and community members in real scientific problems and discourse with other students and scientists via telecommunications, laying the groundwork for research in this area.

This dissertation study focused on the question "What are the essential design elements, practices, and structures of online learning communities used in citizen science projects that foster and result in local environmental actions?" To address this question, the research examined three citizen science projects that use online learning communities to promote collaboration and local action: Public Lab, Vital Signs, and WeatherBlur. All three projects were ideal examples that had shown success in using online communities to support these goals.

This dissertation was framed as a two-part multiple case study. The first part developed a new conceptual framework, based on sociocultural learning theory, to understand online citizen science communities: the Non-Hierarchical Online Learning Community (NHOLC) framework. The findings from a Q methodology (McKeown & Thomas, 2013) study is then shared. These findings highlight the key components of the NHOLC framework that participants in the three projects believed to be important to fostering collaboration online.

The second part of the study looked deeper into participants' experiences to identify how they engaged with the online community, specifically the technological functions of the site.

The final product of this research yields recommendations for designing successful online learning communities in citizen science. This conclusion provides a brief synopsis of the core findings of the study.

Recommendation 1: Online learning communities should bring together diverse participant groups from vast areas of expertise.

Across all of the projects in this study, it is evident that one of the most valuable aspects of an online community is the people it brings together. The projects have varying levels of diversity, but in each case it is the access to different groups and expertise that persuaded individuals to participate. As new citizen science projects begin to design their online community, they should think carefully about how to draw in the diverse participants they need. This audience will shift and change dependent on the goals of each project. It is important to move beyond the traditional conception of citizen science that brings the general public together with scientists as the experts. Instead, think about the types of expertise the general public can provide, including local traditional knowledge, technical expertise, and diverse stakeholders on the topics at hand. Successful projects should be able to leverage those groups to sustain the project through conversation, sharing of ideas, and robust feedback between participants.

Recommendation 2: Online learning communities should provide access to the tools and stories about how others reached their goals.

Participants from all of the projects agree that having both the tools to do the essential work of the project and stories of how others used those tools is a high priority design element of online communities. Many traditional citizen science projects share data collection protocols, but the projects explored in this study also allowed members to tweak and change those protocols to suit their needs. Each of the projects differed in the amount of user input, but everyone believed this was a key component that enabled both collaboration and local action. Members needed to know how others had used the tools of the project: they wanted to read stories and examples. They then used this information to determine whether they could apply those tools to their own questions and goals. New and developing online communities for citizen science projects need to provide venues for members to share the successes and failures they experience. This provides an opportunity for members to get feedback from the community on how to improve and apply the knowledge of the community to different contexts.

Recommendation 3: Online learning communities should foster participant-driven, real-world investigations that are relevant to participants' lives.

The analysis of the data collected throughout this study supports the importance of citizen science projects focusing on real-world topics that are relevant to members of the online communities. Citizen science in its purest form is simply defined as a project that asks citizens to provide large amounts of data or analysis of large data sets to answer a scientific research question. Not all citizen science projects are locally focused. For example, Galaxy Zoo asks members to classify distant galaxies from images captured by the Hubble telescope and the Sloan Digital Sky Survey. Others, such as the 1000 Genome project, asks for help from the general public to identify novel genetic variants in examples of Y chromosomes from across Europe to track the historical migrations of humans. These are exciting ways to engage in citizen science and scientific questions, but it does not necessarily relate to a participant's everyday life. The individuals that participated in the three projects explored in this study were drawn to the community because they knew that their work would affect the world around them. Whether through the development of new tools or by applying those tools to local environmental questions, these projects focus on topics that were relevant to participants' lives: essentially, how will the work each individual takes part in change his or her world? What makes it meaningful to them? How can it bring about the change they wish to see in the world? When designing an online citizen science community with the goal of fostering collaboration and local environmental action, one must ask how this project will make a difference to the real-world topics each member cares about.

Recommendation 4: Online learning communities should bridge online activities with off-line activities

The original impetus of this research study was to examine only the online functions of each community that fostered collaboration and environmental action. But it quickly became apparent that the dynamics between the online and off-line worlds were very important to each project's success. Relationships and connections built in the online community cannot exist in isolation and the online community cannot be divorced from the evolution of projects in the real world. The online community must serve as a gathering place for people engaged in off-line, and often place-based, scientific investigations. Sometimes, the online community serves as an entry point, connecting members with a topic they never knew would interest them. Sometimes, it plays a reinforcement role, providing feedback on how to improve the ongoing investigations of community members. In yet other instances, the online community plays the role of knowledge archive where members learn from others and apply those insights to their own situations. Developers of online communities must steer clear of the fancy bells and whistles of online platforms that can easily detract from the core mission of projects. Instead, they must focus efforts on how the online environment will support and enable the work to be done in the off-line world. There is still a great deal of research ahead to fully understand the relationship between how online activities influence off-line activities, but the research at hand provides some initial insights into this complex relationship.

Upon initial reflection of these results there is nothing groundbreaking or inherently surprising. But further reflection brings all of the additional design principles that could have risen to the top into focus. For example, participants may have wanted to use the online community to connect with others just like them, but no, the diverse stakeholders present were a major driver in success. At the same time, communication structures were originally a major component of the NHOLC framework, but its role and structure was not a core design principle that participants emphasized. The same is true of an overall shared goal of the community. The importance of the major results from this study is found in the laser focus they place on specific design principles. Namely, those discussed above and throughout the chapters in this dissertation for others to use as they embark on designing new online learning communities for citizen science that foster environmental actions.

Next Steps

The research discussed in this dissertation provides important insight into the essential design elements, practices, and structures of online learning communities in citizen science. It specifically addresses for the first time how the structure and role of collaboration in online communities can help achieve project goals, enhance science literacy, and nourish environmental stewardship and action. The design principles and

NHOLC conceptual framework presented here provide a research-based starting point that other researchers and program designers can learn and build from to leverage the affordances of digital connectivity.

However, the results presented are only a first step in this rapidly evolving area of research. New questions include, but are not limited to:

1. How is information translated from one place-based context to another as individuals learn and collaborate with each other online across vast geographic distances?
2. How does a participant's concept of identity change while and after participation in an online learning community for citizen science?
3. What lessons can we learn from citizen scientists who are successful in turning their online collaborations into on the ground actions?
4. How does using the NHOLC framework in the development of an online learning community for citizen science influence its outcomes related to learning, action, and sustainability?
5. What is the range and variation of environmental actions these projects foster?
6. What types of skills or forms of action competence are fostered throughout the process of participating in online learning communities for citizen science?
7. What types of relationships between diverse participant groups develop in online learning communities for citizen science and what types of actions do they result in?

As one can see, at the conclusion of this research there are more questions to answer than there were at the start of this journey. Hopefully, the NHOLC framework and associated research presented here provides a starting point to address these additional questions. Additionally, this research builds a solid foundation for understanding the role of online learning communities in tackling the complex environmental questions that influence us all at the local and global scales.

The involvement of local people in all aspects of scientific inquiry through citizen science can lead to faster and more reliable data collection (Newman, Crall, Laituri, Graham, Stohlgran, Moore, Kodrich, Holfelder, 2010). This, in turn, can inform environmental decision-making at a much faster rate with high rates of local community buy-in than more traditional scientific approaches (M. P. Mueller & Tippins, 2012). As seen from the research presented here, citizen science is more than just a service that the public provides for scientists. It is also a powerful tool for communities and individuals to ask their own scientific questions as they work toward building healthier and more sustainable communities. By leveraging the digital connectivity available to communities today, citizen science can empower people with tools to better understand their environments, share those understandings with a broad audience, amplify connections across the globe, and develop the knowledge and skills to turn their online collaborations into on the ground action. I look forward to continuing this exciting area of research as the field builds on the different models and structures that have successfully integrated the power of global connectivity, citizen empowerment, and scientific questioning to enable local environmental actions.

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APPENDICES

Appendix 1: Interview Protocol

Sample Interview Protocol Part 1

Hello, my name is [insert name] and I am calling to ask a few questions about your experience in the Vital Signs citizen science project. It should take about an hour or less. The Vital Signs project is part of study that is looking at a series of citizen science projects that have online communities. The purpose of my call today is to ask you a few questions about the purpose of the **online community** in the project and your experience with it.

Given the purpose of the interviews, it is important that you share your most thoughtful, candid feedback. I might use quotes in the report.

Are you willing to participate in the 45 to 60 -minute interview?

1. Can you please provide a brief description of what you did with the _________project? What were the outcomes of your project?

2. How long have you been part of__________?

3. This study is about citizen science projects that have been able to foster environmental actions. Can you please share some stories about the types of environmental actions (both small scale and wide scale) that resulted from your participation in _______? Did the **site** support you in taking those actions?

4. What parts of the site did you use to complete your project? How did you use each of them?

This next series of questions will ask about how different concepts 1) played a role in your experience in the __________ community; 2) how was that concept fostered by the online community's functionality (Structures).

Explain each element of the NHOLC conceptual framework including a definition and any clarifying statements needed.

	Elements:	Structures:
	Was this idea or concept a part of your experience in the _______ project? How?	*Where on the site can users? How does the site foster….*
1. Bring together diverse participant groups from vast areas of expertise to enable multi-directional learning opportunities in which everyone that joins the community has something they can offer and teach others within the community		1c. How does the site foster connecting with diverse stakeholder groups? Which functions allow them to connect?
2. Sharing place-based data across geographic boundaries		2c. Which functions on the site foster the sharing of place-based data?
3. Shared Purpose and Goals of the Project		3c. Which functions on the site foster a sense of shared goals in the project?
4. Participant driven real-world investigations that are personally relevant to participants' lives - "why should I care and what can I do about it"		4c. How do the functions of the site foster crafting real-world projects that matter to individuals?
5. Unhindered Communication to Build Relationships – opportunity to connect with each other via a variety of mean (discussion, messages, etc.?)		5. How does the site foster communication between participants to build relationships?

_____________________________ *If time allows ask the two questions below*

5. What does not work so well in the online community? How could it have been improved?

9**. Anything else that we should know about?**

Appendix 2: Online Observation Protocol

Online Observation Protocol

Case: _______________________________ Observer: _____________________________

Date: _____________________________

NHOLC observation protocol

Theoretical Framework Theme	Where it is found on the site	Description of How the function works
Diverse Stakeholder Groups		
Shared Purpose and Goals		
Real-world relevance		
Communication to build relatic		
Sharing place-based data		

Opportunity to define new Questions or ideas for discussion		
Where does conversation between users occur?		
How and where do users share content?		
How is context identified?		
Building Connections ?		
Expression of purpose?		

Appendix 3: QSort Statements

Statements
The online learning community provided a structure to encourage the sharing of responsibilities and decision-making.
The online learning community connected individuals who have similar interests, but did not use the same resources for work (the same language, tools, experiences, definitions).
The different perspectives of online learning community members assisted in developing individuals' roles on the online learning community.
The online learning community encouraged members to value the variety of expertise present in the community.
The different perspectives of online learning community members aided in developing relationships with others in the community.
The online learning community encouraged members with historic and cultural knowledge relevant to the project to share that knowledge with others.
The online learning community brought together the diverse stakeholders needed to achieve the project's goals.
The online learning community's overall shared purpose motivated members of the community.
Online learning community members had a commitment to the same overall goals.
The online learning community had a mechanism that provided the opportunity to critique and help shape new ideas that emerge from the members of the community.
Online learning community members had a commitment to building knowledge that could be used by the whole community.
The online learning community attracted new members by showing the relevance of the project to potential member's lives and interests.
The online learning community provided a starting point for conversation.
The online learning community encouraged any community member (no matter his/her age, expertise, or perspective) to propose new questions or investigations on the site.
The online learning community provided the opportunity for members from multiple perspectives to respond to and build on the ideas of others to advance a project.
The online learning community's overall shared purpose united members of the community.
Online learning community members felt like they were working toward the common goal of building new knowledge together.
Members joined the online learning community because they wanted to build knowledge related to the shared goals of the project.
A shared purpose was important in fostering collaboration on the online learning community amongst its various stakeholders.
Online learning community members had the ability to move from new-comer to experienced members as they enhanced their skills and relationships on the site.

The online learning community provided members with the freedom to express opinions and offer suggestions without fear of how the other members would judge it.
The online learning community provided all members with a way to track and understand how and why a project changed over time.
The online learning community provided the opportunity to develop investigations that represented evolving ideas in the community.
The OLC provided a starting point for discussion with stakeholder groups that otherwise not connect to share ideas.
The online learning community provided the opportunity for community members to develop roles on the site.
The online learning community brought together people with different levels of expertise and/or experience.
All members of the online learning community had the potential to influence the direction and focus of projects.
The online learning community provided a place to put resources that were used by the community.
The online learning community had a structure for notifying members of where information came from and how it had been used in the past.
The online learning community provided the opportunity for members to propose emerging project/investigation ideas that were relevant to their interests.
The online learning community encouraged community members to apply information on the site to their own situations and questions.
The online learning community highlighted and made clear the different groups / stakeholder perspectives involved in the project.
The online learning community provided the opportunity for community members to share the relevance of the projects to their lives.
The online learning community's overall shared purpose helped the project feel significant.
The online learning community provided members with the opportunity to share their knowledge of where they live and what they have experienced in their life.
Projects on the online learning community solved authentic, real-world problems.
Each member of the online learning community brought knowledge to the community based on where they live and what they have experienced in their life.
The online learning community provided the opportunity to connect with members who had the expertise needed for an investigation.
The online learning community brought people together from different locations.
The online learning community provided the opportunity for community members to develop relationships with other members on the site.
The goals of the online learning community are defined and refined by members.
The online learning community connected individuals who use similar resources for work (same language, tools, experiences, definitions).
The online learning community provided members with various ways to connect with any member of the community.
The online learning community helped community members connect to and work with members who had submitted information in the past.
Starting with a shared purpose was important in generating trust amongst the various stakeholders.
The online learning community helped foster relationships and built trust among community members.

The online learning community provided the opportunity for community members to share information with one another.
The different types of expertise present on the online learning community were a factor in making members feel like they were working toward the common goal of building knowledge together.
The online learning community provided access to the tools and practices needed to solve authentic, real-world problems.