LEARNING AS CHANGE: RESPONDING TO SOCIO-SCIENTIFIC ISSUES THROUGH INFORMAL EDUCATION

by

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Informal learning is an important venue for educating the general public about complex socio-scientific issues: intersections of scientific understanding and society. My dissertation is a multi-tiered analysis of how informal education, and particularly informal educators, can leverage learning to respond to one particular socio-scientific issue: climate change. Life-long, life-wide, and life-deep learning not only about the science of climate change, but how communities and society as a whole can respond to it in ways that are commensurate with its scale are necessary.

In my three-article dissertation, I investigated the changes in practice and learning that informal educators from a natural history museum underwent in the process of implementing a new type of field trip about climate change. This study focused on inquiry-based learning principles taken on by the museum educators, albeit in different ways: learner autonomy, conversation, and deep investigation. My second article, a short literature review, makes the argument that climate change education must have goals beyond simply increasing learners' knowledge of climate science, and proposes three research-based principles for such learning: participation, relevance, and interconnectedness. These principles are argued to promote learning to respond to climate change as well as increased collective efficacy, necessary for responding.

Finally, my third article is an in-depth examination of a heterogeneous network of informal educators and environmental professionals who worked together to design and implement a city-wide platform for informal climate change learning. By conceptualizing climate change learning at the level of the learning ecology, educators and learners are able to see how it can be responded to at the community level, and understand how climate change is interconnected with other scientific, natural, and social systems. I briefly discuss a different socio-scientific issue to which these principles can be applied: heritable, human manipulation of other biological entities; in other words, genetic engineering.

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PREFACE

This dissertation is the result of four and a half years of late nights, long days, and head scratching. It was made possible by a strong network and a lot of coffee.

I would like to thank my dissertation committee, Abby Kinchy, Mary Kay Stein, and Jennifer Linn Russell for their ongoing support, and particularly my advisor and co-author, Kevin Crowley. His sound advice, openness to my ideas, and sense of humor facilitated the timely completion of this project. My colleagues and classmates in Learning Sciences and Education Policy have been an unending source of good ideas, excellent feedback, and helpful perspective on drafts of each of the chapters in this dissertation, and on other projects. Finally, my deepest gratitude goes to my family, without whose unconditional love and support I would not have been able to imagine attempting or completing a PhD.

1.0 INTRODUCTION: PRINCIPLES FOR LEARNING TO RESPOND

How can informal education can be developed and leveraged to respond to a socio-scientific issue? Informal education is the bulk of the educational or learning experiences that people have in their lives. It includes all the learning that takes place outside of classrooms: learning with family, with friends, while working, volunteering, playing, etc. Sites of informal learning include, but are not limited to: kitchens, living rooms, parks, museums, galleries, libraries, workplaces, etc. This dissertation focuses on informal education leveraged at responding to climate change, a particularly challenging socio-scientific issue. The learning that is detailed and examined here is not learning "about" climate change in the traditional sense (e.g. Lombardi, Sinatra & Nussbaum, 2013). My work instead describes learning as a process of change and development over time, through active engagement with colleagues who are also learning to leverage informal climate change education, using and improving on informal learning experiences being facilitated. The learning that happens at the level of informal educators parallels learning to respond to climate change more generally: learning how to educate for responding is in fact a response to climate change.

Informal learning is particularly well-suited for encouraging understanding of complex phenomena that exist at the intersection of scientific and social issues like climate change, because it is "life-long, life-wide, and life-deep" (Bell, Bricker, Reeve, Toomey Zimmerman & Tzou, 2013; Bell, Tzou, Bricker & Baines, 2012; Bell, Lewenstein, Shouse & Feder, 2009). How

society should deal with the realities of climate change require life-long learning and responding, because adaptation and mitigation are necessary now, and will continue to be so into the foreseeable future (e.g. McCrum et al., 2009; Tschakert & Dietrich, 2010; Walker, Holling, Carpenter & Kingzig, 2004; Wise et al., 2014). These challenges require life-wide learning, because scientific understanding of the problems will continue to develop over our lifetimes, and society's priorities will also change along with our understanding. And finally, these are life-deep learning challenges: "Life-deep learning… and development are deeply guided by spiritual, religious, ethical, moral, and social value systems that operate within social groups" (Bell et al., 2012, p. 270). Responding to socio-scientific issues requires a complex combination of decision-making and interaction with our physical and social environments, which are deeply influenced by our social groups and their values and beliefs (e.g. Kahan et al., 2012; Roeser, 2012; Walsh & Tsurusaki, 2014).

Socio-scientific issues are the complex challenges that result from the interaction of scientific understanding with social systems and dynamics. These issues are often characterized as controversial, because how people respond to complex issues at these intersections depend on their social groups, such as their political affiliations and social class (Dickinson, 2009). They can also be perceived as controversial because how people interpret and respond to the inherent uncertainty in scientific findings also varies depending on their social experiences and communities. The work presented here contributes to our understanding of how people, and particularly informal educators and others looking to utilize the power of informal learning, can effectively leverage learning to respond to climate change to increase collective efficacy in their communities. While this work is focused on climate change, the principles for inquiry and learning to respond, as well as the features of networks organized to promote such response and

inquiry are more broadly applicable to other socio-scientific issues. I provide another example of a socio-scientific issue that I have worked to apply these principles to in chapter 5.

1.1 WHY FOCUS ON LEARNING TO RESPOND TO CLIMATE CHANGE?

Climate change is arguably one of the most important challenges that humans face in the 21st century. One route that researchers, governments, and leaders have promoted to address climate change is through education (see Schreiner, Henriksen & Kirkeby Hansen, 2005). Usually, it is assumed that if people know about climate change, then they will make choices that align with addressing or solving the problem. Unfortunately, climate change is such a complex problem that knowledge of the science of climate change is not predictive of whether one makes choices that are good for the climate (e.g. Kahan, et al. 2012). For this reason, the research I have conducted in the process of researching and writing this dissertation is focused on the different ways that learners, as individuals and in their communities, come to understand and engage in *responding* to climate change—in contrast to a more narrow focus on gaining or mastering scientific knowledge about climate change. This argument is fleshed out in more detail in chapter three, also in press at the International Journal of Global Warming (special issue on Climate Education): "Knowledge is not enough: Participation, relevance, and interconnectedness" (Allen & Crowley, in press).

Responding to climate change is a more complex, ongoing combination of using knowledge and understanding to make decisions about behaviors. Additionally, because of the nature of climate change as an ongoing global and social issue, responding to climate change in a way that is commensurate with the scale of the problem requires not only changes in behavior

and decision-making at the individual level (e.g. choices people make about consumption in their daily lives) but also changes in social behavior—that is to say, engagement with community-level, public-sphere responses to climate change. Examples of these sorts of responses include: volunteering with environmental groups that work to reduce carbon emissions or increase green infrastructure; supporting climate-friendly policies at the local, state, and national levels; and engaging in programs that increase the resilience of cities and neighborhoods to the more extreme weather variations that are already happening.

1.2 PRINCIPLES FOR INQUIRY, LEARNING TO RESPOND, AND NETWORKS AS INTERVENTIONS

My dissertation is comprised of three articles that have been or are currently in the process of peer-review. Each of these articles identifies a set of principles or features that are necessary or helpful for some aspect of learning to respond to climate change, with a focus on coordinating and designing informal climate change educational experiences. Over the course of designing, researching, and writing these three articles, my understanding of what it means to learn has developed into a conceptualization of learning as a process of change. As we engage in learning about the complex, challenging, and messy issues that society and people face, our ideas evolve, and our behaviors and perceptions about those issues and ideas gradually (or suddenly) change to incorporate our new understanding. At the same time, how we engage with our communities, and the ideas, perceptions, and beliefs that we already hold, influence our learning and behavior. Our social worlds and shared belief systems are an important part of what makes us human, and can

be both facilitators and barriers to our ongoing learning and adapting in the face of new information and changing situations.

My dissertation research began with a project situated inside a natural history museum. In chapter two, originally published in January 2014 in Science Education (Allen & Crowley, 2014), I examined the changes that occurred in the practice of natural history museum docents who spent a school year implementing a new kind of field trip for middle school students that was about climate change. The re-framing and re-designing of the typical natural history museum field trip to be: (a) centered around three inquiry principles: learner autonomy, reflective conversation, and deep investigation; and (b) focused on learning about climate change; were dually challenging for the docents, whose varying prior experiences as educators and members of different social groups impacted how they changed their practice with regard to encouraging inquiry-based learning and facilitating learning about climate change.

At several points during the implementation, analysis and writing about this project I have wondered whether having these two very different and new challenges for the docents created a higher level of anxiety or struggle to change—would the docents have had an easier time, or felt more successful implementing the inquiry principles on field trip content that was familiar and less controversial for them? One might guess that this could be the case, however, I think that the challenging content was a catalyst for the adoption of more inquiry-based learning and field trip facilitation for the docents. Because the docents were new to climate change content, and some were uncomfortable talking about climate change because of its politically charged nature, encouraging student exploration and learner-centered field trip activities in contrast to the traditional docent-led tour was a fortuitous combination. Additionally, as is described in chapter three, learning to respond to climate change, and learning about climate

change in a way that is effective in general, requires learning that is much closer to the inquiry model implemented in this project than traditional teacher-centered or docent-centered education that happens in a typical classroom or natural history museum tour.

In this article, we briefly described the process of iterative implementation that the docents used to gradually learn and adapt to the new field trip design and content, and the different ways that they responded to the changes of content, design, and student interaction that they experienced. This process for educators to test and refine a new field trip design on the museum floor was further elaborated in a forthcoming book chapter (Allen & Crowley, in press-a). In the years since the project described in chapter two of the dissertation and in our forthcoming book chapter, the natural history museum has expanded and adapted the inquiry-based field trip format to a number of new field trip programs, including those about climate change.

In chapter two, I examined learning among informal educators as a process of changing practice through taking on new pedagogy and new content simultaneously. In chapter three, in press at the International Journal of Global Warming (Allen & Crowley, in press-b), I present an argument grounded in existing literature that education efforts aimed at addressing climate change attend to three principles specifically intended to promote learning to respond to climate change: participation, relevance, and interconnectedness. These three principles were identified from the existing literature on climate change learning and psychology as important for empowering communities by increasing collective efficacy. Collective efficacy is an important necessary condition for people to decide to change their behavior with regard to a large-scale, social problem such as climate change.

In order for people to successfully learn to respond to climate change, they need the opportunity not only to learn facts and scientific processes related to global climate change, but also the opportunity to participate in responses and engage in active learning about why those responses are necessary and appropriate for climate change. Learning to respond to climate change will not simply come from reading a pamphlet or watching a documentary (although these things might help, they are not sufficient). Furthermore, learning to respond to climate change requires the learner to understand how the impacts of climate change are relevant to their lives—researchers have found that imagery of melting glaciers and lonely polar bears do not influence people's responses to climate change, because although they are scary or sad, most people do not regularly see glaciers or polar bears (Moser & Dilling, 2007). They do, however, regularly interact with the environments in their towns and cities, and they notice when patterns around them change (Whitmarsh, 2008; Whitmarsh & Lorenzoni, 2010).

Climate change is a complex, global problem with myriad and unknown outcomes, and people need to understand how climate change is interconnected with other pats of their lives such as food, energy, transportation, and economic systems. In parallel, people need to be able to see how the opportunities to learn about and respond to climate change are also interconnected—for this reason the concept of a climate change learning ecology is useful when thinking about how informal education can be leveraged for communities to respond to climate change (Kehoe, Russell & Crowley, under review). In chapter four, we examine a network that uses the three principles for learning to respond to climate change, and seems to function as an intervention in the interconnected city-scale climate change learning ecology.

Chapter four, submitted for review to the Journal of the Learning Sciences (Allen & Crowley, under review) is an in-depth case study from participant-observation with a network of

informal educators and environmental professionals who worked to develop and implement platforms for informal climate change learning specifically about local impacts and how people can respond in their communities. This network of diverse organizations and representatives from those organizations collaborated on a complex endeavor to design, test, and implement informal climate change educational tools, and more broadly platforms, that incorporated the principles for inquiry learning described in chapter two, and the principles for learning to respond to climate change from chapter three. The analysis in chapter four seeks to uncover the features of this network that enabled it to function as an internally-learning entity (i.e. members of the network engaged in climate change learning and learning how to incorporate climate change education into their work in various ways) and as an intervention in the city-scale learning ecology for climate change (i.e. the range opportunities available for city residents to learn how to respond to climate change).

Using three different approaches that have been described and developed to leverage networks for learning and for responding to wicked problems, chapter four is an analysis of data gathered over eighteen months of the network's engagement. Over this time, how the network engaged with designing, testing, and using the materials that it was centered around changed from a relatively passive feedback and testing system to an active engagement with all levels of designing, prototyping, improving, and implementing hands-on materials for climate change learning in large-scale festival format. The network's successful changes not only to the designs of the "kits" they had originally signed-on to have access to, but to the processes by which the kits were designed and how they were presented to the public were facilitated by four features of the network's structure and operations: an adaptive hub, a shared system of inquiry, boundary

objects, and heterogeneous niches within the network that allow for cross-sector collaboration and mutually reinforcing activities.

Designing and implementing inquiry-based, informal education that promoted collective efficacy and understanding of local impacts and opportunities to respond to climate change was not a simple task. Throughout the course of the network's engagement, members engaged in their own learning and professional development processes, engaging in conversations about climate change and how it is interconnected with the work and missions of their organizations. Additionally, network members engaged in multiple layers of design processes—they helped to design, and ultimately took over the primary designing role of the hands-on kits that attracted many organizations to the network in the first place. Not only that, but the network, as a whole, tried more than one way to implement the kits they were developing in order to maximize what they perceived as impact on the audiences they were targeting—families and individuals who attended local sustainability-oriented festivals. All of this work incorporated the principles for inquiry based learning described in chapter two: learner autonomy, conversation, and deep investigation. It also incorporated the principles for learning to respond to climate change from chapter three: participation, relevance, and interconnectedness.

The three articles that make up the body of my dissertation are connected through the themes of informal climate change education, conceptualizing learning as changing educational practice through processes of implementation and development, and fostering informal learning opportunities that empower people to engage with their communities through increased collective efficacy for large-scale, global problems with local impacts and community-scale responses.

2.0 CHALLENGING BELIEFS, PRACTICES, AND CONTENT: HOW MUSEUM EDUCATORS CHANGE

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2.1 ABSTRACT

Despite the fact that educators in informal settings can be a key part of the learning experience, they are often poorly supported as professionals. This study followed the professional development of museum educators who participated in iterative implementation of a new school trip program focused on climate change. The learner-centered pedagogy, inquiry format, and controversial content of this program all presented challenges to the educators' existing models of learning and teaching in the museum. We offer four case studies that explore how part-time museum docents engaged in reflective practice through iterative implementation and how their approaches to learning and teaching in the museum changed, or failed to change. Findings have implications for addressing the challenge of effective professional development for informal educators, particularly in content areas that may be scientifically challenging or socially controversial.

2.2 INTRODUCTION

We present a group of museum educators – docents in a natural history museum – who confronted their own notions of learning in the museum as a result of participating in a five month iterative implementation of a completely new school trip, which was different in both format and content from previous school trips that the docents had facilitated. Docents in the United States are usually volunteers or part-time low-paid educators who come to the museum because of their own knowledge and passion for the collections, and/or their desire to share that knowledge and passion with the public (Cox-Petersen, Marsh, Kisiel, & Melber, 2003; Grenier, 2006; Jones, 2012). They are often retired, well educated and see the role of docent as a way to continue their own lifelong learning and to give back to society (Abu-Shumays & Leinhardt, 2002). Docents are most often found in collections-based institutions such as natural history museums, zoos, botanical gardens, aquaria, etc. and nature centers or parks.

Despite their semi-professional status as educators, docents are often the only point of human contact for visitors to museums. This is especially true for school trips, where docents routinely guide groups of students through exhibitions (Cox-Petersen, et al, 2003). Although informal learning settings expand the possibilities for science learning beyond those offered in schools (Bartels, Semper & Bevan, 2010; Bell, Lewenstein, Shouse & Feder, 2009; Bevan, Dillon, Hein, Macdonald, Michalchik, Miller, Root, Rudder-Kilkenny, Xanthoudaki & Yoon, 2010; Falk, & Shepard, 2006), school trips rarely take advantage of the unique affordances of museums, tending to look more like formal learning enacted in an informal setting (Cox-Petersen, et al, 2003; DeWitt & Storksdieck, 2008; Kisiel, 2005a; Kisiel, 2005b). We assert that a major reason for this has to do with the ways that docents and other kinds of museum educators conceptualize and enact models of learning in the museum. Museum educators tend to rely on

familiar epistemologies and pedagogies, which are often rooted in their own personal learning experiences in formal settings (Bevan, & Xanthoudaki, 2008; Castle, 2006; Cox-Petersen, et al, 2003; Grenier, 2005).

Confronting and changing embedded assumptions about learning and teaching is a major challenge for informal and formal educators alike. Stein, Smith and Silver (1999), for example, argue that teacher preparation programs should provide deep-seated reexamination, ongoing experimentation, and critical reflection through scaffolded and intensively analyzed apprenticeships informed by discussions of the latest research on teaching and learning. Rather than viewing teaching as a skill to be trained, teachers develop as part of an evolving community of practice where newcomers may begin on the periphery, but over time move towards the center and become resources for helping new members make progress in becoming members of community (Abu-Shumays & Leinhardt, 2002; Castle, 2006).

Most professional development for museum educators does not yet follow this model. Docent-specific training conventionally consists of occasional lectures from other members of the museum staff, readings, and perhaps briefly shadowing more experienced docents giving visitor tours (Abu-Shumays & Leinhardt, 2002; Castle, 2006; Grenier, 2005, 2009; Grenier, & Sheckley, 2008). Grenier (2005) explored a paradoxical discrepancy between the participatory theories of learning espoused by docent trainers (usually full-time museum educators or staff members) and the transmission or acquisition-based "theories-in-use" during actual docent trainings. "Without training reflective of engaging programs that encourage questioning, interaction and experimentation, docents will likely continue to lead tours in a manner that mirrors their prior learning experiences in schools and in docent training" (Grenier, 2005, p. 6). Ash and colleagues (2012) have recently conducted research with museum educators, finding

reflective practice and a design-based scaffolding framework can result in changes in museum educators' practice towards less didactic, more learner-centered interactions with visitors (Ash & Lombana, 2012; Ash, Lombana & Alcala, 2012). Tran (2006) conducted an in-depth study of museum educators' practices and learning goals for school trip students. She found that museum educators expected students to apply prior knowledge, make connections to real-world situations, and most importantly have a positive experience that sparked enthusiasm for learning in museum environments. Yet, in spite of ontologically different priorities, museum educators demonstrated limited strategies for affectively engaging school trip students, and as a result, their educational practice appeared very much like that of formal classroom teachers. Tran (2006) advocates that museum educators develop their own professional language and appropriate pedagogy to support the top priority affective and student-centered learning objectives museums are uniquely suited to serve.

Castle's (2006) research on how docents conceptualize their own learning in regard to their professional practice further elucidates the need to recognize the chasm between inquiry-based pedagogies museum educators are expected to employ, and the types of professional development they are offered. She offers evidence that docents benefit from a community of practice emphasizing reflection and support from their institution, much like formal educators (e.g. Horn, 2010). Museum educators and docents, like classroom teachers, are often isolated in their practice, with few opportunities to discuss the details and generalities of their practice with knowledgeable colleagues. Several researchers have recommended training for museum educators include adequate support for reflection while training and practicing museum education (Bevan & Xanthoudaki, 2008; Castle, 2006). Grenier, Castle and colleagues have called for a more experiential, practice-based and participatory approach to docent training

(Castle, 2006; Grenier, 2005, 2006, 2009, 2010; Grenier & Sheckley, 2008).

One of the major challenges faced by formal and informal educators alike is dealing with what Sfard (1998) describes as the two main metaphors of learning: the acquisition metaphor, wherein learning is conceptualized as the absorption of transmitted knowledge; and the participation metaphor, wherein learning is conceptualized as an active process. Many museum educators begin with the notion that learning is primarily the acquisition of knowledge, a property to be transmitted from a more knowledgeable person to a less knowledgeable person (Bevan & Xanthoudaki, 2008). The acquisition metaphor fails to recognize learning that happens through experience and interaction. Current ideas about powerful learning in informal settings tend to be built from the participation metaphor, phrasing knowledge as action and making learning inseparable from context and process (Bell, et al. 2009). Cox-Petersen and colleagues (2003) found that traditional, didactic, docent-led tours in a natural history museum failed to educate on the level of 21st century science standards, and that student learning gains were negligible. Our project strived to design and iteratively implement a school trip that encouraged student learning with active scaffolding using research-based principles for inquiry. Neither the acquisition nor the participation metaphor alone can accurately characterize human learning (Sfard, 1998), or usefully inform educational practice—an understanding of the strengths and weaknesses of each is what we hoped our docents could achieve by participating in this experience.

This study examines how natural history museum docents' educational practice and conceptions of learning evolved through professional experience. Docents participated in the iterative implementation of a new school trip program that encouraged student-centered, inquiry-based learning, and asked docents to critically examine traditional, teacher-centered learning

models. We hypothesized that participation in the iterative implementation of an inquiry-based school trip would support natural history docents in developing professionally by adopting a pedagogy of inquiry not previously part of their training or practice in the museum. We address two main research questions: How do docents at a Natural History Museum think and talk about learning in the museum? And, how (if at all) does involvement in iterative implementation of a new, inquiry-based school trip program about climate change influence the way docents think and talk about learning in the museum?

2.3 PROJECT BACKGROUND

Our study takes place in the context of a large natural history museum (NHM) in a mid-sized rust belt city that embarked on a four-year collaboration to develop a curriculum-connected climate science learning experience for middle school students from the local public school district (PSD). PSD is a typical urban school district with a diverse student body, over half of whom qualify for free or reduced lunch. A multidisciplinary and multi-institutional team of staff from the museum, the school district, and a university research group designed the inquiry framework and format that were iteratively implemented by the docents, facilitated and supported by a science educator from NHM and learning scientist (Author1) from the university research group. The new school trip in this study used NASA satellite data and the museum collection to engage students in learning about climate change and its connection to biomes. Table 2.1 shows our driving questions and learning objectives, which were arrived at by connecting the required school curriculum with the affordances of the museum collections.

While the present study is primarily about changes toward learner-centered practice that

docents made, we note that the context of the difficult-to-learn and politically controversial scientific content of climate change is an important facet of these practice-based changes. Climate change is an important issue for museums to address, since it is not addressed in many school curricula (Abbasi, 2006; Cameron, Hodge & Salazar, 2013). Researchers of social responses to climate change have found that science content knowledge alone is not sufficient to induce feelings of concern and responsibility for climate change adaptation and mitigation (Kahan, Peters, Wittlin, Slovic, Ouellette, Braman & Mandel, 2012; Roeser, 2012). Educational researchers and climate scientists agree that climate literacy must include a sense of concern for the environment and responsibility to adapt and change (Crowell & Schunn, 2013; van Kerhoff & Lebel, 2006). We designed the new school trip to provide a balance of scaffolding and autonomy for learners. Iterative implementation improved and refined the design, and supported docents in their professional development and growth as reflective practitioners of science education.

In order to understand the professional development of the docents who iteratively implemented new school trip content and format, we first describe briefly what the traditional school trips and docent training at NHM look like. We then describe the new school trip format and inquiry framework that docents implemented, in contrast to traditional school trips. We then present four case studies of docents, with an analysis and discussion of these findings and their implications.

2.3.1 Traditional school trip format

The traditional school trip to NHM consists of docents leading tours of six to twelve students to areas of the museum, and explaining the significance of exhibits selected by the docent to fit a

designated theme, chosen ahead of time by the teacher or the school's trip coordinator. Traditional school trip themes include a comparison of three cultures, the Mesozoic, and in-depth explorations of specific areas of focus, such as Egyptian artifacts and culture. Docents often engage in back-and-forth questions and answers with students, sometimes checking for understanding or answering questions about exhibits or the museum's role in acquiring artifacts or specimens on display. Docents at this NHM undergo in-depth content training on the permanent exhibits when they join the museum, and attend sporadic lectures from the museum's staff or guest scientists regarding temporary exhibits or new research findings. Docents are attentive to the needs and interests of students, and often ask questions at the beginning of tours to ascertain students' current level of understanding regarding the topics and concepts to be discussed. Early in the development of the new school trip about climate change (December 2011, before the new design), docents were encouraged to talk about climate change and NASA satellite data on their tours, but were not provided training on climate change content, NASA satellite data, or how to address potentially uncomfortable topics.

2.3.2 New school trip format

The pedagogical design of the new school trip had three main elements: driving content questions, learning objectives, and guiding principles for inquiry-based learning. Docents iteratively implemented this new school trip design with students from PSD between January and May 2012 (see Table 2.2 for project timeline). In this section we first describe the structure and format of the new school trip, as it contrasts with the traditional tour format, followed by an explanation of the theoretical underpinnings for guiding inquiry principles docents implemented, and the overall framework of iterative implementation within a community of practice.

The new school trip, unlike traditional tours, included a one class period visit by a science educator from NHM to the school a day or two before the school trip. None of the traditional school trips include a school visit component, which means that docents rarely have in-depth understanding of student preparation. The pre-trip component was intended to enhance student learning and engagement (Gennaro, 1981; Orion & Hofstein, 1994). Sturm and Bogner (2010) argue that adequate preparation and clear objectives for connecting class material to school trip material make school trips much more beneficial to student learning. The goal of the school visit was to introduce and activate students' resources for learning about the connections between climate, biomes, and the animals and plants inhabiting those biomes (Hammer, Elby, Scherr & Redish, 2005) while also framing those resources as useful for the pending school trip (Engle, 2006). The pre-trip component established the main driving question of the experience: How are climate and biomes connected and what happens when they change? (Table 2.1) and introduced the use of observations of real data and specimens as evidence in conversations about biomes, climate, and change. The March 14 docent training included the full pre-field trip component of the program, so that docents had a clear understanding of exactly what students experienced in school immediately before visiting the NHM.

During the new school trip, the only structural similarity to traditional tours was the group structure: each docent was assigned a group of 10-15 students and at least one chaperone from the school. Rather than leading to various parts of the museum and explaining and describing exhibits of the docents' choosing, docents begin the new school trips by briefly modeling scientific observation at a single exhibit as an introduction to an area of the NHM—analyzing the interactions between biotic and abiotic features of the diorama, and discussing connections between adaptations of the plants and animals and the climatic features of the biome

represented. Students were then encouraged to document their own observations and analyses of exhibits in that same area consisting of six to a dozen related dioramas using field notebooks introduced in the pre-trip component. During this time, docents would circulate the area, engaging students in small conversations, answering questions, and scaffolding engagement with the driving questions (Table 2.1). Traditional NHM tours allowed few opportunities for students to choose which of the many exhibits about which they would spend time observing and learning.

<table>
<tr><th>Driving Questions</th><th colspan="3">Learning Objectives</th></tr>
<tr><td>How are climate and biomes connected and what happens when they change?</td><td>Knowledge

I can describe in my own words:</td><td>Skills

I can:</td><td>Disposition & Participation

I will:</td></tr>
<tr><td>What are biomes?</td><td>earth's biomes, using features such as precipitation, temperature, and vegetation.</td><td>utilize NASA data to identify and describe different biomes.</td><td>explore weather, climate, and biome data based on my own interests.</td></tr>
<tr><td>What's the difference between climate and weather?</td><td rowspan="2">the differences and connections between weather, climate, and climate change.</td><td rowspan="2">identify and use scientific evidence (maps, fossils, photographs, etc.) to describe current and past climate change.</td><td rowspan="2">have conversations about biomes, climate change, observations and evidence with peers and adults.</td></tr>
<tr><td>Do climate and biomes really change?</td></tr>
<tr><td>How will humans respond?</td><td>why it is important for people to understand climate science.</td><td>ask questions and connect experiences to my own life.</td><td>identify the parts of my school trip that are of personal interest to me.</td></tr>
<tr><td>How do scientists study change?</td><td rowspan="2">how my school trip site is part of climate science research and education.</td><td rowspan="2">access scientific evidence and learn through authentic objects, data, and living collections on my school trip.</td><td rowspan="2">recognize my school trip destination as a valuable part of my city—a place where I can visit, learn, have fun, volunteer, and find a job.</td></tr>
<tr><td>What does NASA have to do with this?</td></tr>
</table>

Table 2.1 Driving Questions and Learning Objectives

By encouraging students to think about climate change as an ongoing process that has happened in the past and will continue to happen in the future, docents were able to more easily

facilitate and engage in conversations about this controversial topic. The areas visited during the new school trips were those that most closely related to the themes of biomes, climate, and how they might change. For docents, this meant connecting areas of the museum not traditionally presented together during a tour—for example, there is evidence of changing climate in the Mesozoic exhibits, as well as in the contemporary depictions of wildlife in their habitats from around the world. The content portion of the new school trip is outlined in Table 2.1, in the form of driving questions and learning objectives, which docents reviewed and referred to throughout implementation. Content foci for this school trip are the connections between the PSD middle school science curriculum, visualizable satellite data from NASA, and conceptual learning about climate change.

2.3.3 Guiding principles for inquiry

The new school trips were pedagogically founded on three guiding principles for inquiry-based learning from learning science and educational psychology research: learner autonomy, conversation and reflection, and deep investigation. These principles were established by the projects' leadership, based on feedback and reflections from docents following an early attempt to modify the traditional tour to fit the climate change learning goals of the project. Specifically, docents had been frustrated that students did not hold still and listen to their lectures about docent-chosen exhibits; that students were talking amongst themselves at different exhibits than the docents wanted to focus on; and that there was not enough time to cover as many areas of the museum as they desired. We chose these guiding principles for inquiry to directly respond to docents' frustrations, re-framing students' behaviors as positive for an inquiry-based learning experience, and providing research-based justification for encouraging such types of inquiry. The

new format and guiding principles for inquiry were introduced to docents in a three-hour training following the meeting where these frustrations were voiced. A second training, after two school trips and debrief meetings had been conducted, asked docents to put themselves in the place of the students and experience the principles in practice on the floor of the museum (see Table 2.2 for full project timeline).

Date	Description	Participating Case Docents
16-Dec-11	First Meeting	Elizabeth, Steve, Paul
26-Jan-12	Training: Guiding Principles, Learning Objectives & Big Questions, Format introduced	ALL
3-Feb-12	School Trip: ~160 students, 15 chaperones	ALL
8-Feb-12	Debrief for 3-Feb School Trip	Lucy, Paul
10-Feb-12	School Trip: ~20 students, 9 chaperones (Special Education academy)	Elizabeth, Steve
10-Feb-12	Debrief for 10-Feb School Trip	Elizabeth, Steve
14-Mar-12	Docent Training: On the Floor; Principles in Practice	ALL
18-Mar-12 to 22-Mar-12	Online Survey on Docent Training: Satisfaction, Perceived Effectiveness	Elizabeth, Steve, Paul
23-Mar-12	School Trip: ~180 students, 18 chaperones	ALL
28-Mar-12	Debrief for 23-March School Trip	ALL
18-Apr-12	School Trip: ~30 students, 2 chaperones	Paul
18-Apr-12	Debrief for 18 April School Trip	Paul
26-Apr-12	School Trip: ~45 students, 4 chaperones	ALL
7-May-12	Debrief for 26-April School Trip	Lucy, Paul, Steve
13-Jun-12 to 15-Jun-12	Interviews	ALL

Table 2.2. Project timeline.

Learner autonomy plays a significant role in student motivation for learning and engagement (Ames, 1992; Linnenbrink, 2007; Pekrun, 2010; Ryan, 2000), particularly in informal and museum settings (e.g. Barton & Tan, 2010; Falk & Dierking, 2000). Learner autonomy is an important part of inquiry-based learning, as it frames the learner as the decision-maker, and encourages learner-centered choices on the part of the teacher, facilitator, or (in this case) docent. Traditional docent tours provide little to no opportunity for learner autonomy, and

based on docents' reports of student behavior at the first project meeting, it was clear that this particular group of students would benefit from more autonomy. We believed it would be a valuable learning tool when well-scaffolded by docents. Second, conversation and reflection have both been established as important aspects of museum learning (Ash, 2004; Barron, 2003; Author2, Colleague, Colleague, Colleague, Colleague & Colleague, 2001; Colleague, Author2 & Colleague, 2002; Colleague & Author2, 2007; Pierroux, 2010). It was important that these two learning behaviors be encouraged during school trips, since both can lead to deeper engagement, especially with challenging content. Additionally, students were already engaging in conversation with one another, to the earlier chagrin of docents. As a principle for inquiry, we found it important to encourage budding learning behaviors, and give docents a strong foundation upon which to scaffold students learning experiences through their natural exploratory behaviors. And third, deep investigation of a few concepts, as opposed to shallow exposure to many facts, was our third principle for inquiry-based learning. This principle is specifically to help educators from feeling pressure to make sure students "see as much as possible" (Bitgood, 1989; DeWitt & Storksdieck, 2008; Kisiel, 2005a; Kisiel, 2005b; Orion & Hofstein, 1994). Throughout this report, we refer to "inquiry" as the incorporation of these three principles in learning experiences.

2.3.4 Iterative implementation for professional development

We hoped to encourage and document the professional development of the docents who worked to iteratively and reflectively implement the new school trip format. We did this by involving docents in an iterative implementation process where they tested out successive versions of the school trip with students, reflected upon each experience with the project team and the other

docents in facilitated 'debrief meetings' after every school trip, and discussed changes that would make the next version of the school trip more effective. Changes were incorporated into the next version of the school trip with a new group of students, and docents and project leaders re-engaged in the reflection and discussion debrief process. Our research encompasses five successive iterations of the school trip and follow-up reflection and discussion with docents (Table 2.2).

We hypothesized that docents would experience success while implementing the three guiding principles, triggering a change in how they conceptualized learning in the museum, based on new and different approaches to school trips. Iterative implementation allowed docents to refine the new approaches, with built-in reflection and support, and a safe environment to discuss successes and challenges of trying new ideas. This hypothesis is informed by formal education research, in particular Nunnery's (1998) study of teachers' implementation of new classroom methods which revealed that educators do not need to be the sole developers of new approaches, but that they do need to observe successful application of those approaches in-context (i.e. in the classroom, or in the case of the docents, on the museum floor). Engaging the docents in the process of iterative implementation allowed us to avoid the "locus of development problem" (Nunnery, 1998) by including and supporting educators from the inception of the development process, while simultaneously challenging dominant notions of how learning happens on the floor of the museum during school trips.

Informed by literature from informal educator professional development as well as the larger body of research on teacher professional development, the theoretical framework for this study is founded in socio-cultural learning theory (e.g. Greeno, 2006) and communities of practice (e.g. Lave & Wenger, 1991). As noted above, informal educators are in need of their

own professional language (Tran, 2006), as well as adequate support for reflection on their practice (Bevan & Xanthoudaki, 2008). We developed a research-based inquiry framework, as well as a corresponding school trip format that we hoped would enable docents to actively scaffold student-centered learning experiences about climate change on the floor of the NHM. By documenting the iterative implementation of this new school trip through observations, email correspondence, and reflective debrief meetings after each iteration, we are able to present an example of the inception of a community of practice that works together to challenge dominant notions of learning and grapple with challenging (and for some, controversial) scientific and socio-cultural content.

2.4 METHODS

2.4.1 Participants

Eight docents volunteered to participate in this new school trip project in 2010, before research began. These docents are among the most engaged and enthusiastic about their educational practice, all having noted that they almost always sign up for opportunities to try new things on the floor of the museum. All of the participating docents are white, college-educated (some having attended graduate school), and retirees or near retirement age. These docents facilitated all of the observed school trips and participated in debrief meetings (Table 2.2), and seven of the eight were interviewed at the end of the 5-month period of data collection. Data collection

2.4.2 Observations

Throughout the first four months of 2012, we observed four of the five school trips that took place at the MNH where our docents were applying the inquiry-based school trip approach (see table 2.2 for project timeline). Author1 recorded observations in the form of detailed field notes, and wrote reflections within 24 hours of each observation to ensure the general understanding of the school trip was captured. Author1 was a participant-observers for the two docent-training sessions (see Table 2.2) during the first half of the project, after which Author1 also recorded informal reflections.

2.4.3 Debrief meetings

Part of our iterative implementation process included reflective, facilitated debrief meetings after each school trip. We established a format in these meetings (between 4 and 8 docents attended each meeting) where each docent shared his or her experience with the school trip, including successful strategies to be repeated and challenges they wished to discuss and better address in the future. Author1 facilitated these meetings as an active participant and observer, attempting to ensure that all docents were given space to speak and listen. This structure highlighted the importance of reflecting on one's own experiences, receiving feedback, and providing feedback and reflection on others' experiences. Debrief meetings were attended by a separate minutes-taker who typed detailed minutes, used in our analysis. Author1 also recorded informal reflections following each debrief meeting.

2.4.4 Interviews

In June of 2012, Author1 interviewed seven of the eight most involved docents on the project, in an attempt to document their background, prior experiences that informed their work as docents, and experience of being a docent up to and throughout the course of the project. Interview questions included: "What are the moments that make you feel a school trip has been really effective?" "Can you talk a little bit about how museum learning is different from or similar to learning that happens in school?" And, "Please describe the evolution of this project, from your point of view, since you first began working on it." These semi-structured interviews were audio recorded, transcribed, and verified.

Our earliest data were minutes from the December 2011 debrief meeting pertaining to the traditional school trip (Table 2.2). This meeting generated a lot of the initial ideas for the new school trip structure, and informed the decision to use guiding principles from learning science research to support and structure the change. Over two training sessions, five school trips, six debrief meetings, and various informal interactions; we observed distinct moments indicating that docents were changing how they interacted with students, and how they talked about learning.

2.5 RESULTS

We present individual case studies of four docents representing a broad range of experiences, reflections, and responses to the process of iterative development. These cases serve as examples of how educators perceive changes in their own practice, or assimilate new ideas into existing

cognitive frameworks. The first case involves a docent who recognized and demonstrated a great deal of change in his understanding of learning on the museum floor, while the second resisted change to her existing model of learning. The final two cases are examples of docents whose backgrounds and experiences provide different glimpses into the world of informal science education, and the different influences of those varied backgrounds on educators' practice and thinking.

2.5.1 Steve's Case: Reflective Change

> I think the debriefings after each tour were absolutely invaluable... when a docent begins to have an individual approach within the framework that has been established, that is a very, very positive sign (Steve, interview, 13 June 2012).

Steve is a retired geography lecturer and environmental planner for engineering firms, married, without children. He joined the NHM docents after retiring at age 63, in 1998 in an effort to "keep my brain from turning to sauerkraut" (Steve, interview, 13 June 2012), in other words, to continue to learn new things and be around a group of people who were also interested in natural sciences. He is a self-identified curmudgeon and has found his experience as a docent working with younger children to be the most challenging part of the job: "Below fourth grade, I am not very comfortable, and below second grade, I simply will not do the tour" (Steve, interview, 13 June 2012). Steve expressed low expectations for the target audience, which may have influenced some of his early attitudes: "[PSD] kids are not getting as much of a quality education as they deserve... I don't blame this on the school system, I blame it on the parents because the parents are not demanding" (Steve, interview, 13 June 2012). He specifically reflected on the differences between the target audience for this project (urban public school

students) and audiences from other nearby schools with more resources and different demographic compositions:

> We are teaching a way to learn. I am not going to do that, well I would like to avoid doing that for older groups. To be honest, I think it's sort of demeaning. [R: But not for middle schoolers?] Middle schoolers are on the line—it depends on the group. If the middle school is [nearby Catholic] or [Affluent Suburb], same thing. Their preparation is better, and not just the preparation for the tour, but their overall preparation is one of inquiry (Steve, interview, 13 June 2012).

Steve's doctoral degree in geography and his experience as a lecturer at a university afford him a much deeper background in natural sciences than the majority of the NHM docents. He appreciates the rationality, logic, and intellectual stimulation that come with the natural history experience. The content of climate and biomes was what attracted Steve to volunteer for the project, given his deep knowledge of physical geography "which clearly has to do with landforms, fluvial processes, climatology, a variety of things that constitute the physical environment, which relates obviously" (Steve, interview, 13 June 2012). His early reticence to changing how he interacted with students may be related to his primary interest in sharing his knowledge in his field of expertise. In particular, he was apprehensive about allowing students autonomy on the floor of the museum—during the first school trip under the new format; he ignored that guiding principle, leading his group through the museum as a traditional tour (Observations, 3 February 2011). Steve developed a particular strategy for addressing the controversial topic of climate change during the project:

> Climate change I generally kept away from, because with older groups it is politicized. I think the key to it is really explaining that climate change is all the

> time... once they understand that the climate is changing, irrespective of the debate about it changing, that tends to de-politicize it, and I keep away from the causes of it (Steve, interview, 13 June 2012).

The tendency to avoid potentially uncomfortable or political topics was a strategy that many docents employed during the project.

On the second school trip (10 February 2012), Steve was stationed as a "roaming expert" with whom other docents' groups could engage during their explorations at the museum. The opportunity to observe students engaging with the museum in a different way allowed him to reflect on his earlier apprehension:

> This is how it was put to us [in training]: you show them, you model the behavior, and then you turn them loose. And when you turn them loose, horrors! You know, oh my God! What are you doing? I've gotten a little bit beyond that, a smidgeon... I recognize that in certain environments and circumstances, given the objectives of this tour, you have to accommodate [autonomy] to some extent (Steve, interview, 13 June 2012).

Steve more readily embraced the principle of learning through conversation. He maintained that he must start a school trip with a short formal lecture, but noted that he knows a trip is really effective

> when I see kids finding things on their own, commenting about them and raising intelligent questions... every once in a while you get a really good question that indicates the person understands what he's seeing, not just looking at it, that's the light bulb going off and that's when I say AHA! We got something going here, I like it (Steve, interview, 13 June 2012).

As he became more aware of the positive aspects of students' conversations and sharing observations amongst one another, and with him, Steve began to more enthusiastically embrace the process of iteratively improving how he and other docents approached these new experiences. He differentiated this approach from both his other techniques on the floor of the museum, and his own experiences in museums as a middle-school student:

> The approach we took in [this project] did not exist when I made my annual sixth or fifth grade museum trip. We went and looked at the things to look at, we were told what to think about it, we were told, if we were lucky, what it really meant, so to that extent, museum trips are better learning experiences now than they were (Steve, interview, 13 June 2012).

Steve was able to reflect on the process of his own changing feelings regarding this project, and especially found value in the in-class preparation students received before visiting the museum, as well as the opportunities to share and reflect on all the docents' experiences after each school trip:

> There was a point at which we realized that the in class preparation the kids were getting actually made a difference. We were not talking to people who simply looked at us like, 'what are you talking about?' That made a difference... the docents were getting more comfortable with the idea that they were getting better at [the new format]... (Steve, interview, 13 June 2012).

The experience and the changes that Steve had throughout this process inspired him to re-design one of the existing traditional tours offered to school groups at NHM with the principles of

inquiry from our project. He presented the twelve-page document of the re-designed tour to me at the end of our interview in June; with a genuine enthusiasm that so contradicted his curmudgeonly nature he almost seemed embarrassed.

2.5.2 Elizabeth's Case: Struggle and Change

> I am still quite frustrated at the shallow amount o f information that can be obtained by the students. Where does the guidance to proper conclusions come from in so brief a time? I can effectively guide an entire tour group through exploration to collectively learn (Elizabeth, interview, 14 June 2012).

Elizabeth is a former elementary school teacher—a position she left to become a full-time mother in the late 1970s. She emphasized her identity as a mother and teacher, and noted that part of the reason she became a docent after her children had grown was because they encouraged her to seek an activity that would allow her to use her inquisitive nature in a constructive way. She identified her father's observations of nature on their family farm as part of the draw to the natural history museum in particular. Elizabeth makes a concerted effort to bring other disciplines into her tours of the natural history museum, quoting ancient texts, naturalists, and talking about relationships between nature and culture. She had almost the opposite view of Steve's perception of parents, noting, "the parents are far too involved in what goes on in a classroom. I don't think we need that much parent involvement. To me it suffocates the teacher" (Elizabeth, interview 14 June 2012). To identify and define learning both in her former elementary classroom and on the floor of the museum, Elizabeth's predominant references were to vocabulary. She also repeatedly described learning in terms of quantity: "I had a lot of important information for them before we even started", "this child was thrilled to

have learned so much", and "I was really surprised... how little opportunity there was to learn enough" (Elizabeth, interview, 14 June 2012).

Elizabeth does not hold an advanced degree in science, and often described scientific concepts as "too sophisticated" either for her, or for the students with whom she worked. At our first meeting, she conveyed a mistaken understanding of one of the satellite data parameters used in the pre-trip and as a display on the floor during an early version of the school trip. When Author1 followed up with her about it, she was happy and eager to learn a new piece of information. Elizabeth pointed out that there was one exhibit in the museum that she felt represented climate change, but that it was not in an area that had been designated as part of the school trips for this project. She noted that the museum exhibits visited during the new school trips did not directly address climate change: "Actually, when you get up into the polar [exhibit] there is nowhere to really address climate change... it suggests seasonal change, but not climate change" (Elizabeth, interview, 14 June 2012).

Elizabeth actively resisted the notion that students on school trips would be able to learn on the floor of the museum without the direct guidance and interpretation of a docent throughout the project. When asked how she would describe the project to someone from outside the museum, her terse reply was, "Ongoing". With further prompting, she revealed,

> Well, it's a learning style that for the time I don't feel is effective... this is what I see as a weakness perhaps based on a lack of information, but then I'm also trying to figure out how I can take what I see the idea of the project to be, and how I can in some way beef it up... based on something I really don't like but I would like to make what I don't like a little bit better so this project will work within the scheme of my understanding (Elizabeth, interview, 14 June 2012).

Her dissatisfaction with the "learning style," that is to say, the inquiry-based format that was implemented, is closely tied to her definition of learning as a quantifiable amount of knowledge or information, and an adherence to her own "scheme of understanding," her personal epistemology of how learning happens in the museum.

On one occasion, Elizabeth used a set of data maps during the school trip, which the students had used in their in-class preparation. Author1 observed her use of the maps during the school trip, and when asked about this during our interview, she exclaimed, "That worked out! It was serendipitous... I happened to glance down and I saw 'sub-Saharan' and that's when we most effectively used those maps and came up with new vocabulary..." (Elizabeth, interview, 14 June 2012). In this case, Elizabeth used the new tools in a way that fit with her original definition of learning, or "scheme of understanding" as she put it. Elizabeth was clear about how engagement in this project had changed her practice:

> Through my struggles with this [I] have found... I'm even looser with the way I do a tour. But guided and allow them to come up with their own conclusions, with a proper answer though... allowing for more observation, more conversation—I'm finding a lot of success with that because if your children are really excited, they go to an exhibit and they start chattering, that's your avenue (Elizabeth, interview, 14 June 2012).

While Elizabeth found success in "loosening" her tour, she was not entirely comfortable with the school trip format that restructured the docent-student relationship to be more learner-centered. She was clear on her stance that the docent should be in control of the learning:

> Keep good, constructive knowledge guided by a docent. Just don't let them run off unless there's a specific reason the teacher wants an investigative tour... with

> guidance limited by the teacher. I think the basic idea of coming to a museum is to have someone teach you. I've had adults of all different professions say, 'oh, I'm so glad you're here. We love to have a docent. It's the only way you can really know what you're standing in front of.' So to have a docent interpret, that's vital, because we know a lot (Elizabeth, interview, 14 June 2012).

Here is evidence that Elizabeth's success with adult audiences influences how she structures her interactions with children and young adults. She was eager to reflect on her practice throughout the project, even though she disagreed with some of the pedagogical decisions that had been made for the new school trips. She regularly responded to distributed notes from observations with questions about how she could improve her explanations of various concepts and a desire to sound more "sophisticated" (email communication, 10 May 2012). She noted early in our interview "I have key points that through experimentation I have found light up children, make adults more interested or connect" (Elizabeth, interview 14 June 2012) indicating that she recognizes differences in the interests in different groups of visitors, particularly groups with varying age compositions. In general, Elizabeth seemed to base her assessment of the quality of a school trip on how much information she was able to transmit to students, with feedback from their reactions to those ideas and information. Steve, in contrast, seemed to base his judgment of a successful school trip on the conversations and questions students raised during their visit, rather than the information he was able to talk about.

2.5.3 Paul's Case: Embracing Pedagogy to Fit the Learner

> I mean conversation is where it's at. A tour like this, if you're not talking, or you're not conversing, both of you, I mean the students and the leader, if you're not doing that, it's not going to go anywhere (Paul, interview, 15 June 2012).

Paul is a retired schoolteacher, widower and proud grandfather. He retired from teaching in the early 1990s. His docent experience began in 1999, when he initially attempted to become a docent at the art museum that shares a building with MNH, but switched to natural history when he realized "I never would have fit in over there" (Paul, interview 15 June 2012). He is a docent primarily because he loves kids, loves talking, and loves sharing knowledge with other people; and he finds great satisfaction in engaging with visitors, especially when visitors express their own interests and excitement about being involved with the museum. His attitude towards museum learning was well-aligned with the guiding principles of the project from early on: "Rather than trying to impart knowledge, our aim is to have them like their experience here, as well as at least pick up some of the things that they can" (Meeting minutes, 16 December 2011). He noted early on that he would like to see a similar pedagogy applied to the other school trips facilitated by the docents, and that docents who did not work on the project should be exposed to this new format, even if they said they didn't like it at first. He differentiated himself from other docents who were less comfortable with change, identifying as open to change and happy to try new things, even if they were unfamiliar. Paul had a very positive opinion of the students who attended the school trips during the project: "I've had the pleasure of meeting these kids at their best or their finest or whatever, because the kids have all been great" (Paul, interview, 15 June 2012). He connected this to his experience with junior high students on school trips in the 1970s,

noting that no matter how poorly they behaved in the classroom, students were always very well behaved in settings outside of school.

Paul's experience as a middle school science teacher in the 1970's seemed to afford him a much higher comfort level with the students in this project. In contrast, his experience with the curriculum during that time period contributed to a tension regarding the climate change content of the school trip: "I got burned once and I won't be burned again like that, when the scientists predicted we're going to have an ice age, and I was teaching that... I got sucked in on the ice age thing, and went whole hog for that, well I won't do that again" (Paul, interview 15 June 2012). The heavily-publicized "debate" amongst political and economic stakeholders regarding the science of climate change did not help Paul to reconcile the feeling of being 'duped' by science—he expressed suspicion towards scientists and politicians who make decisions about funding for scientific research, noting "I think Al Gore's a total jackass" (Paul, interview 15 June 2012). At the same time, Paul maintained that it is appropriate for the NHM to address climate change, because "it's real, it's always been there, we maybe never discussed it, but it's always been there. It's just something that's an ongoing thing" (Paul, interview 15 June 2012).

Paul's prior experience with middle school students on school trips probably allowed him to feel more comfortable giving students autonomy on the floor of the museum, where other docents were apprehensive about allowing students to explore on their own, for fear that students would misbehave. He discussed his own process of reflection and refining how he conducts a school trip, mostly realizing when he spent too much time talking "I can't ever seem to get this in and I can't ever seem to get that in because I talk too much here and I talk too much there. As I've adjusted, I read through the [driving] questions again, and that's why I've seen it evolve" (Paul, interview 15 June 2012). Paul specifically differentiated between the traditional school trip

tours and our focal project:

> I try to teach factual and identifiable things about the different dinosaurs, and review their knowledge by asking and asking and asking. But that's very different from working through a bigger concept—one thing about [these school trips] that's a bigger concept, what we're trying to do with biomes, working in a different way. I'm asking questions over here, over here I'm presenting areas, and I am facilitating them doing something (Paul, interview, 15 June 2012).

Not only did Paul identify differences between the traditional tours and the different format to meet project objectives, he also noted that the format was particularly successful with the specific age group of the project. When asked if he felt that the new format was more effective than the traditional tours, he responded: "For seventh graders? I'm going to tell you it's much more effective" (Paul, interview, 15 June 2012). Paul's easy adaptation to new on-the-floor pedagogy in the NHM seemed to be fueled by his trust and experience with middle school aged students in the past, and his genuine desire to spend quality time with young people as one of his primary motivations for working as a docent. His opinions about climate change surprisingly did not affect his ability to engage with the ideas and concepts of the school trip centered on climate, perhaps in part because he so readily embraced the inquiry format, putting students in charge of their own learning.

2.5.4 Lucy's Case: Evidence-Based Education

> Because skepticism is so important in science, should there be some way to make that point to the students? Could there be some way to encourage skeptical thinking, or questioning of students' or others' interpretations? (Lucy, interview, 14 June 2012).

Lucy is a former nurse and biology laboratory technician, currently a part-time freelance consultant and writer, and mother. Her interest in science and her love for museums attracted her to the docent role at NHM, which she began in 1996. To Lucy, the museum is a place where scientific thinking is encouraged: "the museum is a more welcoming place where you can come and you can doubt and you can say, 'I'm not sure if I believe that', or 'what's the evidence', and you're not going to get shut down for that" (Lucy, interview, 14, June 2012). She identified one of the rewards of working as a docent as the interpretive aspect of the work:

> I enjoy taking something that's really kind of complicated or scientific or jargon-y and digesting and make it understandable without losing too much of the meaning... not in dumbed down way, but in a clearer way (Lucy, interview, 14 June 2012).

Lucy's passion for and background in science appear to have instilled in her a strong tendency toward concrete, evidence-based knowledge. She was very hesitant to speculate on the learning that takes place on the floor of the museum, but expressed several times during our interview a desire for a more tangible understanding of what is learned in the museum:

> I'm really interested in taking the things people are most mistaken about even when people think they know... and having some kind of evidence for whether the museum's doing a good job helping people to understand those things. But the other part of that would have to be also making sure it's not something they knew before they came here (Lucy, interview, 14 June 2012).

This drive to make decisions based on evidence, including controlling for confounding variables such as visitors' prior knowledge, may have helped Lucy to justify her use of the guiding principles over the course of the project. Even late in the process, she expressed discomfort with the inquiry-based format, voicing that she did not consider the practicing of previously learned skills or applying prior knowledge to be true learning, and that she wanted to "push students further, into new knowledge" (Debrief Minutes, 7 May 2012). However, as she witnessed students' motivation to engage with the opportunities presented during the school trip under the guiding principles of autonomy and conversation, I observed her using these strategies on the floor more and more consistently. Her reflection on the process indicated a similar observation, as well as an indication that she defines her own learning similarly to the way she defines it for students in the museum:

> I think every time I worked on a tour, I did it a little bit differently. So I feel like I have a better idea of being able to model more clearly and send them off to do whatever they're going to do... And my learning of the material itself... I have a long way to go (Lucy, interview 14 June 2012).

Unlike Steve and Paul, who explicitly differentiated between age group and demographics of the target audience for this project, when Lucy talked about the students, she drew distinctions

between the environments that students are or may be exposed to. Lucy considers the museum an advantageous learning environment, in part because it is different from the day-to-day classroom learning experience, because in the classroom students are

> ...socialized to act in a certain way and think in a certain way... the museum is a good fit for conversation with small groups, or one on one... also because the docent or the leader is usually someone they've never met, and probably their impression is they'll never meet you again, you're like really a total stranger, so it's a different conversation than they would have at school with their teacher (Lucy, interview 14 June 2012).

Lucy dealt with several tensions while working on this project. The first was between what she understands to be true learning (acquisition of new content knowledge), and the more motivation and affect-oriented objectives of the project. The second tension is her apprehension with the topic of climate change:

> I find it really hard to talk about it with other people, because it immediately becomes political, so I have mixed feelings about climate change. I think it's a really important issue... museums should be able to [address], but they have to stay very close to the science and the evidence... None of the students took it up as a political argument. I was a little surprised (Lucy, interview, 14 June 2012).

Lucy's apprehension about discussing climate change may have enabled her to embrace the inquiry-based format. By allowing students' interests to guide conversations, and finding that none of them took it as a political issue could have made the strategy more valuable to Lucy

when addressing potentially volatile topics. Overall, Lucy's case demonstrates that an individual educator can utilize pedagogical strategies that range from teacher-to learner-centered as well and from acquisition-to participation-based models of learning.

2.6 DISCUSSION

Experts in learning and education are now looking to the promise of collaborative relationships between schools and museums to "close the gap" of access to high-quality science education in the United States (Bevan et al., 2010). Museums and schools alike face the challenge of changing educational practice away from traditional, didactic, teacher-centered methods and toward inquiry-based, participatory, engaging strategies for learning. This study followed museum educators as they took up this challenge by iteratively implementing a new school-trip design, which was generated through collaboration between a natural history museum, a PSD, and a university-based research group.

As part of the iterative implementation process, all four educators engaged in extended reflection on their own learning in regard to the new school-trip format and its challenging content: climate change. Steve's self reflection included acknowledgement that he'd changed how he thinks about learning, allowing him to recognize the value of a new approach and take it upon himself to apply that approach to an existing traditional tour at the museum. Paul also found value in the inquiry format, comparing it to an educator's academic freedom to try new things and adjust practice as it evolved. Lucy's focus on evidence shaped her reflections, prompting her to indicate that she appreciates having another "tool" or "method" to use on the floor, while maintaining that it would not be a good idea to constrain or limit the different ways

that educators engage with visitors. Elizabeth's reflections allowed her to engage in reimagining her practice to be oriented toward the observations and interests of the students "so that they come out knowing something based on what they're really interested in" (Elizabeth, interview, 14 June 2012).

Each of the four educators had different opinions about and experiences with the target audience for this project, which influenced their expectations and how they interacted with the students. Steve's opinion that the students attending these trips needed an opportunity to "learn how to learn" was based on a deficit model, wherein urban public school students are not as well prepared or supported by their families as students from private or suburban schools. Paul's prior positive experiences with urban middle school students on field trips allowed him to be comfortable with the students and adapt easily to the format that gave students more autonomy. Lucy, like Paul, drew a distinction between school and the museum as learning environments, focusing on the advantages of the museum as a new and different place where students would behave differently. Elizabeth used evidence from tours she'd conducted with adults to justify her pedagogical choices with other age groups in the museum, while also acknowledging that different groups have different interests that can be used to engage them with content.

Informal educators are in need of a community of practice and a professional vocabulary and pedagogy that acknowledges and capitalizes on the unique affordances of learning in informal settings, especially for audiences that are underserved in formal educational settings (Bell et al., 2009; Bevan, & Xanthoudaki, 2008; Castle, 2006). This community can help practitioners to challenge dominant notions of teaching and learning together, differentiate practices and strategies for engaging different kinds of audiences, and support ongoing professional development through conversation and reflective practice. Our study demonstrates

what the beginnings of such a community of practice might look like, and what steps were taken to initiate reflective practice and shared communication among informal educators in a natural history museum. The educators in this study began to develop a community of practice among themselves, supported by the structured iterative process of implementation that encouraged reflection and conversation about practice. By taking into consideration the needs of educators for an open and encouraging process, this project succeeded in sparking change in practice, even for those who struggled with difficult scientific content, politicized topics, and challenging new pedagogical approaches to learning.

Sociocultural learning theory (e.g., Greeno, 2006) and theory specific to communities of practice (Lave & Wenger, 1991) supports the development of communities of learning and practice among students (e.g., Boaler, 2008; Engle, 2006), teachers (e.g., Horn, 2010), mu-seum educators (e.g., Bevan, & Xanthoudaki, 2008; Castle, 2006), and project developers. Communities of practice are rooted in the participatory model of learning, an important as-pect of inquiry. The development of a community of practice achieves the goal set by Castle (2006) and Bevan and Xanthoudaki (2008) of eliminating the disconnection between ped-agogy for educator learning, and pedagogy museum educators are expected to employ by incorporating the principles for learning that museum educators utilized with students into the process of their own learning. By engaging in the reflective, iterative implementation process laid out during this project, museum educators were able to connect what they'd learned in one setting to the other work they do on the floor. The most prominent example of this sort of change and connection is Steve's decision to redesign an existing traditional tour to further utilize the inquiry format. All of the participating museum educators talked about the value of the experience to their own practice.

Beyond the general implications for professional development of informal educators, our findings also have implications for developing communities of practice for the teaching and learning of difficult, controversial, and important scientific content. The particular school trip we designed, implemented, and studied was focused on climate change, which emerged as the central topic and conflict for the emergent community of practice. While each of the educators had very different backgrounds and experiences with science and science education, all of them engaged in a similar strategy of avoiding the controversial aspects of climate change. All four emphasized the importance of depoliticizing the issue of climate change by framing it as an "ongoing process," and none attempted or approached conversations about the causes of climate change. Part of the reason docents took this path through the challenge of climate change was because within their nascent community of practice, the issue was controversial. The docents expressed their own desire to avoid conflict about the issue because it was politically charged. Paul's opinions and feelings about climate change were definitely a driver for these sentiments. Paul's persistent belief that climate change is not caused by human actions is a testament to the well-documented phenomenon that political affiliation is the strongest determinant to people's opinions about this issue (Borick & Rabe, 2010; Hart & Nisbet, 2011). Because both the content and the pedagogy implemented in this project were new and challenging, the docents' emerging community of practice focused more on how to facilitate inquiry than on the topic of climate change, though both of these facets of the project were controversial for this particular group.

Museums are uniquely positioned to function as "agents of climate change governance" (Cameron, 2011b) since the public generally trusts museums to present information free from political influence (Cameron, 2011a; Cameron et al., 2013). Cameron and colleagues argue that museums can move the climate change conversation beyond the restricted frame of ecological

modernization to facilitate community discussions and innovations outside the realms of corporate and government mitigation, or lack thereof (Cameron, 2011a, 2011b; Cameron, & Deslandes, 2011). This idea blends nicely with the sociocultural view of learning that emphasizes agency and identity (Greeno, 2006; Hull & Greeno, 2006) and has been specifically explored in informal science learning by Barton and Tan (2010) who take the position that agency and identity are important factors in science learning and cultivating lifelong interest and engagement with science. To capitalize on the benefits of discourse in learning about these difficult issues, science educators in museums will require supportive communities where conversation about challenging topics is validated and participants feel their voices are heard, even if there is disagreement among community members. Future research should focus on how learning about socio-scientific issues such as climate change happens in informal learning settings, and how it can be improved and expanded to reach key populations who will be impacted by a changing climate.

Our goal was to support educators' reflection and build a community of practice through iteratively implementing a new, inquiry-based school trip about climate change. We studied this process to gauge whether docents' educational practice and perceptions of learning changed as they iteratively implemented a new way to facilitate learning new content and concepts on the floor of the museum. As informal science education becomes an increasingly prominent part of the science education infrastructure, professional development for informal educators is emerging as an important and high-impact arena for change. Informal educators exist in myriad contexts—not just museums, but also community organizations, after-school programs, and NGOs. Formal education has long worked to change dated and dominant paradigms that persist in the collective understanding of how teaching and learning happen (e.g., Cuban, 1984; Tyack

& Tobin, 1994). Dedication, reflection, and support from other educators and experts in content and pedagogy are all necessary for real and sustainable change (Coburn, 2004; Cohen, 1990; Smith, 2000). Connecting what we know about professional development through communities of practice in formal and informal education is an important first step toward broadening the opportunities for high-quality science education for all, particularly when facing important and controversial science issues such as climate change.

3.0 MOVING BEYOND SCIENTIFIC KNOWLEDGE: LEVERAGING PARTICIPATION, RELEVANCE, AND INTERCONNECTEDNESS FOR CLIMATE EDUCATION

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3.1 ABSTRACT

Climate change requires a massive global response: individuals, communities, regions, and nations all need to make substantial change to current habits and behaviors. Education is an important part of changing habit and behavior, yet most contemporary climate change education focuses primarily on individual's knowledge about climate science, which research suggests has limited utility in supporting collective response to climate change. This article proposes a new focus on educational intervention that is sensitive to the shared need for rapid, collective impact. Drawing on socio-cultural learning theory and a review of research on climate change learning, we argue that interventions based on three core principles – participation, relevance, interconnectedness – are more likely to result in people taking steps to respond to climate change than interventions based on knowledge acquisition alone.

3.2 INTRODUCTION

Climate change influences and is influenced by economic, ecological, and political systems at global, national, and local levels. Although people may be gradually becoming more aware of the need to reduce their environmental impact and to respond to climate change, progress is far from sufficient: expanded and immediate institutional, societal, and community changes are necessary to address the effects of current global climate change (Intergovernmental Panel on Climate Change, 2013; Sun et al., 2010). Climate change education for children and adults, both in and out of school, is a part of ramping up a response to climate change, but prior efforts have been scattered and uncoordinated (Abbasi, 2006; Choi et al., 2010; National Science Board of the US, 2009).

A common assumption underlying many educational interventions is that people fail to act in response to climate change because they do not understand climate science (Barr, 2007; Grotzer and Lincoln, 2007; Moxnes and Saysel, 2009; Nigbur et al., 2010; Shepardson et al., 2009, Sterman and Sweeney, 2007). The science of climate change is vast and complicated, covering topics such as the greenhouse gas effect, processes and impacts of sea level rise, increases in extreme weather events, changes in precipitation patterns, and resultant changes in habitat composition (Intergovernmental Panel on Climate Change, 2013). Researchers and educators have explored the best ways to teach climate science and address common misconceptions among both children and adults (e.g., Shepardson et al., 2009; Taber and Taylor, 2009). And they have had success: Although much climate science is difficult to learn, even the more complex topics can be effectively taught under certain conditions (Cordero et al., 2008; Moxnes and Saysel, 2009; Shepardson et al., 2009; Sterman and Sweeney, 2007; Taber and Taylor, 2009).

However, even when people know about climate science, there is little direct evidence that knowledge, or the gaining of it, leads to behavior change. The assumption that decisions are based on scientific knowledge has been described as an oversimplification of how people make choices (van Kerhoff and Lebel, 2006; Zia and Todd, 2010), and psychology researchers have demonstrated that scientific understanding is not what determines people's actions or opinions with regard to climate change (Kahan et al., 2012).

The authors assert that increasing climate science knowledge is not a sufficient outcome for climate education if it is to be leveraged to address the problem of climate change. To contrast with traditional 'knowledge only' climate education, in this article *effective* climate change learning is defined as that which enables responses to climate change that are commensurate with the scale of the problem and appropriate for communities' unique needs and situations. The primary way climate education efforts can do this is by increasing collective efficacy. Collective efficacy is the sense that one's actions, in combination with the actions of one's community and those with whom values are shared, have the capacity to make the desired impact. Responses commensurate with the scale of climate change are enacted at the level of communities and governance systems, and collective efficacy is a requisite for engaging with these systems.

The primary goals of this article are:

1. to consider the evidence that knowledge about climate change is not sufficient for action
2. to argue that educational interventions should focus on increasing collective efficacy for responding to climate change
3. to introduce three learning science principles for effective climate change learning.

In pursuit of these goals, the authors used a systematic methodology for reviewing and synthesising a very large set of adjacent literatures. The process began with a focused review of recently published learning sciences literature concerning informal learning, design-based research, and the relation between learning and action. This review identified a set of three principles that are hypothesized to support effective learning about complex socio-scientific issues. The authors then used these three principles to guide a broad review of literature in climate change education, climate change psychology, and climate change communication, looking for extant educational approaches that might be informed and extended by application of learning sciences concepts.

3.3 FROM KNOWLEDGE TO COLLECTIVE EFFICACY: NEW GOALS FOR CLIMATE EDUCATION

It may seem obvious that, in order to address the challenges of global climate change, people must be well informed about the issue. It may then also follow that the more people know about the causes and consequences of climate change, the more likely they will be to change their behavior to mitigate or adapt to climate change. However, knowledge of the phenomenon turns out not to predictably result in individuals making choices that are 'scientifically informed' or 'environmentally friendly' (Kahan et al., 2012; Pidgeon and Fischhoff, 2011; Shepherd and Kay, 2012; van Kerhoff and Lebel, 2006). So, if knowledge is not sufficient to change behaviors and decision-making, what is?

Understanding what actually influences human behavior and decision-making in response to climate change is a difficult research goal. One problem is that knowledge acquisition is

relatively easy to measure after an intervention (e.g., with a test), while behavior change may occur well after learners have left the intervention context and returned to their lives. Thus, many researchers have approached the question of behavior change by measuring attitudes as a proxy for behavior (Cordero et al., 2008; Devine-Wright et al., 2004; Taber and Taylor, 2009; Aguilar and Krasny, 2011; Ranney et al., 2012). One study suggested that climate change knowledge had some influence on attitude (Ranney et al., 2012), and several have shown that attitudes can be to sensitive to knowledge-based intervention (Aguilar and Krasny, 2011; Cordero et al., 2008; Taber and Taylor, 2009). However, there is evidence from other research domains that attitudes about an issue do not accurately predict real-life decision-making unless the choice being made is relatively low-cost (Boyes et al., 2009; Diekmann and Preisendorfer, 2003). In other words, increasing people's knowledge, even if that knowledge has some impact on their attitudes, may not be sufficient for influencing their behavior with regard to climate change.

The most convincing evidence that knowledge of climate science alone does not impact people's behavior comes from the work of Kahan et al. (2012). They found that even among people who are highly knowledgeable about the science of climate change, opinions about what can or should be done are polarized along ideological divides. They attribute this pattern to the powerful influence of individuals' identity groups: the communities on which they are most dependent for social and physical resources (Kahan et al., 2012). That is to say, people's collective identities have a much stronger influence on their behaviors and beliefs about climate change than their scientific knowledge, which can work for or against the goals of educational intervention (Hart and Nisbet, 2011; Hobson and Niemeyer, 2012; Nigbur et al., 2010). To effectively learn to respond to climate change, people are forced to deal with several interconnected factors outside their scientific knowledge, particularly emotions and collective

identities (Bain et al., 2012; Devine-Wright et al., 2004; O'Neill and Nicholson-Cole, 2009; Patchen, 2010; Roeser, 2012; van Kerhoff and Lebel, 2006). Therefore, climate education must take into account the emotions and collective identities upon which people depend to inform their decision-making. The importance of these factors on climate change learning and the argument for focusing climate change education on increasing collective efficacy follows.

Emotions are an important influence on learning in general (Linnenbrink, 2007; Pekrun and Linnenbrink-Garcia, 2010), and on learning about climate change especially, since it is an emotionally and politically charged topic (Lombardi and Sinatra, 2013; Roeser, 2012). In the case of climate change, emotions can actually impact people's ability to make useful assessments of available information (Lombardi and Sinatra, 2013; Lombardi et al., 2013; Sinatra et al., 2012). For example, teachers who expressed anger towards the topic of climate change had more difficulty accurately assessing climate change information (Lombardi and Sinatra, 2013). A similar relationship between emotions and ability to accurately assess climate change information was found among undergraduate college students (Sinatra et al., 2012). What these survey and test results illuminate is the high level of influence that emotions can have over what has often been assumed a separate, rational system of thinking.

Emotions are also a powerful influence on how people respond to information about climate change. For example, the counterproductive effect of prevalent 'doom and gloom' messages about climate change has been widely documented (Feinberg and Willer, 2011; Grotzer and Lincoln, 2007; O'Neill and Nicholson-Cole, 2009). Dire messages and tragic imagery, such as lonesome polar bears trapped on shrinking ice floes, tend to demotivate and promote disengagement from the issue, and in some cases can even decrease people's belief that climate change is a problem at all (Feinberg and Willer, 2011). For learners who are working to

apply new knowledge in real-life contexts, information that evokes dread, fear, or guilt must be accompanied by clear options for action (Feinberg and Willer, 2011; Grotzer and Lincoln, 2007; O'Neill and Nicholson-Cole, 2009; Wolf and Moser, 2011).

Climate change must be addressed by people at the collective level. Socio-cultural learning theories provide a framework for understanding how learning itself is a shared process that taps into people's collective identities (Greeno, 2006; Lave and Wenger, 1991; Wenger, 1998). Collective identity is a set of values or beliefs that are empowering to those who identify with and share them (Jamison, 2010). One particularly pertinent form of collective identity is ideology, an important set of values by which people assert and connect to their communities.

The importance of ideology on people's opinions about and responses to climate change has been widely documented (Bain et al., 2012; Borick and Rabe, 2010; Feygina et al., 2010; Hart and Nisbet, 2011; Lewandowsky et al., 2012b; Shepherd and Kay, 2012; Zia and Todd, 2010). And, as we have noted, it is the determining factor in how highly knowledgeable people decide what can and should be done to respond to climate change (Kahan et al., 2012). Not only that, ideology strongly influences which information sources people are likely to trust (Terwel et al., 2010; Zia and Todd, 2010). This means that ideology as a form of collective identity can have a strong impact on whether or not people perceive there to be scientific consensus regarding the seriousness and urgency of climate change, which has also been shown to be an important influence on how people respond to climate change (Ding et al., 2011; Lewandowsky et al., 2012a).

The authors assert that the most important feature of learning to invoke effective responses to climate change is the promotion of collective efficacy. Whether or not people possess factual knowledge about climate change does not make any difference if they lack

collective efficacy (Leiserowitz et al., 2012; Van Zomeren et al., 2010). People who are knowledgeable about climate science and what they can do in response may fail to act because they know individual actions make no significant impact in mitigating or adapting to global climate change (Kahan et al., 2012; Roeser, 2012).

Collective efficacy encompasses people's emotions, knowledge, and identity as they relate to their community, all of which have been demonstrated to be important predictors of and influences on climate-friendly behavior (Almers, 2013; Van Zomeren et al., 2010; Whitmarsh and O'Neill, 2010). If people feel like their communities can be effective in responding to climate change, then they will be empowered to respond collectively at a scale commensurate with the problem and appropriate to communities' unique needs and situations. What follows are several examples and three principles for effective climate change learning that have demonstrated success in increasing collective efficacy in educational interventions.

3.4 COLLECTIVE EFFICACY AS AN OUTCOME OF CLIMATE EDUCATION: THREE PRINCIPLES FOR EFFECTIVE CLIMATE CHANGE LEARNING

Recognizing that interventions focused mostly on changing knowledge have not yielded significant changes in how people respond to climate change, several examples of educational interventions that resulted in behavioural changes are used to introduce three principles for effective climate change learning. The authors posit that the difference between traditional intervention and these examples is the increase in participants' collective efficacy, which empowered them to change behaviors.

Two examples of increased collective efficacy through climate change learning come

from research on the professional development of educators. Ongoing, facilitated, and reflective conversation about climate change as a professional development activity has been effective for both classroom teachers and informal educators (e.g., museum educators). These ongoing interventions influence how educators approach climate change content in their practice (Allen and Crowley, 2014) and their everyday actions (Pruneau et al., 2006). In the first case, museum educators in Pittsburgh, USA engaged in a two-year project to develop new field trips about climate change. These educators were active participants in the process of making climate change relevant to their students (and themselves). The climate change content became more relevant as educators saw how it was interconnected with the museum exhibits about which they were experts and their students' learning experiences (Allen and Crowley, 2014). In the second example, a group of teachers in Canada volunteered to make changes in their everyday lives that would have environmental benefit. They met every three months over the course of one school year for professional development on climate change education, to create climate change education models for their classrooms, and discuss and reflect on their efforts in changing their own personal behaviors that impacted the environment (Pruneau et al., 2006).

In both these examples, educators had opportunities to reflect together on their practice and actions that impact climate change. Connection to educators' professional communities was influential on their efficacy beliefs and motivation to respond to climate change (Allen and Crowley, 2014; Pruneau et al., 2006). This kind of conversation-based participation is particularly effective because it is relevant to educators' work, and enables understanding of the interconnected questions and issues in their professional practice, as well as individual and collective choices with regard to climate change. Both examples highlighted long-term engagement with professional development, creating opportunities for interconnected learning

experiences that simultaneously allowed educators to see how climate change is interconnected with other aspects of personal, social, and civic life. Educators from both studies reported that the most important part of their experience was the sense of purpose and efficacy they derived from being part of a network of professionals with whom they identified and participated – in other words, these professional development experiences increased collective efficacy (Allen and Crowley, 2014; Pruneau et al., 2006).

Urban planning researchers have documented another example of increased collective efficacy through self-directed watershed management projects that affected participants' local neighborhoods in Portland, Oregon, USA. Community organizations partnered with urban planning advisors and Portland's public works department to design and implement the projects, which lasted anywhere from one season to several years. The urban planning advisors found that involvement increased when participants felt they had real ownership from the beginning (Shandas and Messer, 2008). Ongoing participation in relevant projects led people to see how their actions and environment were interconnected. Researchers documented increased awareness of local environmental issues, an enhanced network of community partners, and tangible results in improving watershed quality; all of which helped to give participants a sense that their work contributed to real improvement – an increased sense of collective efficacy. When participants were empowered to identify the problems, goals, and processes they would address and use, projects were ensured to be relevant and have maximum success. Projects like this incorporate learning and doing. The combination of action, networked expertise, and opportunities to experience real, tangible results in a community setting increased collective efficacy for participants because they were active participants in their own learning and doing (Shandas and Messer, 2008).

By examining the above examples in combination with further learning science and climate change education research, the authors identified three principles for climate change learning that increases collective efficacy: *participation*, *relevance*, and *interconnectedness*. They are described in detail and followed with an examination of how they might play out in practice. These principles should be tested, examined, and refined in ongoing climate change learning interventions.

3.4.1 Participation

Participation in activities and conversations in communities with whom individuals identify is an important way to enrich collective efficacy, identity, and sense of responsibility (e.g., Allen and Crowley, 2014; Devine-Wright et al., 2004; McCrum et al., 2009; Pruneau et al., 2006). Participation also supports learning and changes in behavior and decision-making (Eberbach and Crowley 2009; Leinhardt et al., 2002; Palmquist and Crowley 2007). Since there is not a singular 'silver bullet' solution to climate change, people need to participate in ongoing processes of understanding and addressing it (Tschakert and Dietrich, 2010; Walker et al., 2004). Although people tend to avoid new information that challenges their world-view or way of life (Dickinson, 2009; Feygina et al., 2010; Shepherd and Kay, 2012) participation in meaningful, relevantly framed group activities and conversations can broaden people's world views and support imagining a way of life that takes climate change into consideration (e.g., Terwel et al., 2010). For climate change learning, participation means interaction with other learners and facilitators, in conversation, deliberation, and activities, which may be models or simulations (e.g., Snyder et al., 2014), or real-life actions (e.g., Shandas and Messer, 2008). Participation with members of one's community is an essential step toward increasing collective efficacy.

Open-minded discussions and critical evaluation of evidence promote conceptual change (Lombardi and Sinatra, 2013; Sinatra et al., 2012), and are important ways for communities to address and grapple with the cognitively and emotionally interconnected issues that come with facing difficult challenges (Cameron et al., 2013; Devine-Wright et al., 2004; Moser, 2010; Pruneau et al., 2006; Van Zomeren et al., 2010). Participating in well-facilitated conversations increases collective efficacy by building trust among community members and between constituents and decision makers (Terwel et al., 2010).

Participation for climate change learning can involve all kinds of interaction and can take place in diverse venues. For example, deliberative workshops use conversation among participants and presenters, interactive presentations, and debates among experts and stakeholders, and can additionally reinforce community identity (Hobson and Niemeyer, 2012; McCrum et al., 2009). Museums create interactive, participatory exhibits where learners can manipulate models of climate impacts on watersheds, and urban infrastructure (Snyder et al., 2014). Museums can also serve as community hubs for conversation and deliberation (Cameron et al., 2013). Local governments in partnership with conservation organizations and educational organizations can provide opportunities to participate in projects that have real outcomes for participants' communities (Shandas and Messer, 2008).

3.4.2 Relevance

Necessary for learners, individually and in their communities, relevance allows people to see why they should care and how they can make meaningful choices based on new experiences and information. Research on behavioural change has identified relevance as an important feature of learning that has an impact on behavior, especially in the specific case of climate change (e.g.,

Akerlof et al., 2013; Bain et al., 2012; Joireman et al., 2010). Relevance is communicated through framing, or the way information is positioned in terms of learners' prior experiences and knowledge. Framing is examined in both education research and in the study of social movements, where participants have opportunities to both learn about and engage (often politically) around a relevant issue. Researchers of social movements have found that "the framing of a condition, happening, or sequence of events as unjust, inexcusable, or immoral is not sufficient to predict the direction and nature of collective action" [Snow and Benford, (1992) p.137]. This has often been the case with efforts to educate about and communicate climate change, when frames fail to communicate the relevance of an issue; the result is disengagement (Feinberg and Willer, 2011; Grotzer and Lincoln, 2007; O'Neill and Nicholson-Cole, 2009).

For framing to be most relevant, it should address the direct and local experiences that people have, because direct experience buffers outside (i.e., media) agendas (Akerlof et al., 2013; Shome and Marx, 2009). Since ideological views influence how communities respond to climate change, frames should be customized to make climate change information relevant to those communities. For example, in more conservative communities, environmentally friendly behavior is much more relevant and satisfying when framed as an issue of economic or energy security, or an act of patriotism, such as buying goods made in the USA (Bain et al., 2012; Shome and Marx, 2009). If learners are unable to identify how information or an experience is relevant to their lives, they are unlikely to be motivated to seek further understanding or make changes based on new information or experiences. Similarly, communities and groups of learners must be able to see how information and experiences are relevant to their lives and what they consider important – collective efficacy cannot increase based on irrelevant information.

In order for educational interventions to be relevant to communities, designers of such

interventions must take into consideration the extant knowledge, expertise, and interests of the communities with which they wish to engage. Engagement with communities should involve community members and leaders identifying what aspects of climate change impacts are most relevant to them. Educators and organizers of programs about climate change can benefit from seeking the insight of their audiences and participants about what is most relevant in a particular community.

3.4.3 Interconnectedness

A single learning event is unlikely to have a lasting impact; however, interconnected learning experiences and engagement that are relevant to learners have been demonstrated to be effective for climate change learning (e.g., Allen and Crowley, 2014; McCrum et al., 2009; Pruneau et al., 2006; Shandas and Messer, 2008). Not only that, but climate change itself is better understood as interconnected with the biological and social systems people interact with regularly, rather than as an isolated phenomenon (Lombardi and Sinatra, 2013; Sinatra et al., 2012). Education researchers who study student conceptions of climate change recommend that curricula present climate change from a "systems-based perspective rather than in isolated segments" (Shepardson et al., 2009) in order for students to see the interconnected features of climate change. If communities can perceive how economic, infrastructural, and political systems are also interconnected with the impacts of climate change, they will be better equipped to engage with those systems to respond to climate change impacts at a broader level. Systems thinking enables learners to improve understanding of both the parts and the interconnections that make up systems, imagine future outcomes and behaviors, and think creatively about how to engage with systems (Meadows, 1997). Unfortunately, systems thinking is not generally recognized as a

strong attribute in most highly educated adults (Houser, 2009). On the other hand, participation in relevant learning experiences that are connected to one another can help learners to better engage in systems thinking and build understanding of how climate change impacts multiple aspects of their communities. Interconnected learning experiences across multiple contexts can promote community-level learning and adaptation (Ito et al., 2013).

By incorporating participation, relevance, and interconnectedness into climate change education, learners' collective efficacy and their understanding of how to respond to climate change in ways that are commensurate with the scale of the problem will be more possible when compared with educational efforts with the single aim of increasing climate science knowledge. Increasing collective efficacy requires that learners experience the real impact of their efforts. People identify with those around them, and make decisions based on implicit social norms within their communities (e.g., Nigbur et al., 2010). Identity and social norms are consistently predictive of climate friendly behaviors (Whitmarsh and O'Neill, 2010), while knowledge and values are more likely to influence behavior when normative pressures are lower (Barr, 2007; Nigbur et al., 2010).

How might designers of educational interventions implement the principles for effective climate change learning? A critical starting place will be to harness the energy and momentum of existing community resources and programs that already have established participants (e.g., Snyder et al., 2014). Tapping into existing networks of action, education, and community development is likely to be one reliable strategy for engaging communities that already have social relationships and shared understanding of what is relevant to them. It is essential that educators and organizers are aware that the communities they hope to educate are experts on their own lives, needs, and surroundings. Working with and engaging communities, rather than

imposing interventions 'on' them, can reveal appropriate frames for understanding and conversations that naturally connect to the systems with which people already engage on a regular basis (Collins and Ison, 2009).

For example, the authors are part of a large-scale effort to incorporate participation, relevance, and interconnectedness into climate change education programs that are implemented through diverse networks of organizations in four US cities (Snyder et al., 2014). In each city, informal education organizations, climate scientists, and learning scientists are networking with community organizations that represent neighborhoods, local environmental efforts, and special interest and affinity groups. Each of these networks is developing a city-specific set of messages, activities, and engagement opportunities that are tailored around current issues and identities in the city. Thus, rather than delivering a top-down message about climate change, the work is embedded in the bottom-up interests of the city and thus reach audiences (and organizational partners) who may not identify with climate change as an issue. Through this ongoing climate change education project, the authors are currently engaged in testing, refining, and better understanding the usefulness of the three principles for effective climate change learning. This work is primarily being conducted through qualitative, observational analysis of the networks' engagement with one another and with their audiences, and how they implement participation, relevance, and interconnectedness in the climate education materials and programs they are creating and refining.

3.5 CONCLUSIONS

In order to take advantage of the impact and influence that collective identities and communities have on how people react to climate change, educational interventions should move beyond the goal of simply increasing people's scientific knowledge about climate change. Many who are knowledgeable about climate change and what needs to be done to respond have low collective efficacy: even though they know what needs to happen, they do not feel strongly that enough other people will take the same necessary steps (Leiserowitz et al., 2012). Increased collective efficacy is a necessary condition for learning to respond to climate change in ways that are commensurate with the scale of the problem and appropriate for communities' unique needs and situations. This article introduced three principles for effective climate change learning by way of increased collective efficacy: participation, relevance, and interconnectedness. Research has demonstrated that learning experiences that incorporate these principles facilitate not only knowledge acquisition, which is not sufficient for effective responses to climate change (Kahan et al., 2012) but also increase collective efficacy (e.g., Allen and Crowley, 2014; Pruneau et al., 2006; Shandas and Messer, 2008). Further testing of the utility and impact of these three principles for effective climate change learning would help to refine and clarify how these principles can be utilized to promote responses to climate change in communities.

Although individuals and their local and professional communities can take steps to adapt to and mitigate climate change, policy level changes are needed for larger scale adaptation, at the level of cities and countries (e.g., Filho, 2010; Steffen, 2011; Sun et al., 2010). Governments harden cities against flooding, shift energy production to renewable sources, distribute water, and regulate emission standards (Jaeger, 2004). Therefore, in order to respond to climate change in a way that is commensurate with the scale of the problem, people need to work together at the

level of policy, toward large-scale changes that address the national and international systems of commerce, energy, and consumption that enable and contribute to the heat-trapping gases that cause climate change.

Collective efficacy is necessary for engagement in political processes. Since climate change is a shared, global problem, political solutions cannot be left out (Jaeger, 2004). However, policy changes in response to it have been difficult to enact, particularly in the USA (Collins and Ison, 2009; Steffen, 2011). The largest causes of carbon emissions are the result of industrial and infrastructural systems that can only be indirectly affected by individuals through participation in political systems and processes, with which people are unlikely to engage if they do not feel their efforts will have impact. Paralleling collective efficacy, trust among community members and decision-makers is an important predictor of engagement in public governance processes (Terwel et al., 2010). Climate change educators and organizers face a major challenge in the ambiguous nature of responsibility for climate change. Many individuals do not feel empowered or responsible to take action on climate, because it is perceived as a distant, global, governmental, or industry-based problem (Moser, 2010; Patchen, 2010). By participating in relevant, interconnected learning and actions, communities will enhance their collective efficacy and capacity to respond to climate change at the scale commensurate with the problem and appropriate to each community' unique needs and situation. Participation can help people feel more efficacious in their responses to climate change; relevant frames can provide the motivation to participate and engage in understanding climate change in one's own community; and the interconnected nature of these phenomena and the experiences learners have will push our communities to be more engaged at all levels.

4.0 HOW HETEROGENEOUS NETWORKS CAN CHANGE LEARNING ECOLOGIES: CITY-SCALE INTERVENTION FOR CLIMATE CHANGE EDUCATION

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4.1 ABSTRACT

Drawing from three approaches to using organizational networks to address learning and wicked problems, this study describes and explains the evolutionary history of a heterogeneous network that functioned as an intervention in one city's climate change learning ecology. We identify four features that characterized the network's success: an adaptive hub; intentional use of boundary objects; a shared system of iterative development; and actively facilitated, heterogeneous niches within the multi-sector network. We provide evidence that these features supported learning and change within the network and that the city-scale learning ecology for climate change became more connected and robust through diverse organizations adopting informal climate change education as a more central part of their work. These findings have implications for the design of networks for informal education intended to be interventions at the level of whole (i.e. city-scale) learning ecologies.

4.2 INTRODUCTION

Climate change is one of our global society's greatest and most complex challenges in the 21st century (AAAS, 2014; Moser, 2007; Pachauri et al., 2013). Many have argued that improved climate change education is an essential component to responding to climate change (e.g. Abbasi, 2006; Anderson, 2010; Moxnes & Saysel, 2009; Sterman & Sweeney, 2007), but that is much easier said than accomplished. There are at least three underlying problems that we need to consider. First, it is not clear what that education should focus on: How people learn about and understand complex systems and socio-scientific phenomena are dependent on social and cultural factors beyond just knowledge (Bell, Bricker, Reeve, Toomey Zimmerman & Tzou, 2013; Bell, Tzou, Bricker & Baines, 2012; Gutiérrez, 2008; Gutiérrez & Rogoff, 2003); a finding that appears to be especially true in the case of climate change learning (Kahan et al., 2012). Second, it is not clear exactly where and how we should design and implement educational interventions. Effective response to climate change will mean support for learning across a wide range of potential learning settings and for all potential learning populations. This breadth pushes the learning sciences far beyond our comfort zone of designing for formal and informal educational settings where learning for the sake of learning is often an explicit goal. Furthermore, responding to climate change requires more than just increasing scientific literacy; changes in behavior and decision-making at the personal and societal levels are necessary at a massive scale and in the fairly near future if we are to manage the impact of climate change (Pachauri et al., 2013).

Finally, even if we clarify what education should focus on, and how we can best intervene; the job of climate education will never be done. Wicked problems are unstructured, crosscutting, and relentless (e.g. Weber & Khademian, 2008). Beyond being wicked, climate

change is also a problem that we are just starting to understand. Climate change education will likely be an important part of every human's life-long learning for the foreseeable future. As science education problems go, climate change is not a case where it will be sufficient for learning scientists to identify the most effective ways to teach about climate change and then "shrinkwrap", scale, and support them in perpetuity. Instead, effective climate change education will require dynamic intervention systems that can continuously adapt to changing societal needs as the problem of climate change unfolds over the next century and beyond.

We have been part of a group of four cities exploring new solutions to these three challenges (Snyder, Hoffstadt, Allen, Crowley, Bader & Horton, 2014). In earlier work, we argued that responding to climate change requires learning opportunities that are participatory, relevant, and interconnected (Allen & Crowley, in press). In other words, we proposed an answer to the first problem stated above– that of identifying effective goals for climate change learning experiences. In the current study, we explore the second and third problems—where and how to intervene and then how to sustain intervention and adaptation over time.

Our approach to both problems is to cultivate networks of organizations that work together to improve learning ecologies for climate change. We define a city-scale climate change learning ecology to be the entire landscape of opportunities for learning about and responding to climate change available in a city, and build on prior work that has developed the notion of learning ecologies to help understanding and explain learning that unfolds over time and across contexts (e.g. Barron, 2004, 2006; Gutiérrez, 2008). An ecological perspective highlights how culture and society influence learning and participation (Lee, 2008; Knutson, Crowley, Russell & Steiner, 2011; Russell, Knutson & Crowley, 2013), which is particularly salient for learning to respond to climate change, because it requires a society-level response, and people's responses

are governed by their social situations (Kahan et al., 2012). Learning ecologies that are healthy are diverse, providing niches for different kinds of learners, and they are interconnected, providing opportunities to continue learning across contexts (Falk et al., 2015; Kehoe, Russell & Crowley, under review). Organizational theorists have also used the concept of a 'learning ecology' as a way to problematize the fact that organizations, like individuals, do not learn in a vacuum (Levitt & March, 1988). By conceptualizing climate change education as something that happens at the level of the learning ecology, we hope to be better equipped to leverage educational efforts to not simply increase understanding about climate change, but increase collective efficacy around actually responding to this wicked problem (Allen & Crowley, in press).

In this article, we chart the evolution of a citywide network to support interconnected, resilient, and sustainable collaboration among a range of diverse organizations. The organizations ranged in size, scope, and the extent to which they had explicitly educational missions, stakes in local climate change issues, or advocated for particular communities. What tied the network members together was their willingness to join a collective informal education effort to help their city adapt to the coming impacts of climate change. Our analysis focuses on elements within the network's processes and work that produced successful, and potentially sustainable, interventions in one city's learning ecology for climate change.

4.2.1 Organizations, Networks, and Learning

The contexts that comprise a learning ecology are often organizations, such as museums, schools, or community non-profits, which have the potential to coordinate their efforts using organizational networks (e.g. Kehoe et al., under review; Knutson et al., 2011; Lee, Robertson,

Lewis, Sloane & Galloway-Gilliam, 2012). Organizational networks provide broader access to the resources of participating organizations and can facilitate learning and change (e.g. Paquin & Howard-Grenville, 2013; Weber & Khademian, 2008). The initial intention of the broader project in which this study's case is embedded was to cultivate communities of practice from networks for informal climate change education. However, the networks themselves were dynamic learning entities, made of organizations with their own agendas, missions, and reasons for participating in the project. As the project progressed, it became clear that while the network was taking on some of the characteristics of a community of practice, there was more happening in terms of the network's functioning as an intervention in the city's climate change learning ecology than could be captured by the standard features of communities of practice.

Thus, our analysis draws from three approaches to networks and networked interventions: communities of practice (e.g. Wenger, 1998); networked improvement communities (e.g. Bryk et al., 2015); and collective impact (e.g., Kania & Kramer, 2013). Communities of practice and networked improvement communities are both learning communities that have been described in professions, industries, and formal education systems (e.g. Bryk, Gomez & Grunow, 2011; Horn, 2010). Networked improvement communities and collective impact are specific, prescribed strategies for engaging networks in processes of collective change toward addressing complex problems in various contexts, including formal education systems and complex public policy challenges (Bryk et al., 2015; Kania & Kramer, 2013; Russell et al., in press). Because we could see that the network called for more than community of practice to describe its evolution, and because the two other approaches we have used are prescribed strategies, we did not expect the network to fall cleanly into any of these categories. Instead, we have identified features from

across the three approaches that describe the network's evolution and which seem important for its functioning as an intervention in the city-scale climate change learning ecology.

4.2.1.1 Communities of Practice

At its core, a community of practice is a connected group of people that includes a spectrum of learners who range from expert to novice, who learn from one another and from the experiences they bring to and have with the community. Communities of practice were first described by Lave and Wenger with a focus on the phenomenon of "legitimate peripheral participation" (1991). Later, Wenger (1998) further elaborated the concept, highlighting important dimensions of communities of practice, including: mutual engagement, joint enterprise, and shared repertoire. Communities of practice were framed as emergent among tradespeople and co-workers (Lave & Wenger, 1991; Wenger, 1998). Since these early descriptions, the concept has been used in many different contexts, and described in myriad ways, including as a strategy for management and improving teacher practice (e.g. Horn, 2010; Wenger, McDermott & Snyder, 2002).

Legitimate peripheral participation is a process whereby newcomers or novices participate in the practice of the community in a real way, albeit one that is peripheral to the central work of the more expert members of the community. This structure affords less-expert participants opportunities to observe more expert practice while building their experience in the community of practice (Lave & Wenger, 1991). Mutual engagement, joint enterprise, and shared repertoire are "dimensions of the relation by which practice is the source of coherence of a community" (Wenger, 1998, p. 72).

When considering a network as an intervention in a city's learning ecology, it is less useful to consider mutual engagement and joint enterprise, since the organizational network does

not spend daily time working together. However, another important aspect of a community of practice is the "boundary object"—an artifact, part of a community of practice's shared repertoire—used to "coordinate the perspectives of various constituencies" (Wenger, 1998, p. 106). That is to say, a boundary object allows people in and out of the community of practice to align their understanding through its use, modification, and discussion. As such, boundary objects have the potential to be very useful when imagining a networked intervention, because the organizations engaging to change or better coordinate the learning ecology will likely need such tools to communicate both within the network and across the learning ecology.

Communities of practice have traditionally been used to describe the emergence or the cultivation of an ongoing, tightly-knit group of practitioners around specific content, vocation, or profession; such as students in a classroom (e.g. Engle, 2006; Engle & Conant, 2002), mathematics teachers in a school (e.g. Horn, 2007, 2010), Xerox maintenance and repair technicians (Brown & Duguid, 1991), insurance claims processors (Wenger, 1998), and tailors (Lave & Wenger, 1991). In this respect, the network we studied contrasts from the traditional community of practice, because it was comprised of a more diverse group of people with a wide variety of roles at their organizations, ranging from part-time workers to top-level leaders, including educators, communications managers, project coordinators, and executive directors. When considering intervening in a learning ecology, the communities of practice approach is useful—especially the notion of boundary objects that allow for enhanced communication across different contexts But, there are more aspects to the intervention than the traditional community of practice approach can capture.

4.2.1.2 Networked Improvement Communities

A networked improvement community is highly structured, uniting "the conceptual and analytic discipline of improvement science with the power of networked communities to innovate and learn together" (Bryk et al., 2015, p. 7). Improvement science is a systematic method for testing, documenting, and implementing changes across systems, with a strong emphasis on expertise and evidence-driven decisions (Perla, Provost & Parry, 2013). Networked improvement communities are a relatively new approach to rapid innovation and implementation, and have begun to successfully leverage improvement science techniques to generate large-scale improvements in complex formal education systems (Bryk et al., 2015; Russell et al., in press). Furthermore, improvement science has been successfully implemented in complex systems such as industries and healthcare, where measurable outcomes are clear and easily agreed upon (Perla et al., 2013).

Networked improvement communities make research and design expertise available to practitioners, and provide a structure for iteratively testing innovations and disseminating the results throughout the network for further testing in varied contexts (Russell et al., in press). Their main features are: 1) specific and measurable improvement goals; 2) a deep understanding of the systemic problem and its hypothesized solutions; 3) a shared and systematic inquiry cycle; and 4) an organizing hub (Bryk et al., 2011; Bryk et al., 2015; Russell et al., in press). The outcomes of networked improvement communities are pre-determined by the measured targets established by the organizing hub, and come in the form of new innovations developed, tested, and implemented in multiple contexts. This strategy is reasoned to accelerate the process of improvement across the network (Russell et al., in press).

The structured approach of a networked improvement community has potential utility when imagining an intervention in a learning ecology that takes the form of a network for informal education. Two features seem particularly useful: the organizing hub, and the shared, iterative system for inquiry. The organizing hub in a networked improvement community champions the hypothesized solutions, supports distributed activity, provides coherence to the description of the problem and the evolving framework for solving it, and also maintains open communication mechanisms throughout the network. The hub is also responsible for "adaptive leadership", meaning that as the networked improvement community is initiated and evolves into a more stable entity, the hub's role will change accordingly (Bryk et al., 2015). Since learning ecologies are distributed across cities or regions, an organizing hub that takes on the role of coordinating activity and communication across the network will facilitate an intervention at the level of the learning ecology. Second, the shared, iterative system of inquiry establishes a culture of reflectively testing new innovations in practice, building in the process of evolving solutions and abandoning parts that do not have the desired impact. This feature is especially useful for developing a successful intervention: since how to intervene at the level of the learning ecology is unknown, systematically developing and testing ideas will be essential.

Networked improvement communities have been implemented and initiated in multiple organizational fields, including the semiconductor industry and large-scale educational improvement initiatives (Bryk et al., 2011; Bryk et al., 2015; Russell et al., in press). These engineered and intentional communities are formed by way of a prescribed, structured strategy for measurably improving large, complex systems using improvement science and the resources of networks (Bryk et al., 2015; Russell et al., in press). In contrast, one can think of communities

of practice as being organic and emergent: They can be shaped and supported through intervention, but may form in any workplace or group that engages in joint activity.

4.2.1.3 Collective Impact

Collective impact is a specific strategy intended to harness the resources and connections of a cross-sector network in order to effect large-scale social change. Networks using this approach unite organizational leaders from different sectors around a common agenda to change complex systems that influence a specific issue, such as public safety or high school graduation rates. Drawing from complexity theory, collective impact is intended to address challenges where expertise in individual fields is not sufficient to remedy the problem (Kania & Kramer, 2011, 2013). Collective impact focuses on large-scale, cross-sector problems using coordinated, mutually reinforcing activities that are identified by a diverse network of organizational leaders, and coordinated by a backbone organization.

A learning ecology is also a large-scale, diverse system comprised of organizations from multiple sectors. Mutually reinforcing activities are important to collective impact's functionality, because it primes leaders to pay attention to how their organizations can support and be supported by other network members, rather than competing for limited resources and attention (Kania & Kramer, 2011; Turner, Merchant, Kania & Martin, 2012). The most important feature from the collective impact approach for intervening in a city-scale learning ecology is the notion of cross-sector collaboration, and the resultant mutually reinforcing activities. This is because a city-scale learning ecology is also comprised of diverse organizations across multiple sectors, working to provide coordinated and coherent interconnected learning opportunities, which ideally will be mutually reinforcing throughout the learning ecology. A networked intervention in a learning ecology will most likely look different from a collective impact

network that engages primarily at the level of organizational leadership, since the people and programs that make up the learning ecology do not necessarily connect directly to leadership, and sometimes exist outside hierarchical leadership structures all together.

Structurally, collective impact networks and networked improvement communities are similar: they both require a shared understanding and definition of the problem they are addressing, a system of shared measurement, an organizing hub, and ongoing developmental evaluation (Kania & Kramer, 2011, 2013; Russell et al., in press; Turner et al., 2012).

However, networked improvement communities emphasize connecting researchers, designers, and practitioners, with a focus on developing new innovations, while the collective impact approach connects organizational leaders from across different sectors, seeking emergent solutions that result from the mutually reinforcing activities mindset that reframes extant solutions from other contexts as applicable (Kania & Kramer, 2013). Collective impact networks differ from communities of practice, because they are by definition cross-sector collaborations of leaders—there is not a shared practice or joint enterprise of this network, but a dedication to collectively addressing a problem that crosses multiple sectors.

Networked improvement communities and collective impact usually start with a theory of change and a hypothesized solution to the problem, based on top-down or hierarchical structures. A community of practice is based around mutual engagement and legitimate peripheral participation, not necessarily finding an optimal solution to a problem shared by a diverse group. Along these lines, communities of practice are more homogeneous in their traditional discipline and application, networked improvement communities specifically and strategically bring together practitioners, designers, and researchers; and collective impact brings together a diverse,

or heterogeneous, group of leaders from organizations from across different sectors. Table 4.1 provides a summary of the features, contexts, and outcomes of these three approaches.

	Communities of Practice	Networked Improvement Communities	Collective Impact
Basic Description	"...an activity system about which participants share understandings concerning what they are doing and what that means for their lives and their communities" (Lave & Wenger, 1991, p. 98).	"A NIC unites the conceptual and analytic discipline of improvement science with the power of networked communities to innovate and learn together" (Bryk, et al., 2015, p. 7)	"…occurs when actors from different sectors commit to a common agenda for solving a specific social or environmental problem" (Turner, et al. 2012, p. 1)
Foundational Theory	Situated Learning, Constructivism	Improvement Science, Networked Communities (e.g. Perla, Provost & Parry, 2013)	Complexity Theory
Traditional Context	Tightly knit groups that share vocations, professions, content learning areas	Industry, healthcare, research & development, formal education systems	Cross-sector collaborations (government, business, non-profit)
Features	Legitimate peripheral participation (Lave & Wenger 1991), mutual engagement, joint enterprise, shared repertoire, and boundary objects (Wenger 1998). Communities of practice emerge in co-working spaces and among practitioners who work together.	Organizing hub and evangelizing leadership; shared understanding of problem, system, and hypotheses for improvement; measurable targets; and shared system of inquiry. Bring together researchers, designers, and practitioners.	Backbone organization, common agenda, shared measurement system, mutually reinforcing activites, continuous communication with developmental evaluation. Brings together organizational leaders.
Outcomes	Learning and functioning practice at the community level	Accellerated learning and innovation of solutions and improvements for complex systems	Change in large-scale, complex social systems, stakeholder learning and behaviour change, recognition of existing or emergent solutions
References	Lave & Wenger, 1991; Wenger, 1998	Bryk, Gomez & Grunow, 2011; Bryk, Gomez, Grunow & LeMahieu, 2015; Russell, Bryk, Dolle, Gomez, LeMahieu & Grunow, in press	Kania & Kramer, 2011; Kania & Kramer, 2013; Turner, Merchant, Kania & Martin, 2012

Table 4.1 Networked Approaches to Learning and Solving Wicked Problems

4.2.2 Study Context

The Climate Urban Systems Partnership (CUSP) is a project that developed informal climate change education platforms using organizational networks in four eastern US cities. Networks in all four cities are comprised of diverse sets of organizations and individuals, reflecting the diversity of the learning ecologies present in these urban environments. This article focuses on

the network in Pittsburgh, Pennsylvania[1]. During the planning phase, Carnegie Museum of Natural History (the hub) and its network partners identified temporary informal learning spaces and activities (e.g. festivals) as their central informal learning platform. For some network members (e.g. museums, botanical gardens, and zoos), including the hub, informal learning is a primary focus. For others (e.g. watershed associations and environmental policy groups), locally-relevant climate change responses align with their missions, which range from promoting use and care for city parks, advocating for and increasing the number of urban trees, or promoting sustainable policies at the city, county, and state level. See Table 4.2 for a full list of network organizations and missions.

In order to engage audiences in temporary informal learning spaces, the network united around the idea of creating a library of approachable and portable hands-on activities, called "kits", that educators and organizers could use to facilitate informal learning about local issues related to climate change. This article documents the network's engagement from spring 2013 through the festival implementations and follow-up conversations in fall 2014. This time period included the network's implementation and testing of individual kit designs, using the kits at local festivals, adoption of the digital mapping platform developed by one of the other cities in the larger project, redefinition of how kits were presented at festivals, and imagining new ways to approach kit design. A detailed timeline of the network's engagement is provided in Table 4.3.

How did this network of organizations function as an intervention in the climate change learning ecology for the city, and what features should a successful network-as-intervention have? In our analysis, we identify features of the network that aligned with features identified in our review of networked approaches, and draw conclusions about which are most important for a

[1] We (the authors) were among the learning science team of CUSP, with Crowley serving as Co-PI of the whole project and Allen working as an embedded researcher and participant-observer in the Pittsburgh network.

network intended to function as an intervention in a city-scale learning ecology. Each of the approaches provided useful features: from communities of practice, boundary objects are particularly helpful to a network-as-intervention in a learning ecology. From networked improvement communities, we see the utility of a shared system for inquiry and iterative testing, as well as the useful role of an adaptive hub. From collective impact, the diversity of cross-sector collaboration, and the resulting mutually reinforcing activities are particularly useful.

Organization	Staff Pseudonyms	Staff Roles	Mission
Carnegie Museum of Natural History	Madison, Margaret	Education Dept.	Carnegie Museum of Natural History collects and cares for specimens and artifacts that document the history of life and human cultures.
Chatham University School of Sustainability	Martha	Asst. Professor of Ecology and Sustainability	To promote, through education, research, and outreach, a transdisciplinary, systems–based approach to simultaneously improve economic, social, and environmental well–being.
Conservation Consultants, Inc.	Iona	Education Coordinator	Founded in 1978 as a 501 (c) 3 non-profit organization, CCI's mission is to promote responsible energy and resource use in homes and buildings.
Engineers for a Sustainable World	Adam	Executive Director	To forge innovative, lasting solutions to local and global sustainability challenges, we: Design and implement sustainable projects through our student and professional chapters; Educate and train individuals and organizations on sustainable policies and practices; Build a global network of communities with a shared culture of sustainability.
Gtech	Trevor, Lucy	Project Manager, Project Coordinator	Growth Through Energy and Community Health (GTECH) cultivates the unrealized potential of people and places to improve the economic, social, and environmental health of our communities.
Green Building Alliance	Jessie, Charlotte, Keith	Vice President, SCA Green Fellows 2013, 2014	GBA inspires the creation of healthy, high-performance places for everyone by providing leadership that connects knowledge, transformative ideas, and collaborative action.
National Aviary	Courtney	Educator	The National Aviary works to inspire respect for nature through an appreciation of birds.
Nine Mile Run Watershed Association (NMRWA)	Stefanie, Stephanie, Barbara	Communication Dept., Executive Director	Our mission is to restore and protect the Nine Mile Run watershed. Through outreach and education, we involve local leaders and volunteers in community greening initiatives to foster a healthy urban environment.

Table 4.2 Pittsburgh CUSP Network Organizations, Staff Pseudonyms, Roles, and Mission Statements

Organization	Staff Pseudonyms	Staff Roles	Mission
Carnegie Museum of Natural History	Madison, Margaret	Education Dept.	Carnegie Museum of Natural History collects and cares for specimens and artifacts that document the history of life and human cultures.
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Table 4.2 (continued) Pittsburgh CUSP Network Organizations, Staff Pseudonyms, Roles, and Mission Statements

2011: Planning Phase	Fall 2012: Project Kickoff
Planning meetings convened by Carnegie Museum of Natural History, brainstormed the idea of creating the library of hands-on, portable activity kits that organizations would use for "tabling" at local festivals and outreach events.	Convened original brainstorming group and some new potential network members, explained the project as described in NSF grant documents.

2013: Hub-Led Kit Development and Individual Kit Implementation Testing			
	Festival Implementations: Hub and some network members present kits as individual organizations at local festivals in spring and fall 2013.		
Quarterly Network Meetings: Hub staff present ideas for kits, network members provide feedback, hub staff iterate on kits and create more detailed prototypes, and process repeats.	Spring 2013 Festival: Hub and some network members present kits at Earth Day festival in a city park, theoretically, visitors to kits would notice that they were related based on similarity in design and minimal branding with CUSP logo, but early evaluation found that visitors didn't notice these subtle hints that more than one organization in Pittsburgh cares about climate change.	Fall 2013 Festivals: Kits were implemented by network organizations at two local annual festivals with environmental focus, with heavier CUSP branding and attempted climate change discussions. Visitors did not tend to notice that the kits were related and network members facilitating the kits had a hard time bringing the conversations all the way to climate change when starting with local issues.	Hub leader met Pittsburgh Center for Creative ReUse at their ReUse-A-Palooza and formed a partnership based on supplying kit materials, and the idea that network members and the general public would get something out of making the kits, not just participating in their use, started to form.

2014: Network-led Kit Development and Kits Implemented as a unified learning environment			
		Festival Implementations: Climate Change Playgrounds present CUSP kits as a unified learning environment	
Kit Design Workshops are held in addition to Quarterly Network Meetings so network members can prototype and workshop their own kit ideas and share facilitation strategies with colleagues. Not all network members are interested in doing their own designs, this niche emerges and some fill it.	Adoption of digital mapping platform begins, some network members find their niche here.	Reflections on the previous years' fall festivals surfaced the idea that network members would be more comfortable and the climate change messages would be easier to get across if the kits were presented in close proximity, in one unified space (approximately a 400 square foot open-sided tent at both festivals).	Fall 2014 Festivals: Climate change playgrounds were implemented by network members and the hub, alongside PCCR's Reuse-A-Palooza where visitors were encouraged to make their own climate change education kits. Facilitators found it easier to talk about climate change when the others around them were also talking about it, and connections were made by facilitators and visitors across kits about local impacts of climate change.

Table 4.3 Project Timeline

4.3 METHODS

In this article, we describe and analyze the evolution of a network that was convened for the purposes of designing and implementing platforms for informal climate change learning at the city-scale. The initial intention of the project was to cultivate the network into a community of practice, which would assist in developing an informal climate change education platform at the city-scale, and then work to adopt and incorporate the platforms developed similarly in three other cities. During early phases of the project, there was a heavy focus in all four cities on the products, or the platforms for informal climate change learning, and an assumption that the networks would simply activate the platforms as they were delivered from city to city. The networks were originally imagined to be communities of practice (not otherwise specified), however, they revealed themselves to be something different.

This article is an analysis and deep description of the evolution of the network in Pittsburgh. We tell the history of how the network's features influenced the platform's development, and changed the overall understanding the network had of itself. The learning we examine in this article is the learning within the network as it developed, and its impact as an intervention in the climate change learning ecology of the city, as we define it: the landscape of opportunities to respond and learn to respond to climate change. The analysis is guided by the question: How can we intervene in a learning ecology? As the network evolved, our understanding of its role in the development, implementation, and adoption of informal learning platforms also evolved, and our analysis of the network as a learning entity and an intervention in the learning ecology reflect this evolution.

The members of the network were aware that the project was, in part, a learning research project, and that its development was informed by learning theory, as well as by the presence of

Allen as an embedded researcher and participant-observer in their work (Labaree, 2002). Allen's role in the network was as a learning scientist who provided expertise on learning mechanisms and the specific challenges of learning about climate change, and as a researcher, collecting data to understand the development of the platform and the network members' learning over the course of the project. Since Allen was so deeply involved in the network, we do not claim to provide an unbiased account of the network's evolution, but rather an explanation from the point of view of the embedded researcher, with attention to the parts of the network's evolution that were most relevant from the standpoint of the learning scientist "in the room".

Allen engaged with the network in Pittsburgh as a participant-observer and embedded researcher (Labaree, 2002) for 18 months. Allen attended quarterly network meetings, hub planning meetings, and events public engagement events, which we refer to as "implementations". Qualitative data collection began in spring of 2013 and finished in late fall of 2014. Allen took in-depth field notes at meetings and implementations, wrote detailed reflections on the general themes, questions, and tone following each, and regularly interviewed people representing 13 of the network organizations over the course of the project. These data are summarized in tables 4.4 and 4.5, and explained below.

4.3.1 Observations

Full-network meetings took place approximately quarterly. The hub held planning meetings as-needed, most often weekly in the two to three weeks leading up to a network meeting, which sometimes included other core network members. If Allen was presenting or facilitating during a quarterly network meeting, a research assistant was enrolled to take detailed field notes. Allen also attended and took detailed field notes at training sessions, design workshops, and debrief

meetings following implementations, which were attended by subsets of the network. In the few cases when Allen was unable to attend a meeting, hub leaders provided meetings notes, and an email or verbal explanation of the meeting. See Table 4.4 for a summary of observation data.

In 2013, Allen observed each of the individual organizations implementing kits at festivals for at least three separate interactions with visitors. Observations focused on how the facilitator and the kit were able to connect local climate change impacts to local responses already in progress. These observations were verbally debriefed with facilitators throughout the day. In 2014, the group implementations were observed in detail throughout the entire day. Particular attention was paid to how visitors circulated through the space, how network members interacted with visitors, and how network members interacted with one another. Allen also documented conversations among network members and between network members and visitors, noting especially if connections were made between the kits and other activities inside the climate change playground, or between kits and other activities in the broader festival.

Data Source	Date Collected	Format	Length
Quarterly Network Meeting at CMNH	18-Apr-13	Detailed field notes	8pp
Earth Market Implementation	23-Apr-13	Detailed field notes, kit observations	14pp
Hub Staff Meeting at CMNH	13-Jun-13	Detailed field notes	3pp
Hub Staff Meeting at CMNH	9-Jul-13	Notes from hub leadership	1pp
Quarterly Network Meeting at CCI	11-Sep-13	Detailed field notes	3pp
ALCOSAN Open House Implementation	21-Sep-13	Notes from hub leadership	3pp
Green Innovation Festival Implementation	28-Sep-13	Field notes and reflection	4pp
Quarterly Network Meeting at CMNH	9-Jan-14	Meeting reflection	2pp
Kit Design Workshop at PCCR	21-Jan-14	Notes from hub leadership	2pp
Kit Design Workshop at PCCR	6-Feb-14	Notes from hub leadership	2pp
Digital Map Workshop at CMNH	6-Mar-14	Detailed field notes	9pp
Hub Staff Meeting at CMNH	27-Mar-14	Detailed field notes	3pp
Quarterly Network Meeting at Aviary	9-Apr-14	Detailed field notes	8pp
Presentation Workshop at PCCR	1-May-14	Detailed field notes	4pp
Hub Staff Meeting at CMNH	7-May-14	Notes from hub leadership	1p
Quarterly Network Meeting at CCI	19-Jun-14	Detailed field notes	9pp
Climate Change Playground Small Group at CMNH	6-Aug-14	Detailed field notes	4pp
Climate Change Playground Small Group at CCI	8-Aug-14	Detailed field notes	5pp
Climate Change Playground Tent Training	12-Sep-14	Detailed notes, Audio transcript	37pp
Climate Change Playground Tent Training	18-Sep-14	Detailed field notes	7pp
ALCOSAN Open House Implementation	20-Sep-14	Detailed field notes, evaluation data	5pp
Climate Change Playground Debrief with Jessie from PPC	22-Sep-14	Audio recorded phone interview Transcript	12pp
Climate Change Playground Debrief Meeting	23-Sep-14	Audio transcript, detailed field notes	37pp
Climate Change Playground Debrief with Michelle and intern from Phipps	26-Sep-14	Detailed field notes	4pp
Green & Innovation Festival Implementation	27-Sep-14	Detailed field notes, evaluation data	2pp
Hub Staff Meeting at CMNH	10-Oct-14	Detailed field notes	5pp
Green Innovation Festival Debrief interview wth Lucy from GTECH	10-Oct-14	Audio transcript	10pp
Debrief interview with Clare from CMNH	16-Oct-14	Audio transcript	7pp
Quarterly Network Meeting at CMNH	16-Oct-14	Detailed field notes	9pp

Table 4.4 Meeting and Event Observation Data

4.3.2 Interviews

In the fall of 2013, Allen interviewed 13 network members from eight member organizations, including the hub, using a semi-structured interview protocol. Round one interviews touched on network members' organizations and roles within them; their personal and professional backgrounds and motivations; and their perceptions and expectations for the network and the overall project; and how climate change education fit their organizational and personal goals. With hub staff, the first round of interviews also covered their perceptions of how the project as a whole was evolving, their impressions of the network's development, and their personal goals for the project. See Table 4.5 for a summary of interview data.

In spring 2014, a second round of interviews were conducted with six of the same network members from the fall interviews, and five new members either from the same organizations, or whose organizations had joined the network since fall 2013. Round two interviews focused on what network members thought would be meaningful indicators that the group's efforts were successful, both for their organization and for the public engaging with the network's implementations. For those who had participated in round one interviews, round two interviews also followed up on themes and questions that had emerged previously.

In fall of 2014, Allen conducted the third and final round of interviews. Depending on the role of the network members and their organizations, interviews focused on the processes of designing and implementing the activities in the climate change playgrounds, adopting the digital map platform, and how network members gauged the success of the project over the course of their involvement, based on their own organizational and personal goals and the shared goals of the network. Like round two, these interviews included follow-up on themes and ideas from previous interviews. Round three interviews included six organizations that had been interviewed

in both rounds one and two, three organizations that had been interviewed for the first time in round two, and two organizations that had joined or become active in the network since round two.

4.3.3 Analysis

As a participant-observer and embedded researcher in the network, Allen used reflections, field notes, and interview transcripts to describe how the network evolved from the beginning of the project through the second year of implementations. An important part of the network's evolution was how the kits were implemented in two vastly different formats at the same two annual festivals in the fall of 2013 and 2014. Data collection and in-depth participant-observation began the spring before the 2013 festival season and ended following the 2014 festival season, allowing Allen to observe the full trajectory of the development and implementation of the kits as well as other resources. This trajectory and the network's history include how the network reacted to early prototypes and came to share the process of iteratively developing them, how they changed the physical kits and the kit design process to better reflect and achieve their goals, and how they overhauled implementation at festivals in order to have a more positive impact on audiences and on their own sense of collective efficacy as educators.

Allen's conversations with network members during meetings, workshops, and interviews were informed by participation and understanding of how the network organized and re-organized itself over the course of the project. For this article, Allen systematically analyzed the interview transcripts and observation field notes from this informed perspective, writing vignettes based on interview transcripts and meeting notes for each organization in the network (Miles, Huberman & Saldana, 2013). Using the participant-observer experience with the network

as the entry-point for data analysis enabled identification of the themes and features of the network's development and members' experiences between spring 2013 and fall 2014. This analysis was guided by the question: How can a network of organizations function as an intervention in the city's climate change learning ecology, and what features should a successful network-as-intervention have?

	Round 1: Fall 2013 Interviews			Round 2: Spring 2014 Interviews			Round 3: Fall 2014 Interviews		
Organization	Name	Date	Length	Name	Date	Length	Name	Date	Length
Green Building Alliance	Charlotte	7-Oct-13	33pp, 54m						
Pittsburgh Zoo and PPG Aquarium	Matt	14-Oct-13	16pp, 37m						
Conservation Consultants Inc	Iona	7-Oct-13	27pp, 54m	Iona	1-May-14	28pp, 70m	Iona	3-Nov-14	24pp, 63m
Pittsburgh Parks Conservancy	Takashi & Maureen	8-Oct-13	23pp, 46m	Takashi	28-Apr-14	28pp, 64m	Jessie	22-Sep-14	12pp, 35m
	Marina	12-Nov-13	32pp, 68m						
Phipps Conservatory	Amy & Kathryn	14-Oct-13	29pp, 62m	Amy & Michelle	30-Apr-14	25pp, 63m	Michelle	31-Oct-14	26pp, 78m
Pennsylvania Environmental Council	Leslie	9-Oct-13	28pp, 67m	Leslie	2-May-14	26pp, 64m	Leslie	12-Nov-14	25pp, 78m
				John	5-May-14	15pp, 38m			
National Aviary	Courtney	25-Oct-13	26pp, 53m	Courtney	2-May-14	18pp, 48m	Courtney	7-Nov-14	25pp, 71m
Carnegie Museum of Natural History	Margaret	3-Dec-13	24pp, 49m	Margaret	27-Mar-14	22pp, 52m	Margaret	11-Nov-14	27pp, 73m
	Madison	2-Dec-13	28pp, 45m				Madison	10-Nov-14	29pp, 75m
	Phillip	4-Dec-13	16pp, 54m						
Pittsburgh Center for Creative Reuse				Kelli & Nicole	1-May-14	35pp, 73m	Nicole	31-Oct-14	29pp, 87m
							Kelli	31-Oct-14	23pp, 64m
Chatham School of Sustainability				Martha	28-Apr-14	25pp, 73m	Martha	3-Nov-14	18pp, 50m
Nine Mile Run Watershed Association				Stefanie	29-Apr-14	26pp, 62m	Stefanie	3-Nov-14	19pp, 54m
Tree Pittsburgh							Jack	10-Nov-14	28pp, 75m
Engineers for a Sustainable World							Adam	30-Oct-14	24pp, 60m

Table 4.5 Interview Data

4.4 RESULTS

How can a network function as an intervention in the city-scale climate change learning ecology, and what features should it have? We present our results in two sections: a brief overview of the 18-month trajectory and evolution of the entire network and then in-depth accounts of four

organizations in the network. Drawing from the three approaches to networks that framed our analyses, we highlight and explain network-enabling features: boundary objects, an adaptive hub, a shared system of inquiry and iterative development, and the value of cross-sector collaboration to produce mutually reinforcing activities.

4.4.1 Network Evolution: From Homogeneous Contribution to Heterogeneous Interactive Niches

During the initial planning phase of the project, the hub convened a series of meetings with local organizations with which it already had collaborative relationships (e.g., a botanical garden) or that had explicit connections to local environmental issues, (e.g., local watershed associations). From these early discussions emerged the practical idea of creating and sharing "kits": hands-on, portable learning activities that organizations could borrow to use for outreach and informal education efforts:

> I wanted something good to do for tabling.[2] Because we get so many tabling requests and it sucks to table. It's just very hard to table and we're just looking for something fun and engaging that would relate to what our mission is that would be educational that we could do regularly (Marina[3], Pittsburgh Parks Conservancy director of education, interview, 12 November 2013).

The original idea was the development of a "kit library" from which network organizations would check out kits to promote their organization's goals, and also make connections to local

[2] "Tabling" is when organizations go to festivals, open houses, or other kinds of public events where they typically sit behind tables or staff booth where they share information and activities with whatever members of the public happen to show up.
[3] All personal names used in this article are pseudonyms.

climate change impacts, with the specific intention of implementing these kits at large local festivals where many organizations already regularly conducted outreach activities. The network wanted the kits because they needed something fun and hands-on to attract visitors. Festival visitors, project leadership hypothesized, would notice that multiple organizations were using the same kinds of kits to talk about climate change, and these repeated encounters would provoke visitors to realize that it is an important and interconnected issue for Pittsburgh. Like a networked improvement community or a collective impact network, this group started with a specific idea and theory of action for how they would interact with one another and with the public. The kits were designed to embody the principles for climate change learning identified in collaboration with the learning scientists working in project: participation, relevance, and interconnectedness (see: Allen & Crowley, in press). To be relevant and participatory, kits were hands-on and connected local environmental issues to opportunities to respond to climate change in the form of programs offered by network organizations. The kits were a tangible resource made available by participation in the network that functioned as boundary objects to which conversations and ideas could be anchored. Like boundary objects in communities of practice, the kits facilitated communication within the network, and with the public, as part of a more coordinated learning ecology. Accordingly, the kits were intended to be recognized as part of a bigger system of kits and organizations, demonstrating that the impacts of climate change and responses to it are interconnected, just as systems in a city are interconnected.

The kits were also intentionally designed with a "do-it-yourself" aesthetic so that they would not appear finished and polished; the idea was to invite continual modification and tinkering by network partners and also to appear approachable to visitors at tabling events. This was achieved by using familiar materials and simple hand-built construction techniques. For

example, one popular kit, the Storm Water Runoff Demonstration, featured a city model with buildings made from Legos (see Figure 1).

Figure 4.1 The Storm Water Runoff kit, also known as the watershed demonstration model, is an example of the aesthetic and interactive design features built into the kit library. It uses familiar materials that communicate to children and adults that it should be played with, and also makes it clear that if learners wanted to engage with the ideas in the kit more deeply, they could build one of their own relatively easily.

During the first year of the project, hub staff created several prototype kits that they felt would be useful to the network:

> In the beginning, we started out providing our best stab at what it was so that people [in the network] would have something to refer to, instead of just starting from scratch… our intention was that these would be things that people would want to use (Margaret, hub leader, interview 3 December 2013).

The hub established a system of iterative prototyping by which they co-developed the kits in order to make them as useful as possible for the network. This system became what networked improvement communities call the shared system of inquiry. Kit prototypes were often a central focus of the network's quarterly meetings. Typically meetings, which lasted several hours, began

with kits laid out around the periphery of the meeting space and network members were encouraged to try them out and provide verbal or written feedback to inform the next round of iterative improvements. For example, network members would comment on what was most useful from the experience or suggest other topics they wanted to address using existing or future kits. In subsequent meetings, the hub would bring revised kits and talk with the network about how their feedback had been incorporated and tested on the floor of the museum or by network members at outreach events.

Organizations in the network implemented the kits at their own tables or booths at three festivals during the first year of the project. At these events, Allen observed varying degrees of success engaging visitors in conversations about local impacts and solutions to climate change (field notes, Green & Innovation Festival, 28 September 2013). For example, a successful engagement about climate change included a family approaching the table with a question about the kit, an interactive use of the kit where both the family and facilitator were involved in a conversation, and the facilitator using the moment to talk about their organization and how climate change is impacting the local environment in ways that connected to their organization's program or mission. An unsuccessful engagement about climate change would be a one-way interaction where either the visitors or facilitator did all of the hands-on work or talk. It was also considered unsuccessful if there was mutual exchange and activity, but the facilitator did not guide the interaction towards the principle of interconnection by talking, for example, about storm water runoff and sewage overflow, but failing to introduce the idea that climate change is expected to cause more extreme rain events that cause storm water runoff and sewer overflow problems, and thus impact the quality of life for future Pittsburghers.

Successful interactions were initially not that common. After the early rounds of implementations, the main feedback from network members was that it was difficult, and sometimes uncomfortable to work climate change into conversations about their organizations, even while using the kits. They also felt isolated, and drained from facilitating the kits and talking with the public for up to six hours at a time (field notes 23 April 2013; field notes and reflections 28 September 2013). Furthermore, the network members did not feel like a coordinated intervention in the learning ecology when they went out to implementing kits separately:

> I was at ALCOSAN [Allegheny County Sanitary Authority Open House] and we had a bunch of people doing kits there, but I didn't even see them all because I was at my own table. So I didn't even really see what they were doing and I wouldn't have known they were there except for Madison [hub staff] came over and was like we have so-and-so over here and so-and-so over there. I didn't even know that I was going to be one of multiple kits [at the festival] (Amy, Phipps educator, interview 14 October 2013).

After about a year of working together, different niches for network member organizations began to emerge from what had been a relatively homogenous structure of providing feedback for and then checking out and using kits independently. For example, in year two, the network began the process of adopting a digital mapping and communication platform developed by a sister climate change education network in New York City. The opportunity to adopt this new platform quickly created new niches in the network, because some organizations took on identifying and designing how the map would be used, while others focused on using and improving the kits:

> I could see myself getting a call [asking] "Where are there green roofs in the city?" And it'd be really nice to direct people to a map or even just for me to pull it up on the phone and name five buildings because I can easily find that information rather than try and remember it off the top of my head. (Leslie, PA Environmental Council program manager, interview 2 May 2014).

Not every organization in the network had a need for digital mapping tools, just as not every organization had a need for the kits as outreach tools. As some network members filled more design-oriented niche by working to adopt the new digital mapping platform, others found niches that allowed them to engage with the network's resources in ways that fit their needs and interests. For example, designing kits was a task originally designated to the hub. However, after the first "festival season" in the fall of 2013, network members expressed interest in designing kits themselves:

> So that's how I see my role, as a learner, an ally, a facilitator, and hopefully a developer at some point if I get to that point. It seems like I am so busy this way but I really want to sit down and try to help structure some of these kits (Charlotte, Green Building Alliance conservation fellow, interview 7 October 2013).

In order to bring network members into the kit design process, the network needed access to materials, space, and experienced makers to facilitate the kit design process, which were not available through the hub. Fortunately, the Pittsburgh Center for Creative Reuse (PCCR) joined the network upon learning about it at the festivals in fall 2013. PCCR was able to not only provide reclaimed materials to make kits, but also space and facilitation resources to host "kit

design workshops". Hub leaders and staff were eager to adapt to these changes in network operation, and see new relationships as models for future intra-network relationships:

> I love the idea of piggybacking off of PCCR, since we have sort of special relationship with them… it might be easier to do that with them first (Margaret, hub leader, interview, 28 March 2014).

> This was the key year of the Center for Creative Reuse, I think they've been invaluable, and that really stepped up [network engagement] this year (Madison, hub education program development coordinator, interview 10 November 2014).

This flexibility at the hub level is an example of what networked improvement communities and collective impact projects refer to as adaptive leadership. The hub was flexible in adapting to a new way of thinking about kit development, and eager to support organizations as they found more specific niches and ways to engage with the network and the project. The network's engagement went from an initial model of developing kits for use by the network (homogenous engagement), to using the network as prototype testers, to eventually incorporating a new partner with making resources as part of a non-hierarchical design collaborative (heterogeneous niches for diverse network organizations). In other words, by actively supporting the diversification of how network members contributed to the project, the hub was enabling more cross-sector collaboration and the potential for mutually reinforcing activities. Thinking in the hub and throughout the network also evolved from the kits being stand-alone experiences that any partner could implement into an exhibition-like, complementary set of experiences that we describe below.

Kit design workshops were hosted at PCCR, which attracted new organizations to the network from different sectors. For example, Adam, the executive director of a national engineering outreach organization, joined the network by way of the kit design workshops:

> I started with the workshops over at PCCR, which were working on kits and I didn't really know what kits were at that point, I didn't know why kits existed or, so I was like okay, let's talk about climate change and here's some ideas.... How much information can we convey to people? (Adam, Engineers for a Sustainable World executive director, interview 31 October 2014).

Adam went on to distribute the kit format and what he had learned about climate change communication to branches of his organization at universities across the US, another example of a mutually reinforcing activity, and an unexpected expansion of the project's influence beyond the city-scale. Similarly, Lucy, a program coordinator at a green design non-profit organization was eager to get involved in designing activities that connected her organization's work to climate change, and found that opportunity at the kit design workshops:

> I had seen [Margaret] at a few other tabling events and talked to her there... I latched onto it because I think everyone in my office is interested in climate related things, and I have been wanting to figure out how our work at GTECH fits into that type of thing (Lucy, GTECH program coordinator, debrief meeting 10 October 2014).

A third example of network expansion and niche diversification came from Martha, a university professor of sustainability who served on the PCCR board of directors and also joined the network after learning about it from PCCR staff. She used the design workshops and

quarterly meetings as opportunities for her students to learn about educational design and how nonprofit organizations can collaborate.

Kit design workshops generated new ideas for kits, and opened up the network's thinking for what could constitute a kit—instead of only tabletop activities, new kits were designed to be whole-body games for children, use metaphors from sports to calculate carbon footprints and understand urban green space distribution, and three dimensional puzzles representing the different parts of a city's transportation infrastructure. One result of more network involvement in designing kits and adopting new tools (like the digital mapping platform) was the comfortable stance toward trying new things more generally. This mood was particularly salient around the idea of presenting the kits as a unified learning environment at festivals, instead of having them distributed and facilitated separately by individual organizations—an idea that originally surfaced during a hub planning meeting, and was first brought to the network with positive responses in spring 2014 (hub staff meeting notes 27 March 2014; quarterly network meeting notes 9 April 2014). Network members who had participated in the distributed kit facilitation were eager to try something new: "I think us all being together, we're much more exciting… I want to be part of something that is big and appealing to people and makes people want to be there" (Michelle, Phipps educator, interview 30 April 2014).

The network decided to call this new style of implementation the "climate change playground." The organization and layout of the climate change playground was designed through a series of meetings between the hub and network members who intended to participate. The network and the hub agreed that they wanted the climate change playgrounds to feel inviting, have space for conversations, resting, reading, and self-directed activities in addition to facilitated kits. Once the design for the climate change playground was agreed upon, the hub

hosted several ‘playground trainings’ at the request of the network, so that members could talk with one another about strategies for facilitating the various kits; including asking specific questions about climate change science, local impacts of climate change, how the kits’ messages relate to programs hosted by network organizations, and how to talk about climate change if visitors seemed uncomfortable. These trainings took place in ‘mock climate change playgrounds’ where network members circulated through the kits and engaged in conversations as though they were at a festival, so they could get the feel for the tone and structure of the climate change playgrounds.

At the climate change playgrounds (see Figure 2), facilitators were be able to help one another in practical ways, such as giving each other breaks, and through mutual reinforcement, by connecting visitors to one another’s resources and programs. For instance, when a visitor had a question about different kinds of renewable energy, a network member from the botanical garden was able to direct the visitor to the director of the engineering outreach organization with specific expertise in renewable energy generation. Inside the climate change playground, visitors were able to make connections across the kits and conversations they were having with different network members and organizations. When the network members saw this happening naturally, they started to direct visitors from one kit to the next that provided an opportunity to connect local climate change impacts to local responses, and use the ideas introduced at one kit in the conversation and activity at the next (field notes, ALCOSAN Open House, 20 September 2015).

Figure 4.2 The Climate Change Playgrounds were an entirely different way to implement the kits than had been attempted in the first year of the project. Network members facilitated the kits at adjacent tables arranged so that visitors could see connections and continue conversations and inquiries across kits and across the organizations with which they engaged. The playgrounds included areas to engage with organizations, and areas to rest and explore self-directed activities, and read information about network organizations.

The climate change playground approach left network members positive and excited:

> It was way more positive than tabling events by ourselves or even when other [network] groups were at separate tables. You're there in a big space, that has a theme, and you're not competing with somebody who has a possum in a cage or a bunch of chickens. In that big space, even if you can't reach everybody, everybody who comes through is going to have some kind of good interaction in there. I really liked how integrated the activities were… We felt like we were really part of something important, and people were getting something out of it. And there was a bigger impact because we were a group there, together. (Michelle, Phipps educator, debrief meeting, 26 September 2014).

Network members were observed sharing techniques for how to use the kits to engage visitors in meaningful conversations about climate change impacts on the local environment and how organizations and individuals can respond (field notes, ALCOSAN Open House and Allegheny Green & Innovation Festival, 20 and 27 September, 2014).

The kits were a central focus and important boundary objects, and the climate change playgrounds were an important instance of mutual engagement for the network. However, these were not the only parts of network participation that members identified as valuable and important. Regular opportunities to meet and interact with colleagues, access to climate change information and communication techniques, and the credibility associated with collaborating with visible and established organizations such as the hub were all reasons cited for participating in this network:

> It was one of my goals to become a partner because I knew how valuable it was, one for the networking opportunity… talking about potential program alignment is very important (Jack, Tree Pittsburgh community education coordinator, interview 10 November 2014).
>
> I get a lot out of it because of the network… I really value working with all of these organizations and us having these meetings where we get to talk and get to learn from each other, and we can create other partnerships (Michelle, Phipps Botanical Garden educator, 30 April 2014).
>
> I was attracted to this project for a couple reasons. First of all, it was at the Natural History Museum and I liked that. And it's a National Science Foundation grant, so that seemed impressive… I knew it was a collaboration. I'm very fond of

collaborations, being an educator (Iona, Conservation Consultants Inc. education coordinator, 7 October 2013).

In the next section, we present case studies of the hub, Pittsburgh Center for Creative ReUse, the National Aviary, and Nine Mile Run Watershed Association as examples of different ways that organizations and their staff participated in the network and used its resources to make changes at their own organizations. We argue that changes at the network level, described above, and at the organizational level, described below, are evidence that the overall climate change learning ecology in Pittsburgh was influenced by this network-as-intervention.

4.4.2 Carnegie Museum of Natural History: The Adapting Hub

The network hub, Carnegie Museum of Natural History (CMNH), is a large natural history museum with a world-renowned collection and scientists who regularly publish peer-reviewed research articles. They also have full-time education and outreach staff, including Margaret, who was the hub leader, Madison, who was the lead coordinator, and several other education specialists who worked from time to time on developing kits and facilitating in-field educational experiences. The hub staff regularly met with the national partners from the other three CUSP cities to discuss how their networks were developing, what new ideas they were testing, and how the platform development and implementation processes were progressing. They also had regular access to up-to-date climate science information and research from the climate scientists at Columbia University who participated in the larger project, which provided some of the credibility and resource availability that was appreciated by the network:

> [The network has] really great resources of respected scientists on our team… I'm really excited to get clear messages so that all of the organizations can be talking

about it and using the same language… and say hey, this was checked by experts (Takashi, Pittsburgh Parks Conservancy educator, 8 October 2013).

The kits were a key part of the project from the onset, but their development was not easy nor a given. Madison, who had been a part-time educator, was recruited to work on the project full-time because of her interest and expertise in climate change and her work on previous climate change projects at CMNH. The hub staff has limited exhibit development and design experience, which she perceived as an obstacle:

> I really feel like we're hampered by not having any kind of production activity… we have ideas but we don't have any actual developers, like makers, working with us, so that makes it a little bit harder. (Madison, CMNH education program development coordinator, interview 4 December 2013).

Madison was the main developer and designer of kits early in the project, and she explained at the end of the first year how she saw the network evolving:

> At first I saw it more as a tool for the development of the kits. We would bring kits to them and they would say yes or no, help us test them out. They were the group of people that would be using them so a lot of it was about recruiting people who would use the kits at festivals. I saw it as really focused on the kits: the [network] and the kits were the same thing. But as things have gone on, [I'm] seeing it as a collaboration of people hoping to maintain that collaboration over time… it's becoming focused on education in particular, and it's a group of people who are looking for ways to improve their ability to educate or to add certain types of messages to what they're doing that they don't have the expertise

> or experience to add (Madison, CMNH education program development coordinator, interview 4 December 2013).

This evolution of the network meant that the hub would also need to adapt to meet the needs of the network and overall project. After the first year of hub staff creating the kits and presenting them to the network, they were ready for the network members to start filling the kit designer niche:

> It would be nice if they were actually doing some of the [kit] development and sharing ideas because we're all wanting to use them in similar ways. I think that they can take a little more ownership over some parts of the kit development process (Madison, CMNH education program development coordinator, interview 4 December 2013).

The hub was starting to recognize that the network would work better if member organizations found, or were provided, appropriate niches. Informal education organizations, like museums and botanical gardens, sometimes filled similar niches in terms of kit use and design, while others had different needs and therefore became involved in adopting and customizing different tools, such as the digital map:

> Some partners are a lot like us, like Phipps, and there are some partners who are different but aligned enough that the original idea is working… I like bringing people into the design process because then people like Barbara [Nine Mile Run Watershed Association executive director] can say, "I like this map. I think there are stories to tell [with it]. Here are the stories we had trouble telling." We can deliver something back to her that tells that story. (Margaret, hub leader interview, 28 March 2014)

It was important for the hub to take into consideration that organizations without capacity to facilitate learning experiences with public audiences could still be useful partners by providing resources and information about local responses to climate change:

> A lot of these organizations only have so much time and space to do anything beyond getting bare bones amount of work done, focused on their very specific goals, that adding the climate piece is just too much to ask…They may end up being like a resource. We've been talking to some people who want and are happy and delighted to provide information, but not necessarily to do the education. (Madison, CMNH education program development coordinator, interview 10 December 2014)

The hub staff's ability to see and work with the different constraints, needs, and resources available for the overall network's functioning is an example of adaptive leadership, described as essential for both networked improvement communities and collective impact (Bryk et al., 2015; Kania & Kramer, 2011). Over the course of the project, the hub was able to be flexible about how it engaged the network and the different niches that it supported within the network's operations. This flexibility was important for the hub to adapt to the evolving network, and continuing to support the network's growth and success as an intervention in the climate change learning ecology.

How did being part of this network influence the other work happening within the hub organization itself? First of all, the kits started to be picked up for use by other education programs in the museum:

> The kits already have been used by the teen programs as an outreach component for their work and as little mini exhibits that they can do around the museum...

> And some of the kits also work really well as prepackaged activities for summer camps (Madison, CMNH education program development coordinator, interview 2 December 2014).

But perhaps more importantly, the project also influenced general attitudes towards climate change education in the museum. Early on, some educators felt uncomfortable bringing climate change into their work at the museum; a phenomenon we documented in the context of a prior climate change education project (Allen & Crowley, 2014). However, having important resources dedicated to climate change education and the credibility of a large federal grant and national partnerships, led to a gradual change in the overall culture of the organization to be more unified around the importance of climate change learning, and to see connections for the museum's functioning in not only its scientific research, but also its outreach projects:

> I think that the culture shift over the last several years in our education department has been towards presenting a unified approach and description to what we do, rather than a big lists of specific programs each with their own objectives. CUSP and other grant-funded programs have been operating fairly independently and not tied in to ongoing program operations. So, maybe the old culture was that CUSP or [a previous climate change project funded by NASA] were the climate change programs, and we only used the climate change tools and resources in those programs. Something that has been very consistent in our culture is to make sure that all of our programs are tied very concretely to the resources at our museum. In this past, this meant that we focused on the specific research of our scientists, or the content of our exhibits. I think that CUSP has pushed us to find connections between natural history, our collections/research/exhibits, and local

> climate change impacts and adaptations. (Lillian, CMNH Assistant Director of Education and Visitor Experience, email communication, 20 October 2015).

The hub sees the network as part of a long-term effort to respond to climate change, and would like to see it persist in the future in some form, recognizing that these kinds of relationships are dynamic:

> I see [the network] in its ideal form helping people feel excited about a level of work that's happening here that does address climate change but also has beneficial impacts for the city… there's cool, exciting work going on in the city helping people become aware of it and giving them the opportunity to have a say or some participation in it… ideally 10 years from now many of the same people are still working together (Madison, CMNH education program development coordinator, interview 10 December 2014).

The hub embraced the changing nature of the network's operation, allowing the network to find success as an intervention in the climate change learning ecology in Pittsburgh. For the hub, this meant doing the work of creating the first kit prototypes to serve as functional boundary objects, and then transferring the shared process for iterative design to the network members. It also meant working to understand the constraints, resources, and goals of network members and potential network members in order to ensure they were able to fill the appropriate niche to achieve both network goals and individual organizational goals. These achievements serve as evidence that CMNH was an effective adapting hub, through supporting change and facilitating the evolution of unique niches so that the heterogeneous organizations of the network could engage usefully with regard to their strengths, needs, and resources.

4.4.3 Pittsburgh Center for Creative ReUse: Creative Making as Climate Change Action

The Pittsburgh Center for Creative ReUse (PCCR) is a small non-profit organization dedicated to reducing waste by collecting would-be landfill items to sell in a curated art supplies and craft store and conducting workshops where people can make creative and useful projects out of reclaimed materials. A lot of PCCR's reuse is focused on creative or artistic projects, but many of the materials they collect and sell are simply useful, such as office supplies and kitchen equipment. Kelli and Nicole are the two staff most actively involved in the network. Kelli is a teaching artist who facilitates workshops, and Nicole is PCCR's community liaison, who has a background in art theory and history. Both Kelli and Nicole view the use of reclaimed materials in climate education kits as a form of "putting your money where your mouth is," meaning that the materials used to create the kit can be an example of a response to climate change. They quickly recognized that people learn not just from using kits, but also learn when making kits—something that they experienced first-hand with network members at the kit design workshops and something that they then advocated for in terms of the experience of public audiences. They made this possible by strategically connecting PCCR's outreach and the network's climate change playgrounds at the festivals in fall 2014 (see Figure 3). PCCR regularly facilitates "Reuse-A-Palooza" events at regional festivals, wherein reclaimed and reusable materials are provided to the public who are encouraged to create sculptures, inventions, and other physical manifestations of reuse that they can take home with them. In the fall of 2013, PCCR staff were impressed with the network's kits that they saw at both of the major regional festivals, and suggested that they could provide materials for the kits:

> I just looked at the kits and went, we could supply you with everything you need to build these kits and it's all reclaimed materials and hey, doesn't that put your

> money where your mouth is (Nicole, PCCR community liaison, interview 1 May 2014).

Since the kits were already being intentionally designed for approachability through recognizable materials, the idea of using reclaimed materials sourced from PCCR made perfect sense to the other network members.

PCCR filled an important niche in the network by providing not only materials, but also a focused philosophy about them. The materials became an important and tangible component of the kits' functioning as the boundary objects for the network. This provided more opportunities for the network to use the boundary objects to enhance their collective understanding of climate change and informal climate change education. In this niche, PCCR served as what Margaret termed an "anchor" organization (Margaret, hub leader, interview, 28 March 2014), with a tighter relationship to the hub, which included a contract to pay for the time and the materials provided by PCCR to the project as a whole. The ability and willingness of the hub to use project resources to legitimize and support this relationship was key to enabling PCCR to fill this niche, and is another example of adaptive leadership.

Kelli and Nicole both focused on what reclaimed materials represented in the network's process, and the learning opportunities embedded in making the kits:

> In the [network] partnership, a few people are going to look at all these different kits and after looking at a few different ones, they're going to start to see some consistency in the reclaimed materials that are being used and maybe it will inspire them to do the same (Kelli, PCCR teaching artist, interview, 1 May 2014).

For Nicole, the experience of making a kit and thinking through the messages the kits embody are both important:

> There's just so much more to think about when you're making a kit. You're thinking about not just your own perspective but the perspective of whomever might be interacting with the kit. You're thinking about the actual design and construction and what's going to work and what's not, so you're utilizing all your, you know, problem solving skills and actual building skills… But I'd say the biggest value is just really thinking outside of yourself and thinking, "Oh, is this going to communicate the information we're looking to communicate to somebody else?" Or, "Am I in my own brain?" … Is it saying what we want it to say and are people actually understanding it. I think that that's where it becomes very valuable because you're thinking much more about the kind of issues than if you're just doing the kit (Nicole, PCCR community liason, interview, 31 October 2014).

In response to PCCR's emerging niche in the network, subsequent climate change playgrounds were organized to be in close proximity to the Reuse-A-Palooza tents, and visually connected with the same style of banners and signage (see Figure 3). As a result, both Nicole and Kelli were hopeful about continuing to bring making and climate change together:

> Both tents were really bustling and active and people were having a good time and were excited about it, it seemed… we need to have more focused activities that are related if we're going to be next to each other… However, if we are somehow like more combined, I think, if we're not just like next to each other but we're really together—integrated, then I think we'll get some really, really awesome stuff happening (Nicole, PCCR community liaison, interview 31 October 2014).

> I think that the climate change playground was gorgeous. It looked great. And by bringing them together under your tent both metaphorically and realistically, was a good way to get buy-in from those groups because we're really sharing resources. (Kelli, PCCR teaching artist, interview 31 October 2014).

Figure 4.3 The Climate Change Playgrounds and the Reuse-A-Palooza tent had the same kind of signage throughout. Inside Climate Change Playground, areas were labeled "Demonstrate", "Participate", "Contemplate", and "Investigate"; and the nearby PCCR tent was labeled "Communicate" to convey the idea that visitors would make their own climate change kits to take home and use to communicate what they had learned with friends and family.

Both Kelli and Nicole recognized the utility of the network as an intervention in the climate change learning ecology:

> I think connecting all of these groups makes it clear that climate change is a huge, huge concept and by breaking it down into all these different organizations, each one has a relevant point and a relevant effect on climate change and by bringing them all under the umbrella of [the network], people are like wow, a lot of different things affect climate change and how we all have to adapt (Kelli, PCCR teaching artist, interview, 1 May 2014).

Similarly, for Nicole, the network members help one another understand the issue better, and having the network also helps audiences and the public get access to the responses to climate change that are most interesting and relevant to their lives:

> There's been a lot of filling in each other's gaps too, in terms of our gaps of knowledge about what other organizations are doing. It's been very enlightening to know what people are up and how what we do is related to what they do… that's the beauty of the network: many different aspects of [climate change] are addressed, and people are different and have different interests, so [they] might veer towards one aspect more than another (Nicole, PCCR community liaison, interview, 1 May 2014).

What is more, being part of the network has helped PCCR to make stronger connections with other organizations and to climate change in the other work that they do:

> I think we have connected to some of the [network] partners in ways that maybe they didn't realize that we could. They could benefit from working with us and that has been good. Also I think that it has been helpful in getting some of the curriculum connections to some of the program that we do at Creative Reuse. More of the scientific factoids and information that backs up why we do what we do. [The network has] provided us with tools so we can apply that (Kelli PCCR teaching artist, interview, 31 October 2014).

And, they have incorporated the kits into their other programming, sometimes at the request of their partners:

> Through PCCR, we have been taking the kits and going to libraries with kids to understand the kits and then do just what we had hoped: duplicate them within

> their own practice using our materials, and the results have been fantastic. The kids are completely engaged and the one-on-one interaction has been just great and the libraries are calling us going, "Hey, you have those kit things, we want more of that". As out-of-school programing through PCCR, it's going to become one of our regular programs, partnering with [the hub] (Kelli, PCCR teaching artist, interview 31 October 2014).

Thus, even though they began the project very far away from thinking of themselves as part of climate change education, PCCR became an essential member to the network because of their unique material, spatial, and facilitation resources that they were able to contribute to the network's evolution. They enabled the network to engage more deeply with its boundary objects and the shared iterative inquiry process the network used to create those boundary objects.

4.4.4 National Aviary: Bringing Network Resources into Organizational Work

Pittsburgh's National Aviary is a zoological organization dedicated to conservation of and education about birds from all over the world. The main network participant from the National Aviary was Courtney, an educator who is motivated to engage visitors in learning that moves beyond simple stories about birds: "the birds are a good gateway ambassador, but we want [our visitors] to learn more than, 'oh, the cute penguins are in trouble'" (Courtney interview 2 May 2014). The Aviary fills a different niche in the network than other informal learning institutions, because, unlike organizations that typically use materials similar to the climate kits for off-site outreach efforts, the Aviary usually uses live birds.

This is not to say the Aviary did not find a use for the kits, however. Courtney was so inspired by how the kits functioned at festivals and meetings early in the project that she adapted

the format to design similar kits for volunteers to use for demonstrations that go along with the Aviary's newest exhibit about environmental degradation:

> The exhibit that's opening in a few weeks, Canary's Call, has its own built-in demonstration cart and we're going to be assembling over the next year or two at least six different table top activities that will show different concepts about bird declines in the wild… I definitely think we're going to either modify or use the run off demonstration [see Figure 1], because it's so engaging (Courtney, Aviary educator, interview 25 October 2013).

Over the course of the project, Courtney persisted in adapting and designing kits to be used by volunteers and educators on the floor of the Aviary. She was very insistent that even though her organization didn't check out the kits to use for outreach the way others did, that they were still valuable to her work:

> But we want the kits! And we have venues here where we want to build in deeper learning, because the birds are great at getting people through the door. But while they're here, we want them to be able to learn more about certain topics and we would like climate change to be one of those. So we have a framework in place and we're trying to expand on having our volunteers out at certain times of day with kits… the climate change kits in some form or fashion are going to be something our volunteers can hopefully talk to people about while they're here (Courtney, Aviary educator, interview 2 May 2014).

Six months later, Courtney described the research she had conducted in the process of adapting the network's kits into the on-the-floor presentations at the Aviary:

We appropriated the hand-crank generators [see Figure 4] for something that we do called Aviary a la Carte, which is a half-hour to 45-minute demo in our Canary's Call exhibit. It's supposed to compliment the exhibit and tie in with messages about sustainability, population growth, conservation, and birds as environmental indicators. I did take it one step further. I mean, we really loved the hand-crank generators as a touchable thing, and they're a kid magnet, but we wanted to incorporate them into a bigger message about tying light bulbs and energy choices in with birds. It took me a long time to find a connection, but I ended up discovering that compact fluorescents contain mercury and incandescents contain lead. And both of those are major environmental contaminants for large birds especially, eagles… in the broader lesson plan, we can tie eagles in with light bulbs, where they look like they really don't have anything to do with each other, but our volunteers can sort of lead people through the connections. So, choosing what kinds of light bulbs you use in your house can actually have a much greater environmental impact even beyond the amount of energy that it takes. Compact fluorescents are still better than incandescents because they release less mercury when broken than the mercury that is produced to burn enough fuel to power your incandescent bulb. (Courtney, Aviary educator, interview 7 November 2014).

Figure 4.4 The Energy Matters! kit, also known as Hand Crank Generators, proved to be a versatile and simple demonstration of how much physical energy is required to power different types of light bulbs. LED light bulbs require the least energy, and are the easiest to power by hand. Incandescent, or traditional filament light bulbs, require the most energy and take the most work to power via the hand crank. Courtney took this simple demonstration and added a lot of new content specific to her organization to it.

Courtney's participation in the network also influenced other features of the Aviary's new exhibit. For example, during one of our interviews, Courtney took Allen on a tour of the new exhibit that she helped create kits for. Allen remarked on one of the interactive computer kiosks that allowed visitors to see how many other people had used it to learn about palm oil and then made a commitment to pay attention to where their food comes from:

> Actually I think that's a thing I got from one of our [network] meetings! We were talking about some degree of accountability but also that community momentum being able to say, "You're not alone! You're part of this great big movement! And all of these other people are doing it; won't you do it too?" It's like positive peer pressure (Courtney, Aviary educator, interview 7 November 2014).

Courtney's experience was different from most in the network because she did not participate in the festivals, climate change playgrounds, or digital mapping platform, yet considered herself a core network member and valued how the kits and collaborative work

enabled her to be a change agent back in her home organization. In her view, largely thanks to the network, the Aviary now has more hands-on learning opportunities for its visitors, and more current and accurate information directly relating to climate change:

> Not everyone here is terribly well versed in climate change information- or at least not the most recent information and there's still definitely a learning curve getting people to talk about climate change rather than global warming. So that's a little bit of an uphill climb, but for the most part, it's very easy to incorporate [climate change information] whenever we talk about some of our birds. I've really enjoyed this project so far because I like making sure that all of our information in our education programs is current and we don't let it stagnate and put studies in from ten years ago that aren't applicable anymore. It's nice for me to get really up to date information from everyone at these meetings and figure out how to apply it toward curriculum development here (Courtney, Aviary educator, interview 25 October 2013).

4.4.5 Nine Mile Run Watershed Association: Focusing on Climate Change within a Narrow, Local Mission

Nine Mile Run Watershed Association (NMRWA) is a small, focused advocacy organization whose goal is to preserve, conserve, and protect the Nine Mile Run Watershed, a 6.5 square mile urban watershed that flows into the Monongahela River in Pittsburgh. Two staff members from NMRWA participated in the network in different ways: Barbara, the executive director, served as a resource person and connector to watershed and water treatment issues in Pittsburgh; and Stefanie, the communications manager, attended to network meetings, used the Storm Water

Runoff kit (Figure 4.1) for NMRWA events and communication efforts, and facilitated the Storm Water Runoff kit at climate change playgrounds.

Both Margaret and Madison from the hub made it clear that although Barbara did not come to most network meetings, and was not available for interviews for our study, she filled a very important niche in the network:

> Barbara's launching into a position on the board at ALCOSAN [Allegheny County Sanitation Authority, the sewage treatment facility]. Even though she's not fundamental to [network] meetings, I think her involvement in developing the [digital map platform], and providing information that's not just, "Here's what happened," but "Here's what's coming down the pike," is key (Madison, hub education program development coordinator, interview, 10 November 2014).

Margaret confirmed Barbara's role: "Barbara at Nine Mile Run doesn't necessarily come to the meetings, but was really instrumental with the map" (Margaret, hub leader, interview 11 December 2014).

Stefanie started coming to network meetings in the beginning of 2014, and at first was a little bit hesitant to talk about climate change as part of the context for her work at NMRWA (Field Notes, Quarterly Network Meeting, 9 April 2014). At our first interview, she described how the organization's focus on the watershed made it harder to bring climate change into the conversation:

> [Our goal] is getting excess sewage and storm water out of the stream, since our organization exists for the restoration [of the watershed]. In that vein, a lot of the work that we do is really targeted at the storm water aspect of things. You know, trees, rain gardens, etc. We're really working hard to get storm water out and also

> getting people to understand why it's important. And then the relations to climate change…we really need to start doing a better job at getting that in the message as well because it's so important… [it's] also a question that we're grappling with. Because we do need to incorporate it more. You know, I have like a standard spiel I like to say when I do go down and give tours… And I think one of my main points needs to start being mentioning climate change at some point (Stefanie, NMRWA communications manager, interview 29 April 2014).

Between Stefanie's interview in April—before the first climate change playgrounds—and her interview in November, she grew much more confident in talking about climate change as part of her work as communications manager for NMRWA:

> It's been really nice to interact with all the other groups [at meetings] as well at the tabling. It's very easy for me—and I don't want to speak for others but I would assume others at Nine Mile Run—to just get caught up talking just about storm water, and sometimes it's hard for me to remember to work in the climate change message. But being a part of this group has made me obviously think a lot more about it and realize how important it is. It's brought an extra dimension to [my work]: even when I'm thinking about going out for certain education outreach grants, I'm trying to incorporate that part into it because it is so important… it's brought more awareness to me personally, which has been really nice. And I'm hoping that that will continue to reflect through our work as an organization (Stefanie, NMRWA communications manager, interview 3 November 2014).

Stefanie saw the value of networking with other non-profit organizations in order to broaden audiences and advance missions together. She also recognized that the network needed to be diverse and interconnected to impact the climate change learning ecology:

> Learning from other groups or just having more opportunities for collaboration… working closely with other non-profits to advance your missions at the same time and getting a wider audience of people to know what you're doing and be involved and participating… it's not simple. It's complex, so there's power in having multiple people, knowledgeable about multiple things and being able to share that and empower each other (Stefanie, NMRWA communications manager, interview 29 April 2014).

4.5 DISCUSSION

Over the course of this study, the network developed from a simple hub-and-spokes structure focused on resource distribution to a dynamic and collaborative design network whose activities and programs were well aligned, and in large part responsible for, an emerging climate change learning ecology in the city. Four features, surfaced through interviews with network members and resonant with prior literature, were important for allowing the network to grow and learn as an ongoing response to climate change through informal education. The network used boundary objects, similar to those in communities of practice. It had an adaptive hub, identified and emphasized as important for networked improvement communities and collective impact. It worked though a shared system of iterative development and inquiry, a key feature of networked improvement communities. Finally, it supported heterogeneous, cross-sector collaboration and

engagement through facilitated, unique niches that fit organizations' specific missions, needs, and expertise—an important aspect of collective impact.

The adaptive hub in the network we profile here was able to respond to the changing needs and realizations of its partners by maintaining open communication and a flexible approach to how the overall goals of the project could be achieved. The overarching changes that the network was able to make to the way it approached building the kit-based informal climate change education platform—starting with the network as a feedback or focus group around kits designed by the hub, and ending up as involved designers and prototypers of kits produced through a non-hierarchical design-workshop process—is a key example to the hub's flexibility and adaptive approach to its role. Had the hub staff clung to their role as the primary kit designers, or failed to communicate the process of prototyping, iterating, and improving the kits clearly and openly to the network, they would not have been able to facilitate the engagement around kit design or foster the culture of trying new ideas and working collaboratively to produce high-quality informal climate change learning experiences that came out of the eighteen months of documented network engagement detailed above. Furthermore, the hub adapted to the emergent need among network members for unique niches within network operations. By recognizing and facilitating heterogeneous niches for network members to contribute to and access resources in the network, the hub successfully adapted to network needs while simultaneously facilitating opportunities for mutually reinforcing activities to take place in the cross-sector collaboration, as explained below.

Organizations in the network found their own niches and purposes within the shared work of developing kits, adopting new platforms, and implementing informal education programming for public audiences. The kits, in particular, were a central organizing feature of

the network. They served as boundary objects created by and for the network, enabling within-network communication as well as a way to frame and learn from communication with the public. The kits were the seeds around which a shared system of inquiry and design was able to grow. The kits that the network prototyped, designed, and developed over the course of its engagement were not immediately useful as boundary objects or tools for connecting outreach efforts to informal climate change learning. Their utility developed through the joint efforts of network members who provided feedback and contributed to the shared system of prototyping that enabled iterative design to connect local impacts of climate change to network organizations' specific programs and missions. In the end, the shared design culture that grew around the kits became one of the most valued aspects of the network by its members; and one that bodes well for the network's long-term sustainability. Members saw the network as having more than tools to share; it had a way of working together that was engaging, useful, easy to tune to local opportunities, and focused on solving typical problems of practice in informal learning.

The shared system of inquiry and design, and the evolution of how the kits were implemented by the network, were made possible through adaptation to the network's changing needs and operations by the hub organization. This system enabled network members to be confident that the feedback they provided about kits, other tools, and implementation experiences would be heard and responded to by the project as a whole. The network saw that when they asked for changes to the kits, and asked for changes to how the kits were designed, their voices were heard and the system by which decisions for making changes were made was transparent and understood by the whole network. This allowed for increasingly better versions of kits, platforms, meeting foci, and implementation strategies to emerge.

In contrast to communities of practice, where organizations and individuals tend to share the same professional identity or role, or networked improvement communities, where the roles of researcher, designer, and practitioner are prescribed by the structure, or collective impact, where meetings are attended exclusively by executive-level organizational leaders; this was a heterogeneous network where heterogeneous organizations and a wide range of individuals from those organizations focused on producing, improving, and utilizing a shared set of tools and strategies for engaging the public in informal climate change learning. Not all the organizations (with their diverse missions and reasons for participating in the project) needed or wanted to use the network's resources in the same way. For example, not all organizations in the network participated in kit design workshops, attended every quarterly meeting, or participated in the climate change playgrounds. Each organization in the network was able to find, create, or co-create a niche in the network that enabled it to use network resources and contribute to network success in ways that made sense for its organizational mission. The facilitation of multiple kinds of niches was the result of the hub recognizing and adapting to the heterogeneity of the network. By actively working to ensure that organizations were getting what they needed and contributing what they could to the network's efforts, the hub provided opportunities for mutually reinforcing activities to take place within the cross-sector collaborative network. In this context, mutually reinforcing activities included making connections across organizations by providing information about or opportunities to respond to climate change at the local level (at the climate change playgrounds and in informal conversations with the public), and in sharing space, time, and resources to design and implement effective outreach and informal learning opportunities at local festivals.

Complex, wicked problems such as climate change require the life-long engagement of whole communities—climate change is not a problem that will be solved through one-time actions or single policies. In order to provoke a response to climate change that is commensurate with the scale of the problem, the climate change learning ecology needs to provide connected opportunities for ongoing learning and responding to the problem. Unless network leadership is willing to enable bottom-up redirection of network activities, it may end up restricting access to organizations or initiatives that may have important audiences, innovations, or approaches to complex problems just because they do not fit the networks current ways of working. We note this involves a fair amount of risk by the hub organization. An easier and less risky approach to the network would have been to see it as a dissemination and implementation strategy. The hub could certainly have brought a plan for building and sharing kits to the partners on day one of the project, and then pumped energy into the network to encourage partners to share their audiences with the hub and show up at festivals using the hub's kits. This would have broadened the impact of one organization's efforts to do climate change education in Pittsburgh by multiplying the numbers of people that the hub was able to reach.

Ultimately, this would have been a short-lived and less potent intervention. We argue that networks aimed at long-term impact on a learning ecologies are better served by establishing ongoing systems of iterative development centered around boundary objects that the network, and its public audience, see as relevant, participatory, and interconnected to their lives and work. Rather than measuring success purely by numbers served, the hub in our study decided to pursue the longer game of changing a regional learning ecology by developing a local network of organizations who would continue to share responsibility and work together for climate change education long after the project funding had ended.

5.0 CONCLUSION: APPLYING THE PRINCIPLES TO SOCIO-SCIENTIFIC ISSUES OUTSIDE OF CLIMATE CHANGE

The two important features of my dissertation that I want to emphasize in the conclusion are (1) the conceptualization of learning as a process of change that takes place over time, and (2) the notion that education about complex socio-scientific issues particularly requires this conceptualization of learning as an ongoing, participatory process that is interwoven with other personal, professional, and social systems with which learners interact. By working with groups of people who are striving to change and improve their own efforts to educate about challenging topics, I observed how their learning takes place across time, through conversations, and in the activity of designing, testing, and improving tools and strategies for engaging learners in informal educational experiences. Over the course of the projects where I have made these observations, my own learning and understanding of these challenges has developed similarly—that is to say, over time, through conversations with colleagues and collaborators, and by actively engaging in designing, testing, and re-designing the materials, tools, and exhibits that I use to communicate.

In chapters two and four, I focused on the networks and learning communities that support ongoing, participatory learning—specifically, learning how to leverage informal climate change education experiences to increase collective efficacy among learners. As I have emphasized, learning in communities and the power of networks to bring together physical,

mental, and economic resources are well-documented here and in the extant learning science and organizational networks literatures. In chapter five, I pivot toward the application of informal learning, and the principles and features of informal learning described in chapters two through four, to a different socio-scientific issue outside of climate change. In this chapter I focus on applying the principles for inquiry-based learning (learner autonomy, conversation, and deep inquiry) as well as the principles for learning to respond (participation, relevance, and interconnectedness) as well as the use of boundary objects to the design of an informal learning environment: a small museum of which I am co-director.

Socio-scientific issues are the greatest challenges for science communicators, because they require communication not only about scientific processes and understanding, but also about how that understanding affects and interacts with the systems that society is made from: religions, beliefs, employment, and ideological communities. If people were able to easily take in scientific information and make rational decisions based on that information, science communication and science education would not need to be fields separate from science itself. However, the way we as individuals understand the world does not necessarily fit with the rigors of scientific research—we understand the world from a single point of view, through our own personal experiences and the experiences of those around us, and make decisions based on what we perceive to be the best possible option (e.g. Whitmarsh, 2008). We take into consideration not what makes the most rational sense on a global scale, but what fits with the expectations we have for ourselves, and the expectations our communities have for us. For these reasons, it makes sense for people to engage together (i.e. in groups) with these issues, have conversations, ask questions, and think about not only the scientific side of complex socio-scientific challenges, but also engage with the social side—what systems interact to turn issues into problems? What parts

of society are contributing to those problems? Are economic forces at play? Are religious systems of understanding in conflict with scientific ways of understanding phenomena? Can these understandings be reconciled in decision-making? By engaging with the full range of questions, over time, people will be better equipped to face these complex challenges and make decisions that are hopefully in the best interest not only of their immediate surroundings, but of the full range of impacted beings and environments.

Another particularly complex socio-scientific issue that has social, economic, and environmental impacts is genetic engineering. In its most general sense, genetic engineering is simply the manipulation of living things in ways that are useful and heritable—for example, one could consider the process of selective breeding for desirable traits in garden vegetables to be genetic engineering. When a gardener notices that a tomato plant is particularly prolific, and that another produces delicious tomatoes, and breeds those two plants together, they are hoping to blend these two desirable traits into an even better tomato plant in the future. That plant's genetics will have been, in a sense, engineered to suit the needs of the gardener. However, when people read or hear the phrase "genetic engineering" they rarely think of backyard gardeners pollinating tomato plants. They think of biologists wearing white coats and using high-tech laboratory equipment to add and subtract specific genes from an organism's DNA—for example, to make a tomato that doesn't become overripe (e.g. Krieger et al., 2008), an Atlantic salmon that grows three times faster than its wild counterpart (e.g. Ledford, 2013), or corn that doesn't die even when exposed to powerful herbicides (e.g. Gaines, Allee & Ratliff, 2001). All of these laboratory-based examples of genetic engineering are "transgenic" organisms—they have been manipulated to have and express DNA from a different organism using laboratory methods, as opposed to cross-breeding or hybridization. To some, these scientific innovations are major

breakthroughs in food production, with positive outcomes for feeding the growing global population. To others, the environmental impacts of monoculture-based, large-scale farming are dangerous outcomes of using genetically engineered biotechnologies. At the same time, the idea of changing the genetic makeup of various organisms in a laboratory can be viscerally unappealing to those who see the benefits and the dangers of biotechnology, and to those who have yet to engage in trying to understand its broader impacts.

In Pittsburgh, there are places people can go and organizations people can find to learn more about climate change and how it impacts our city and community. Many of these places are museums, such as the natural history museum, science center, zoo, and botanical garden. Other places are temporary engagement opportunities, such as the festivals I described in chapter four. Where might people go to learn more about genetic engineering? This could be a topic for a place like a science center—in fact, the Exploratorium in San Francisco has a number of exhibits about the science of genetic engineering and how it is performed (for example, exhibits titled "Glowing Worms" and "Microscope Imaging Station: Zebrafish Embryos" both feature transgenic organisms that have Green Fluorescent Protein [GFP] from jellyfish added to their DNA). It could also be addressed at a natural history museum, where issues such as human population and species extinction have been addressed (for example, Carnegie Museum of Natural History's "Population Impact" and extinct bird specimens on display). There is, in fact, an entire floor of exhibition space dedicated to genetic engineering at the Naturalis, the main natural history museum in the Netherlands. However, there are very few places where people are encouraged to engage in thinking and conversations about not only the science of genetic engineering, but also the cultural drivers, drawbacks, and ethical questions associated with these practices. One example of an informal learning environment where these activities are

encouraged is a small museum that I have collaborated to build and maintain since 2010: the Center for PostNatural History.

The Center for PostNatural History is dedicated to the advancement of knowledge relating to the complex interplay between culture, nature, and biotechnology. Its mission is to acquire, interpret, and provide access to a collection of living, preserved, and documented organisms of postnatural origin. We define the term "postnatural" as a descriptor for living organisms that have been intentionally and heritably altered by human interventions, through processes of selective breeding, domestication, genetic engineering, and synthetic biology (Pell & Allen, 2015). By focusing not only on the scientific processes and understanding that enable these interventions, but including the stories of the human needs, fears, and desires that inspire the manipulation of other living organisms, the Center for PostNatural History provides an informal learning environment where people can engage with all sides of the socio-scientific issue of genetic engineering. Aesthetically, the Center for PostNatural History represents itself as an intimate, object-oriented space, in the vein of traditional 19th century cabinets of curiosity and early 20th century natural history museums. This aesthetic stands in contrast with the content of the exhibits, which are usually organisms unlikely to be featured in museums of natural history, because they are considered "too common" or "uninteresting" due to their separation by human means from their "wild" counterparts: farm animals, rodents, and bacteria, for example. These sorts of organisms are no longer representatives of the vast biodiversity of earth's creatures, because their evolutionary paths have been intervened upon by human needs, fears, and desires.

These contrasts seem to help inspire our visitors to pay closer attention to these everyday organisms that are usually overlooked. Many visitors enter looking for an answer to the question, "Is genetic engineering good or bad?" Thankfully, even though the Center for PostNatural

History does not answer that question, they are rarely disappointed. Because genetic engineering is another hot-button issue in science and society today, much like climate change, most people expect a place dedicated to such organisms to take a position. However, by focusing on the history of human manipulation of living things since the dawn of domestication approximately 10,000 years ago (Pell & Allen, 2015), the question of whether something so embedded in human culture could be "good or bad" becomes less important, while seeking to understand the nuance of different examples and the changes to these practices and the contexts in which they are applied becomes the focus. When people ask me whether these practices are good or bad, I talk about the good and the bad things that have taken place as a result of these practices: without genetic engineering, many of the medical advances that have been made in the last half-century would not have happened (e.g. Zhu, Zheng, Lee, Homer & Elias, 2002). At the same time, genetically engineered crops have not increased crop yields or provided major economic advantages for farmers as some might assume (e.g. McBride & El-Osta, 2002). Our exhibits focus on the organisms, and why they were created, under what contexts, and for whose benefit. I have taken to referring to this stance as one of "radical neutrality": we at the Center for PostNatural History intentionally refuse to make claims as to whether a particular specimen or practice is good or bad, instead offering its history as a venue through which our visitors can start to decide for themselves if they think something is good, bad, or otherwise.

The stance of radical neutrality has allowed the center to establish itself as a resource for people seeking information, and a place where teachers, researchers, activists, and families can go and potentially meet others who have had different experiences and hold different opinions than they do. Since our exhibits tell the human and scientific histories of modified organisms, and our visitors understand that these histories contain more than simply declarations of their

value, conversations among scientists who use genetic engineering in their research, activists who believe that manipulation of living things shouldn't take place in laboratories, and parents whose children are interested in biology can happen.

As I have researched and studied the learning that happens over processes of change around informal climate change education, I have also applied what I have learned to the exhibit design and philosophy we use at the Center for PostNatural History. When visitors enter the center through our front door, we greet them and briefly describe what we mean by postnatural. They are then invited to browse the imagery in our front gallery, and enter the main exhibit hall, a learner-centered, free choice environment. This is an intentional choice to promote learner autonomy among our visitors—just as we promoted learner autonomy for middle school field trip students in chapter two. As noted above, we have designed our space to encourage conversation by including short histories of our specimens and exhibits that are viewable from several angles. Because the contextualizing information is provided in either written label form or in user-activated audio-recordings, visitors can share their thoughts with one another and start conversations easily. The center's exhibition hall also includes an extensive library related to postnatural history, which is available for casual visitors and researchers to engage in deep investigation. Additionally, an informed representative of the center is available for questions and conversations whenever the center is open. It is through these conversations that we have learned what the most common questions are about our specimens. As a rule, we do not claim to know all of the answers about our collection—when we invite people into the exhibits, we tell them "If you have any questions, I'll do my best". We encourage our visitors to take pictures, make notes, and stay in contact with us over email or by returning to the center to continue the conversations that we start—and they do.

In chapter three, three principles for learning to respond to a complex socio-scientific issue are explained in-depth. There, I apply them specifically to the challenge of climate change. They are not only applicable to learning about climate change, however. By incorporating participation, relevance, and interconnectedness into how we think about the exhibits, presentations, designs, and conversations we have about the Center for PostNatural History, we have experienced and witnessed inspiring engagement with the topic with professional biologists, activists, and families—especially families with children who are curious about biology and science. This engagement is demonstrated through the follow-up emails, conversations, and return visits that people make to the center. Many museums, small and large, can frame their exhibitions as participatory learning experiences. The Center for PostNatural History is not a deeply interactive exhibition space—our exhibits are mostly objects under spotlights with short histories associated with them. However, when we conceptualize participation as active engagement with content, and particularly participation in conversations, we can see that the learning that happens at the center happens in conversations, both with other visitors, and with those of us who represent the center.

Free-choice learning environments like museums allow learners to identify what is relevant to them. At the Center for PostNatural History, visitors come because they stumbled upon it, heard about it on the radio, or read about it in a magazine or on a website. Some people are interested in a particular specimen, or have a hobby or professional interest in biology. Lots of people are interested in food. By designing for learner autonomy, we give visitors the opportunity to find what's relevant to them, and they seek out further relevant information from us and from other sources after they leave the center, and sometimes when they come back for another visit.

By broadening the notion of genetic engineering to the whole category of postnatural (intentionally and heritably altered by people) we can have a bigger conversation about the relationship that people have with the rest of the living world. One of the best examples is the first: the first domesticated organism is widely believed to be the dog (*Canis lupus domesticus*). Archeologists have found evidence of domesticated dogs that date back approximately 10,000 years (Leonard et al., 2002). Today, dogs have the biggest size variation within a single species of any animal on earth—because of people's influence. People selectively bred the smallest dogs to get "teacup Chihuahuas" and selectively bred the biggest dogs to create Great Danes and Saint Bernards. Given the cultural importance of dogs around the world, it would be difficult to argue that dogs are "bad" (though there are some bad individual dogs, of course) as a whole. At the same time, dogs are the result of human manipulation—if humans hadn't intervened in the evolutionary history of dogs by selectively breeding the friendliest ones and selecting out the ones that didn't get along with people, they'd still be wolves. Dogs and people are interconnected in many ways—people hunt with dogs, use dogs for security, entertainment, therapy, and social status. Bringing "companion species" (Haraway, 2003) into the conversation about genetic engineering, gives our visitors an opportunity to see how human culture is interconnected with all the different organisms that people have manipulated for our own purposes. After we think about dogs in this way, the leap to thinking about corn, and laboratory mice, and transgenic mosquitoes as representations of human culture becomes less difficult—and it becomes more difficult to see the entire landscape of the postnatural as something to be relegated to a single opinion of "bad" or "good".

The Center for PostNatural History is one organization that has yet to find a network like the one described in chapter four. However, at the center, we are able to capitalize on one of the

features described in chapter four as part of our exhibit design and communication philosophy: boundary objects. At the center, we focus on bringing specimens or representations of specimens of postnatural origin and interest into the spotlight. Many genetically modified or engineered organisms that are referred to by activists and in news stories are not easily visible or available for people to observe in real life, in living or in preserved form. By making these organisms available for the general public to see and discuss, the center provides a boundary object for visitors with different perspectives and backgrounds to build their conversations around. One important example at the Center for PostNatural History is the aquarium of GloFish™, among the first exhibits visitors see when they enter the main exhibit hall. They are important because they are one of our few living exhibits, and because they are one of the few visually (and stunningly) genetically modified organisms in our collection. The GloFish™ serve as a boundary object for conversations because they are charismatic, they are an example of one of the most commonly used transgenes (GFP), and they are an example of a human manipulation for purely aesthetic purposes. Visitors are able to engage with these fish as boundary objects because they are cute and fun to observe, and they can ask questions about the origins of the fish, and decide for themselves if they think this manipulation was a good or a bad idea. The matter is not settled: GloFish™ are only legally allowed to be sold in the United States (but not in California). Some people love them, and some people think they are sad, but everybody is able to better understand the phenomenon of genetically engineered fish with the help of this living, glowing boundary object.

There are a number of complex socio-scientific issues to which the principles for inquiry-based learning and learning to respond could be useful, and in my future work I hope to be able to continue to test hypotheses and design informal learning environments and experiments that

leverage informal learning for the overall improvement of our human existence. By understanding learning as an ongoing process of change, we can better design and implement networks that capitalize on the power of collegial relationships, motivated collaboration, and deep, participatory investigation in difficult challenges. I started my PhD journey with the belief that learning was the key to solving our most complex social problems, which are the interacting and interrelated challenges of environmental degradation and social inequality. Over the course of my research as a graduate student, I still believe that learning is an important feature, but my conception of what learning actually is has changed in a deep and meaningful way. Learning is not simply communicating facts, ideas, or processes to people with the assumption that they will use that information in a way that makes sense to the communicator. Learning is the ongoing process of change that we actively engage in when we care about a problem that requires our whole communities and societies to act in order to solve it.

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