Partnerships in the Nanoscale Informal Science Education Network (NISE Net):

A study of partnerships between university scientists and museum professionals

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Left cover photo: Hodges, G. (2015). NISE Network Sciencenter, Ithaca, NY. Retrieved from https://nisenet.smugmug.com/NanoDays/2015-OMSI-NanoDays/i-G3LKHLR. Access date May 27, 2015.

Right cover photo: Akers, C. (2012). NISE Network Science Museum of Minnesota NanoDays. Retrieved from https://nisenet.smugmug.com/NanoDays/SMM-NanoDays-2012/i-W7VDkqF. Access date May 27, 2015.

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Executive Summary

This report describes findings from SRI's research on Nanoscale Informal Science Education Network (NISE Net)-supported partnerships between university scientists and museum professionals to educate the public about nano-scale science, engineering, and technology ("nano"). These kinds of partnerships have the potential to leverage the expertise of both scientists and museum professionals, which is a particularly important benefit in an area as complex and as difficult to distill for public consumption as nano. At the same time, cultural differences between the institutions of universities and museums make for particular challenges that scientists and museum professionals must work through in order to gain the benefits of collaborating. This report focuses on understanding how scientists and museum professionals deal with these challenges, and how they ultimately leverage each other's perspectives and expertise when they collaborate to produce products intended to educate the public about nano.

Research questions for this study focus on

1. the key aspects of museum-scientist partnerships that support their collaborative efforts,
2. how products they create are used in communicating nano to the public, and
3. whether and how these partnerships build capacity for those who participate.

Over a period of five years, from 2010 to 2015, SRI researchers collected and analyzed data from a number of different sources, including interviews, observations of meetings and events, reviews of NISE Net artifacts, and reviews of other NISE Net research and evaluation reports. We collected data on the Nano & Society workgroup, which we reported on elsewhere (Lundh, Stanford, & Shear, 2014); conducted numerous interviews with university scientists and museum professionals about their partnerships; observed NanoDays events and interviewed event facilitators; attended meetings and conducted interviews related to other general Network activities; and gathered data related to the development of the NISE Net content map.

Findings

What key aspects of museum-scientist partnerships support their collaborative efforts to produce educational materials and strategies for communication with the public? University scientists and museum professionals in the partnerships we studied experienced strikingly similar challenges related to the different ways in which they and their respective institutions understand and practice science and public outreach. These challenges related to language use, basic assumptions of what science and public outreach mean, and the different values and practices in their respective professional fields. For example, while the science profession tends to give primacy to the complexity of science and the rigor of science practices, museum professionals are primarily concerned with the pedagogical challenges of engaging museum visitors. Collaborators attributed their success in overcoming these challenges—so that they could successfully leverage each other's strength—to several factors in particular: having shared or overlapping authentic goals, building personal trust, and cultivating strong and personal relationships. While these were not the only important factors, they stood out as particularly important in these types of partnerships, possibly because of the complex content they were grappling with, as compared the formal agreements and policies that have been highlighted in studies of other types of partnerships that universities and museums engage in. The complexity of the topic placed a particular burden on scientists to understand the nuances of how to distill the essential elements of nano and make them accessible to diverse museum audiences; and on museum professionals, many of whom did not have science backgrounds, to grapple with unfamiliar and challenging content. Being open to critique and reflecting on their own assumptions was key; personal trust and strong relationships were therefore essential enablers of the process.

How do scientists and museum professionals use these products to communicate complex scientific ideas to the public? To address this question, we focused specifically on NanoDays events. Here, we found that the NanoDays materials and the facilitation of activities combined science and public outreach in powerful ways to engage audiences in conversations about nano. In particular, the materials and supports for facilitators were typically designed to:

1. Initiate visitors in ways that are fun and generate interest;
2. Connect with visitors' own experiences; and
3. Generate conversations that facilitators can build on to engage visitors with the more scientific nano content in ways that are accessible and relatable.

While activities were grounded in the complex ideas of nanoscience, the products leveraged knowhow from both expert scientists and expertise in public engagement to introduce the science to visitors in ways that were both accessible and compelling.

How do museum-scientist partnerships build the capacity of each partner? Interviews with university scientists and museum professionals suggested that capacity building was primarily tied to the personal connections collaborators made with each other. While we saw some evidence of potential capacity building at the institutional level, most capacity building took the form of professional learning and growth for individual collaborators. Scientists, for example, gained increased understanding of and appreciation for public outreach, and reported that the collaboration had increased the quality of their outreach and put them in positions to disseminate insights about public outreach to others in their institutions. Conversely, museum professionals gained a deeper understanding of the science and of the perspectives of scientists, which in some cases was influencing the scope and ambitions for future exhibits and events in their institutions. Both types of collaborators also reported an increase in social capital, having made connections to a broader network of individuals and institutions that they said they could call on for help and advice in their work. Some of these connections also led to additional grants and partnerships.

Conclusion

Our study has pointed to the importance of NISE Net's long-term efforts to connect individuals and institutions around the challenge of communicating nano, while demonstrating some of the positive outcomes of these efforts. The challenges with cross-institutional partnerships highlighted in this study are common to many other types of partnerships that universities and museums engage in. Partnerships of various kinds have a long history in these institutions; our findings contribute to a more recently emerging literature focused specifically on what makes partnerships successful. While many other studies have pointed to the more formal aspects of how to structure informal learning science partnerships well, this study focuses on the importance of the informal, personal aspects of how individuals work together to overcome the cultural differences between their institutions and professional fields. While the complexity of nano presented the partnerships in our study with particular challenges, which raised the stakes for collaborators to be particularly open to reflecting on their own understandings, values, and practices, we believe that the emphasis on goals, trust, and relationships carry over to many other types of partnerships as well.

Introduction

When the Nanoscale Informal Science Education Network (NISE Net) began to form ten years ago, its creators envisioned mutually beneficial partnerships between research universities and science museums. Each institution would bring expertise and insight to the other, in order to build capacity to educate the general public about nanoscale science, engineering, and technology ("nano").

At the same time, the scientists and museum professionals that participated in the early shaping of NISE Net were aware that the benefits they could bring each other also came with challenges. They perceived a cultural divide between these two types of institutions; professionals in each institution thought differently about how to portray science and what effective communication about science with the public looks like. The challenges associated with these differences were particularly salient with regard to nano, since the scale and complexity of nano-related phenomena and nanoscale engineering and technology is particularly difficult for many people to grasp (Crone, 2008).

Over the years, NISE Net has supported a variety of different partnerships between these two types of institutions. A great number of research and evaluation efforts have been conducted on various initiatives, with foci on exhibits and products, professional development and other capacity building efforts, impacts on audiences and institutions, and evaluations of the overall NISE Network. SRI's role has been to contribute to this body of research by looking at the kinds of partnerships where university scientists and museum professionals work very closely together on a specific project (e.g., developing a product or approach), highlighting what is unique about such close collaborations in an area as complex as nano.

To this end, SRI's research has looked at a number of different partnerships to understand how museum professionals and university scientists work together to collaborate on nano-related public outreach initiatives of different kinds, how NISE Net products and strategies developed collaboratively are used to communicate nano to the public, and how these partnerships build capacity for collaborators. Central to this research has been the effort to understand how collaborators bridge the divide between the two institutional cultures in order to leverage their respective perspectives, expertise, and experiences.

The word "partner" is in common use across NISE Net, and the Network has brought together scientists and museum professionals in a variety of configurations. For purposes of SRI's research, we define "partnerships" as very specific collaborations between university scientists and museum professionals who combine their expertise to create a product or service, or to achieve some other kind of specific outcome. Our use of the word "partnership" throughout this report reflects this specific definition. We also occasionally refer to university scientists and museum professionals who participate in such partnerships as "collaborators." Consistent with common usage within NISE Net, we continue to refer to individuals and institutions who participate in NISE Net more generally or in other capacities as "partners."

The type of partnerships featured in this report reflects some of NISE Net's key goals. NISE Net's mission was to create synergy among participating institutions and to increase capacity to communicate nano to the public through connectedness:

> The Nanoscale Informal Science Education Network (NISE Net) is a national community of researchers and informal science educators dedicated to fostering public awareness, engagement, and understanding of nanoscale science, engineering, and technology ("About," n.d.)

The complex nature of nano science, engineering, and technology renders these areas of research and development difficult to communicate in a meaningful way to the public. History has also cautioned about how science can become misunderstood in the public eye, as was the case with genetically modified foods in Europe and—to a lesser extent—in the United States (Sandler & Kay, 2006). NISE Net's task was to figure out how to translate nano into ideas and activities that non-experts could engage with, meaningfully and constructively. In particular, NISE Net articulated four challenges (St. John, et al., 2009a): What to teach and how to teach it; how to design informal learning resources for nanoeducation; how to develop institutional capacity and readiness; and how to develop and manage a national supportive network. Bringing together university scientists with science museum professionals was one means of building capacity to address these challenges.

NISE Net has built and maintained the Network to achieve these goals over a period of nearly a decade. The breadth, scale, and duration of NISE Net provide an unprecedented opportunity to learn about a type of collaborative partnership that has not yet been studied in much detail. SRI's focus on NISE Net's partnerships between university scientists and museum professionals, what makes them work, and how they build capacity is driven by the need in the field to understand these questions better. Much research has been done on other kinds of partnerships, such as between universities and schools and ISE institutions and schools (Coburn, Penuel, & Geil, 2013). The present study builds on this research and adds a needed perspective.

Research Background

The types of partnerships that are the focus of this study are part of a broader tradition of cross-institutional partnerships that universities and museums have engaged in for a long time. While the partnerships NISE Net has generated are different in many ways from these other partnerships, we believe it is important to situate them in this larger context. This section, while not exhaustive, describes some of these differences and commonalities.

Many scientists and museum professionals have great interest in learning how to better engage the public, and have in recent years put more time and resources to this effort (Chittenden, 2011). There are a lot of benefits for institutions to collaborate (Mattessich & Monsey, 1992). Collaboration benefits both university scientists and museum professionals, by helping scientists disseminate and advocate for their work and by helping museum professionals build more science content expertise (Crone, 2008; Crone & Koch, 2006). From the university perspective, communicating more with the public has been reflected in the National Science Foundation's 1997 requirement that projects include Broader Impacts Criterion (BIC) statements, about how the research project would impact science, education, and society. But there has also been resistance to BIC requirements (Holbrook, 2005), for a number of reasons. University scientists don't always believe that they are trained to do educational outreach. Many are concerned that the BIC requirement slows down research. It is also thought that researchers who are early in their careers are unduly burdened by this requirement, in particular since educational outreach does not help them with tenure (Alpert, 2009). There can also be misalignment between expertise in science, which is specific to a specialized field, and educational outreach skills, which require more general knowledge (Davis, Horn, & Sherin, 2013). Deep expertise can even become a barrier to being able to understand the gaps in knowledge members of the public have (Nathan, Koedinger, & Alibali, 2001; Nathan & Petrosino, 2003).

Creating partnerships between university scientists and museum professionals to leverage each other's strengths and expertise has emerged as an important way for both types of professionals (and institutions) to better address these goals of effectively communicating complex science to the public (Alpert, 2009; Crone & Koch, 2006). However, very little research has been conducted on the *nature* of partnerships between university scientists and museums. While there are some studies of specific collaborations (Hopwood, Berry, & Ambrose, 2013; Payne et al., 2005; Saxman, Gupta, & Steinberg, 2010; Selvakumar & Storksdieck, 2013), even these are few and far in between.

Notable examples of other types of partnerships that universities and museums increasingly engage in include partnerships between universities and schools or school districts, between museums and schools or school districts, and between museums and afterschool programs. Partnerships between schools or school districts and museums have, for example, focused on getting elementary and preschool children more access to science and connecting with the community outside of the school environment (Kelly, Stetson, & Powell-Mikel, 2002); and on improving and broadening formal science learning in schools (Stocklmayer, Rennie, & Gilbert, 2010). Partnerships between science museums and afterschool programs tend to help bring access to science expertise for afterschool staff, who usually lack science expertise and backgrounds (Afterschool Alliance, 2013); and, vice versa, provide resources to university scientists such as professional development for public outreach (Selvakumar & Storksdieck, 2013).

While museums and universities have engaged in these and other types of partnerships for a long time, studies on what makes them work are emerging only in recent years. In terms of partnerships between university researchers and school districts, for example, there are currently almost no organized means for potential partners to learn and develop the skills to build successful partnerships; rather it's been a learn-as-you-go process (Coburn, Penuel, & Geil, 2013).

Successful research-practice partnerships between university researchers and school districts have been defined as long-term, focused on problems of practice, committed to mutualism, using intentional strategies to foster partnership, and producing original analyses (Coburn et al., 2013). These types of partnerships can also carry the potential for political tensions (Firestone & Fisler, 2002; Gupta, Adams, Kisiel, & Dewitt, 2010). Other challenges in research-practice partnerships between researchers and school districts include cultural differences between institutions, developing trust, maintaining mutualism, and balancing local relevancy with scalability (Coburn et al., 2013).

Successful partnerships of all types are driven by the potential to leverage each institution's strengths; this is true in partnerships between universities and science museums (Hopwood et al., 2013; Payne et al., 2005; Saxman et al., 2010; Selvakumar & Storksdieck, 2013), between science museums and afterschool programs (Afterschool Alliance, 2013), and when scientists partner with museums to do outreach, reaching broader audiences (Steinberg, 2004). It's been observed that partnerships between universities and school districts are successful when they are "grounded in a sense of respectful, reflective equity among the participants" (Bickel & Hattrup, 1995, p. 58). In museum-university partnerships, shared investment of time and clarity regarding roles and responsibilities have been emphasized as important (Owen & Visscher, 2015).

Since its inception, NISE Net has been working to address the issue of how to build partnerships between researchers and museum professionals. One example was the Research Center — Informal Science Education Partnerships (RISE), which NISE Net created in 2008 (Alpert, 2009). The RISE model embodies the principle of combining informal science educators' expertise in how to engage the public with the science expertise of university researchers. While strengthening the overall resource base for meeting the BIC criteria, it also affords science museums additional content and resources for their work (Bell, 2009). NISE Net's implementation of the model constitutes one attempt to institutionalize the close collaboration between STEM researchers and museums across the nation (Alpert, 2009).

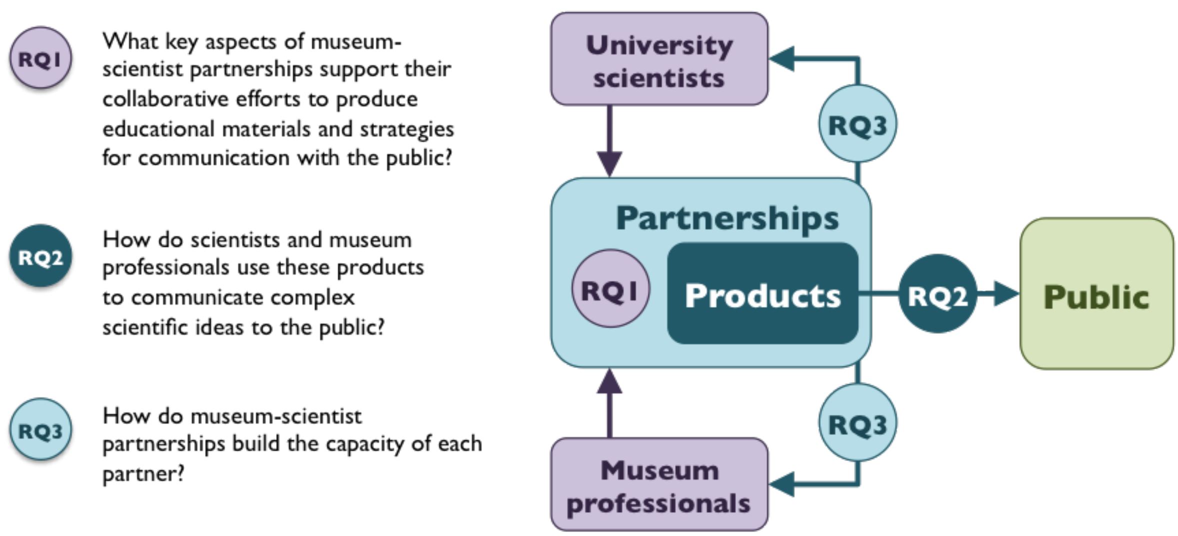
As a very large-scale and sustained experiment into partnerships between researchers and museum professionals, NISE Net offers an unprecedented opportunity to extend the research on partnerships and dive deeply into the characteristics of this particular type of partnership, looking at what makes them work and what makes them unique.

Research Questions

The study was guided by three research questions:

1. What key aspects of museum-scientist partnerships support their collaborative efforts to produce educational materials and strategies for communication with the public?
2. How do scientists and museum professionals use these products to communicate complex scientific ideas to the public?
3. How do museum-scientist partnerships build the capacity of each collaborator?

Figure 1. Research questions and how they conceptually relate to one another



Research Question 1 addresses the ways in which scientists and museum professionals collaborated as they came together to develop products (educational materials, approaches, and support for facilitators) that were the means for communicating nano to the public. We focus here on the key ingredients that appear to underlie the success of specific partnership activities. These characteristics have implications for several types of collaborations in other settings, including other partnerships between groups of different expertise that must all be leveraged to create a high-quality product, and in a complex and undefined scientific space. In Research Question 2, we look at how scientists and museum professionals actually use the products created through partnerships in their work with the public. Finally, in Research Question 3, we look at how these partnerships between scientists and museum professionals built capacity for collaborators to communicate with and educate the public about nano, both for individuals and their respective institutions, with a particular focus on capacities that have persisted beyond the funded partnerships.

Methods

Much of the foundational work with museum and university partnerships was established and conducted in years 1-5 (2005-2010) of NISE Net, prior to the inception of this research project in year 6. In addition to examining key relevant documents produced by NISE Net during that time frame, we agreed with NISE Net leadership on an opportunistic approach to the research: we looked at the status of the various network activities when we began our work in Year 6, and selected areas where we expected data collection to yield important insights. This final report is based primarily on the following strands of data collection and analysis:

Nano & Society workgroup: When we began our work in Year 6 (beginning in late 2010), many NISE Net materials and programs had already been developed. The Nano & Society (N&S) workgroup was still at an early stage, affording us the opportunity to watch a key partnership evolve. An SRI researcher was "embedded," to the extent practically possible, with the N&S team. She attended key workgroup meetings (both in-person and virtual) over an 1.5-year period, collected a wide array of documents and other artifacts, conducted semi-structured interviews with key participants, and either participated in debrief meetings from each pilot session or collected notes from each of the four workshop sessions. The findings from this partnership have been reported elsewhere (Lundh, Stanford, & Shear, 2014), and insights from the partnership have grounded the framing and analysis of the present report.

NanoDays Events: This important NISE Net activity was a key source of data for observing the use of NISE Net products in Research Question 2. Data collection included observations of NanoDays activities and semi-structured interviews with scientists and museum professionals who facilitated the activities. In spring 2014 we observed NanoDays events at Lawrence Hall of Science in Berkeley, California, and Stanford University, California, to inform the development of observation instruments and interview protocols. In the spring of 2015 we visited three NanoDays events: California Academy of Sciences in San Francisco, California Science Center in Los Angeles, and Santa Barbara Museum of Natural History. We observed each of the nano stations and conducted short interviews with all of the facilitators of the observed activities as well as the science coordinators at two of the sites. In total, we observed 26 separate activity facilitations representing 17 different NanoDays activities, for a total of 36 individual observations. A total of 30 interviews with facilitators (mostly scientists) were conducted.

Interviews with NISE Net participants. We developed several interview protocols and used them to conduct interviews with museum professionals and university scientists. The interviews were conducted in person, when possible, or over the phone. We conducted a total of 17 interviews with museum professionals and 5 interviews with university scientists. Some of these interviews were conducted within the context of the Nano & Society workgroup; others brought in additional perspectives. Additional interviews were based on revised protocols and were conducted in early 2015 to supplement our dataset.

General network activities and reports. This study is also based on attendance at or notes from additional NISE Net sub-awardee, project-wide, and local Regional Hub meetings and presentations, as well as collected artifacts and relevant content in NISE Net reports from other research and evaluation groups.

Content map development: Most of the work to create the content map took place in Years 4 and 5, prior to SRI's involvement in NISE Net. Because this collaboration was very important to the progress of NISE Net, one SRI researcher attended the teleconference meetings held twice a month during the last several months of the content mapping effort. We collected notes of the exchanges during that time and conducted an analysis based on a large compendium of collected artifacts (including meeting notes and agendas, textual and visual iterations of the content map, etc.) and interviews with two of the workgroup leaders. Insights from these data have helped frame and inform other data collection and analysis.

Data in the areas described above were collected in NISE Net Years 6-9, and the Nano & Society Case Study was produced in Year 9. Figure 2 aligns the research questions with the datasets that are contributing most directly to the analysis of each question.

All data were analyzed using a grounded theory approach (Corbin & Strauss, 1990; Glaser, 1992; Glaser & Strauss, 1967), in which individual and team-based processes were established to review the various streams of data with respect to each hypothesis and to surface, substantiate, vet, and refine themes.

Table 1: Research questions and associated datasets

Research Questions	Datasets
1. What key aspects of museum-scientist partnerships support their collaborative efforts to produce educational materials and strategies for communication with the public?	• Nano & Society Case Study • Content Map Analysis • General Network Activities • Final Year Interviews
2. How do scientists and museum professionals use these products to communicate complex scientific ideas to the public?	• NanoDays Observations & Interviews • General Network Activities
3. How do museum-scientist partnerships build the capacity of each collaborator?	• Nano & Society Case Study • NanoDays Observations & Interviews • General Network Activities • Final Year Interviews

Study Context

SRI's partnership study was focused on partnerships perceived as successful, to provide the opportunity to gather data on the various factors that museum professionals and university scientists believed contributed to healthy and productive collaborations. We collected data about partnerships from university scientists and museum professionals interviewed as part of the general Network activities data collection, as well as in focused partnership interviews. To identify candidate partnerships for the latter, SRI consulted with several key people in NISE Net leadership and others that SRI had contacted and interviewed before. Several potential candidates for interviews were identified. Many interviewees reported on numerous partnerships they had participated in, including those that had been unsuccessful in the past. Below is a list of some notable examples of successful partnerships and the outcomes of those partnerships.

Table 2: Types of partnerships and outcomes they focused on

Type of Partnership	Outcomes of partnership
Nano & Society Workgroup: University and several museums and science centers	Materials and strategies for communicating social and ethical issues in nano
NISE Net Content Map Workgroup: Professionals from several universities and museums	NISE Net Content Map
Children's museum and several local universities	NanoDays, afterschool program, mobile nano program for students lacking access to transportation, Saturday morning family program, Friday science labs for homeschoolers, NISE Net mini-exhibit, NISE Net mini grants for various small exhibits
Children's museum and a local university	NanoDays, training for scientists, summer camp program components, vetting and developing activities
Science Museum and a local university	Development to expand nano mini exhibit and other exhibits, scientists presenting at museum
Science Museum and a local university	NanoDays, demonstrations of science equipment, field science activities, developed facilities for doing science experiments in museum
Natural history museum and local university	NISE Net mini grants, youth teacher youth program, training for scientists to do public outreach
Hands-on science museum and university in a different state	Training of museum staff, development of nano activities, providing materials for museum, training of university scientists, development of nano-themed interactive space
Children's museum and two local universities, nano-related industries, and other museums	NanoDays, development of exhibits and activities, mobile program for rural schools, science labs for homeschoolers, family programs, NISE Net mini exhibits, several NISE Net mini grants, nano activities for children with special needs, presentations by scientists

Findings

This report organizes the study's findings according to the three research questions. First, we describe the findings of how university scientists and museum professionals work together, with particular attention to the specific challenges posed by the complexity of nanoscale science, engineering, and technology, the efforts collaborators made to understand each other's institutions and practices, and the key ingredients of doing so successfully. We then describe findings from the study of the NanoDays events for the second research question. Here, we focus on how the NanoDays activities and facilitation supported the engagement of the public with nano in ways that reflected some of the challenges and successes of partnerships between scientists and museum professionals. Finally, in our presentation of the findings for the third research question, we describe how many of the capacity building impacts of partnerships were related to the informal, inter-personal dynamics of the successful partnerships themselves.

Research Question 1

What key aspects of museum-scientist partnerships support their collaborative efforts to produce educational materials and strategies for communication with the public?

INTRODUCTION

Based on research to date on NISE Net, participating institutions have succeeded in an impressive list of accomplishments, including defining the conceptual space of nanoscale science, engineering and technology in ways that can be communicated to various publics, building collaborative practices, creating products and strategies for engaging publics in conversations and activities related to complex science content, and building capacity for participating individuals and institutions (NISE Network, 2014). Many of these outcomes were achieved through work that was accomplished by partnerships between museum professionals and university scientists. SRI's first task was to understand how museum professionals and scientists collaborate successfully and what the ingredients of such successful collaborations are.

When compared to, for example, partnerships between universities and school districts, where the differences between the institutional cultures of research versus administering a school system are potentially quite large (Bickel & Hattrup, 1995), it would seem that science museums and scientists, with their mutual focus on science and shared interest in communicating that science to the public, would have initial solid ground to build on. But their respective understanding of science and public outreach are quite different, particularly in the area of nano. Our findings on how they collaborate together relate to this particular challenge.

FINDINGS

Across the variety of ways in which partnerships between scientists and museum professionals functioned, the participants we interviewed all talked about the challenge of learning to understand each other's perspectives, practices, and expertise. There were three key things related to this challenge that made these partnerships successful—shared goals, trust, and positive relationships.

It is also important to note that all the partnerships that are discussed in this report were supported financially, either through NISE Net or some other grants, or received material supports (such as NanoDays kits). In addition, most of the interviewees reported on partnerships that had built on previous partnerships, which meant that collaborators had learned over time what works and what doesn't. This was evident, for example, in the history of the N&S workgroup. Given the unusually long time period the NISE Net grant provided for, collaborators in this partnership were able to draw from and build from a range of past experiences. Some collaborators mentioned that there had been a number of attempts to form partnerships in the past that had floundered. But they were able to learn from these experiences and improve their approach. The N&S partnership owed its success in some part to these past experiences, which would not have been possible within a shorter grant or without the persistence of collaborators in making it work.

> *"It took time, but it also took sufficient development of a relationship with the partners, so that we began to understand what we could do together with both our visions of what needed to be done."*
>
> – Museum Professional

Museum professionals and university scientists were initially faced with the challenges—often very personal—of understanding each other

Collaborators talked about the challenges around different understandings of science and public outreach that stemmed from their respective organizational cultures and the roles that each institution plays in its field. Scientists operate deep within the complexities of science and they see public outreach as a way to communicate that complexity. Scientists also place a lot of value on scientific rigor and accuracy. Museum professionals, on the other hand, operate deep in the pedagogical space of public outreach. When they think about the science, they look for the aspects of the science content that have the potential to interest and engage members of the public. They place a lot of value on the visitor's experience given the particular constraints around his or her encounter with the science.

These differences were often apparent in the early stages of partnerships. Many interviewees reported feelings of frustration when they first began working together, because they felt that there was a lack of understanding of their respective fields, or even in some cases that their collaborators held simplistic or inaccurate ideas about either the science or about how to communicate with the public. For example, in one partnership discussed by a scientist, the feedback about their proposed activities from the museum was very harsh. Scientists were very concerned with precision in science language use, sometimes expressing that museum professionals were being "sloppy" with the language. The issue of language was also a marker of the differences in underlying conceptual understandings of the science and what was important to communicate. In one example, where scientists and museum professionals worked together to create

> *"Language is always the barrier in these kind of collaborations."*
>
> – Scientist

> *"…it was in another language. [The scientists] wanted to maintain all the language, details, and it took a little time convincing them that it would not work with our audience. We want to make sure it's still accurate, but it has to be at a level…where a lot of people could understand it."*
>
> – Museum Professional

signage for a nano-themed interactive space, the university scientists wanted to keep lots of details, as a way to ensure the science content was accurately represented. In another partnership, scientists took exception to the lack of citations in a museum-produced slide presentation, and scientists also reportedly found it unfathomable that people in leadership positions at the museum did not have science backgrounds.

> *"They look at programs we have created, but they think that all this stuff is really elementary."*
>
> – Museum Professional

Museum professionals reported feeling frustrated about scientists initially not taking seriously the pedagogical complexity of the museum space. They felt that they had to guide the scientists to step out of their preoccupations with the science itself to have a deeper understanding of what communication with the public means. Museum professionals also reported feeling uncomfortable about the science. One museum professional from a children's museum described how her staff felt particularly challenged about the content, since the museum was not a science center. Her staff had no science background and felt fearful of working with a topic with which they were unfamiliar.

Table 3 summarizes some of the main differences between university scientists and museum professionals. While the table is necessarily an oversimplification, it represents some of the more commonly-recognized contrasts between the institutional cultures in which university scientists and museum professionals typically work.

Table 3: Differences between university scientists and museum professionals

University Scientists	Museum Professionals
Priorities: Scientific accuracy	*Priorities:* Real-world relevance
Typical audience: Mostly peer academics or young adult college students, academically qualified, enrolled in a program of learning	*Typical audience:* All ages, widely varied scientific backgrounds, self-selected according to interest
Vocabulary: Lexicon of precise technical language	*Vocabulary:* Accessible to appeal to wide audiences
Writing style: Prescriptive with citations	*Writing style:* Colorful and inviting
Career incentives: Primacy of publications	*Career incentives:* Primacy of public satisfaction

Successful collaborations began with shared or complementary goals that were authentic

Successful partnerships were built around two main purposes; to do public outreach to bring nano to the public and to leverage each other's expertise. Museum professionals often pointed to a concern about some university scientists who would take a "check-the-box" approach to initiating partnerships, where the motivation was driven more by the need to comply with the broader impacts requirements of grant applications versus the intention to forge intentional and invested partnerships. The opposite of the "check-the-box" approach to partnerships was to base partnerships on shared or complementary goals, which was indeed one of the key things that collaborators said were essential to a successful partnership.

University scientists in successful partnerships were highly motivated to communicate their science to the public. For example, in one partnership, the department chair at the university championed bringing science to the public. Another partnership was driven by a grad student's vision for a nano-themed interactive space concept that he wanted to see implemented nationwide. The museum wanted to upgrade this particular outdoor space and this provided a great opportunity to do so.

Museum professionals saw the expertise that scientists brought as essential to improving their own efforts to communicate with the public. One museum professional said they valued gaining access to science, research, and expertise, which legitimized their work.

Even when university scientists and museum professionals were focused on their own, individual goals, which happened to overlap, they were clear about the complementarity of what they each brought to the partnership. For example, scientists knew that museum professionals understood the museum audience, while museum professionals knew that scientists brought deep insight into the science.

Personal trust was key for collaborators to understand each other and leverage each other's expertise

The shared goals of bringing nano to the public and leveraging each other's mutual expertise provided the necessary premise for successful partnerships. To reach these goals, however, university scientists and museum professionals first needed to address the challenges posed by differences in values, practices, and perspectives. The most important first step in doing so, interviewees reported, was to establish trust. Trust is fundamental to all partnerships, but has been described in different ways. For example, in partnerships between researchers and school districts, establishing trust has been discussed in terms of formal agreements, such as establishing accountability to commitments, having a "no surprises" policy, and transparency, among other things (Coburn et al., 2013). In contrast, the university scientists and museum professionals we interviewed talked about the need for deeply personal trust between individual collaborators.

> *"If the researcher only wants us on the grant for show, the partnership will not be successful. If they want to educate the public, however…any time that we can share those bigger goals there's more enthusiasm and more willingness to work together."*
>
> – Museum Professional

> *"There is this sort of constant complaint about the 11th hour phone call from a PI who wants a letter of support for a thing that he will never do."*
>
> – Scientist

> *"Scientists there are hard pressed to communicate their science, constantly looking for way to increase that outreach, so they were thrilled to participate. That became the motivation."*
>
> – Museum Professional

> *"We also found it fun and exciting, getting to work with the biggest science museums in the country. That was like a dream. Who doesn't love to get to know those people? A lot of scientists, the reason they came into science was because of museums… and now to go back and be part of that is awesome, a dream come true kind of thing. This is really cool!"*
>
> – Scientist

To leverage each other's expertise and perspectives, collaborators said they needed to build an understanding of each other, listen to each other's critique and feedback, and learn from each other's perspectives, expertise and experiences. This took personal trust in each other. A scientist who was involved in a number of early NISE Net partnerships said that the in-person connection and the trust that it enabled helped collaborators get past difficulties and reconcile their differences in terms of how to represent the science. One museum professional said that trust is important, because it enabled partners to give critical feedback.

Collaborators said that the establishment of trust emerged over time from seeing and experiencing each other's work. One scientist said that seeing how the quality of the materials museum professionals developed with them increased dramatically built trust. One museum professional said that appreciating each other's work and learning from each other was important as well. Another museum professional emphasized the importance of taking each other's work seriously. When collaborators had established a level of trust, they were able to understand each other's perspectives, listen to critique, and integrate each other's strengths into the product or strategy that they were working on. One museum professional said that it was essential for collaborators "to think outside the box" and another museum professional said that having established trust meant "having partners on both sides that are willing to experiment, go beyond the boundaries, and taking a general interest that made it work."

Trust emerged from the cultivation of strong, personal relationships

The emergence of trust was driven by the simultaneous cultivation of good, personal relationships. One scientist, when asked to describe what contributed most to a successful partnership said, "to know each other, developing relationships and trust, spending social time together and having fun together."

When talking about the benefits of relationships, collaborators sometimes suggested that there was something serendipitous about the good relationships they developed. In these cases they had developed such strong, personal relationships that it was hard for them to articulate how the process that led to them could be formally replicated.

> *"Trust is the main thing."*
>
> – Scientist

> *"We worked together long enough to trust the competency which each other has."*
>
> – Scientist

> *"Sometimes if they still don't feel comfortable, [we] will invite them when there is another scientist, so they can see what it looks like."*
>
> – Museum Professional

> *"They saw that the scientists were willing to take chances, listen to their perspective."*
>
> – Scientist

> *"It wasn't until the second phase of NISE Net work that I got to know personally some people who were involved in the field, that's when there was a shift in my mind, about these places being conveners for conversations about science in America."*
>
> – Scientist

> *"If you are friends with your collaborators the work goes so much better"*
>
> – Scientist

> *"Not sure if the magic between our facilities can be replicated…It was fortuitous that we found each other."*
>
> – Museum Professional

Even so, as collaborators described the actual process of cultivating good relationships, they commonly focused on the importance of good communication, in particular in-person communication. In one partnership, where scientists had ambitious ideas for creating a museum exhibit that simulated an atomic force microscope, they discovered when implementing a number of prototypes of the exhibit that young museum visitors failed to comprehend its meaning. As scientists grappled with the problem, it was the constant and intensive communication with museum professionals about the ideas and problems that helped them improve through multiple iterations and in the process cultivating strong relationships between the collaborators. In another partnership, where two university faculty worked with a children's museum to develop a nano exhibit focused on the nose as nano sensor, the museum professional leading the partnership emphasized the importance of responsiveness in their communications.

While all partnerships in our sample relied primarily on communication via phone and email, they all began with—and sometimes continued to incorporate—face-to-face meetings, which were deemed essential for developing a good relationship. One scientist also said that once he and his museum counterparts knew how to communicate with each other, they "spent a lot of time together, worked hard, and had fun." A museum professional, who worked with university scientists on a nano-themed interactive space, said that of crucial importance for the relationship was "having those structured meetings scheduled, scheduling the next meeting, making sure the relationship is not dying on the vine."

> *"I don't know how to put my finger on why this is. We have developed a friendship with each other. We are able to draw on each other's strengths."*
>
> – Scientist

> *"The whole key is just communication, face-to-face, occasionally email, but it seems to work much better if you work face-to-face."*
>
> – Museum Professional

> *"If I have questions, if I see a cool article I share it. We keep in touch throughout the year"*
>
> – Museum Professional

> *"They were really responsive to our questions. Answered in a very timely manner. I call that out, because in other collaborations that's not always the case."*
>
> – Museum Professional

For some, partnership is like dating

This children's museum has engaged in a several partnerships over the years. The museum professional interviewed said that the museum first encountered NISE Net at a workshop at a children's museum conference. After her interest was piqued about nano, she wanted to incorporate nano into the museum's exhibits. However, she was worried and fearful about not having a science background, so she began emailing people for help. This led to several new partnerships, some of which led to yet other ones. Having experienced both successes and failures over the years, she began to create a structure that emphasized the importance of shared goals and mutual commitment, giving collaborators time to learn about and understand each other, and to iteratively build toward increasing commitment and larger projects. She described the partnership structure she set up as "dating":

- **Start by talking to each other:** Have a conversation to see if you want to partner with each other
- **Learn about each other's institutions:** Have potential partners visit the museum, explain what they do and that it has to be a mutually beneficial arrangement
- **Make goals and visions explicit:** Make a list of what the partners would want in a perfect world. Don't contact right away, but wait to see if they send the list and express interest in working with museum. She said they were interested in people who were truly motivated to work with them
- **Negotiate:** When the potential partner has emailed back, negotiate back and forth. Write up what each collaborator wants and what they can mutually agree to.
- **Create an agreement:** Draft a partnership agreement that outlines what each partner will do, what data to use, activities to engage in, and so on. Partners iterate back and forth until they come to a final agreement.
- **Assign a point person:** The partner is assigned to a museum staff member who becomes the main point of contact, keeps them up to date, and handles schedules and other organizational tasks.
- **Start small:** Even with the most enthusiastic partners, it's best to ask the partner to start with one or two smaller collaboration efforts in the first year, to see how they like it, and "if we want to continue dating we will."
- **Emphasize communication:** Send a thank you note and have a conversation about everyone's experiences. "Communication and honesty is very important."
- **Go bigger if it makes sense:** In the second year, they might move on to more work, depending on the health of the partnership and everyone's motivation and commitment. "I only ask what I need, and I don't let them over promise. I try to keep it very real, would rather have something small that is real."
- **Partnership is a personal, intimate relationship:** "We treat them like they are part of our staff. So they feel like they are part of something, not like they are guests. They are part of the family. If they feel part of it, and they feel comfortable teaching us, having back and forth with us, we become interdependent instead of dependent."

Nano and Society Workgroup

The Nano and Society workgroup (N&S) was a partnership between university scientists and museum professionals at several science museums and science centers around the U.S. Partners in the N&S workgroup collaborated to create workshops to educate museum staff and educational products to engage the public about the Social and Ethical Issues (SEI)[1] of nanoscale science, engineering, and technology (nano).

Partners were able to leverage mutual expertise and knowledge through the building of positive relationships that were created and cultivated through several face-to-face meetings that transitioned to frequent communication over phone and email. The partnership resulted in many ideas that were translated into real products for training museum staff to engage museum audiences. Other important factors that contributed to a successful collaboration were shared goals and institutional support.

As a result of the numerous and involved conversations between scientists and museum professionals, in which they continually examined and challenged each other, there was a conceptual shift with regard to how collaborators thought about SEI, to focus more on visitors' ideas and values, which resulted in a slightly different content focus than had been originally conceived, along with specific strategies for how to engage the visiting public and how to train staff.

1. Society and Ethical Issues as a title for this work later changed to Nano & Society (N & S).

Research Question 2

How do scientists and museum professionals use these products to communicate complex scientific ideas to the public?

INTRODUCTION

Our second research question addresses how products that are created with input from both scientists and museum professionals are used with the public. We focus this exploration on the NanoDays events, which has been one of the most important and influential initiatives of NISE Net. NanoDays is an annual nano-focused festival hosted by various institutions throughout the U.S. Over 250 different science museums, research centers, and universities participate in hosting NanoDays events each year. NanoDays has been considered a "catalyst" for institutions to get more involved in nano education (Pattison, Benne, & LeComte-Hinely, 2011). One evaluation report stated that, "For many institutions new to nanoscience education, NanoDays serves as the 'gateway' activity to further interaction with the NISE Net" (St. John et al., 2009e).

Facilitators at NanoDays events use materials from the NanoDays kits to engage the public directly in conversations and interactions around nano. The NanoDays kits are important examples of how products and strategies produced by scientists and museum professionals engage and educate the public, and how it builds capacity for the institutions that host NanoDays. While most of the materials in the NanoDays kits were produced—or adopted from existing materials—by museum professionals, university scientists provided science expert feedback and sometimes played other roles. The NanoDays events thus represent some of the modes of collaboration in which university scientists and museum professionals contributed to the creation of public outreach materials and approaches.

A number of studies have already focused on NanoDays. These include looking at who uses NanoDays and what ideas get communicated (Alexander et al., 2012); institutions' interest in and attitudes about NanoDays (Nelson, 2009); the delivery and reach of NanoDays (Pattison et al., 2011); quality, value and relevance of NanoDays to institutions (Rosino, Cardiel, Beyer, Cohn, & McCarthy, 2013; St. John et al., 2009e); the online impacts of NanoDays (Scheufele & Su, 2014); the role of NanoDays within NISE Net's overall strategy (St. John et al., 2009e); and the public impacts and influences of NanoDays (Biser & Benne, 2009; Pattison et al., 2011; Svarovsky, Tranby, Cardiel, Auster, & Bequette, 2014). SRI's research contributes to this work by adding a focus on how NanoDays events showcase the outcomes of the work of partnerships, and *how* scientists and museum professionals communicate with the public through NanoDays events.

Findings

When university scientists and museum professionals worked together, their main goal was to take complex science and present it to the public in ways that are accessible. Every activity created for use in NanoDays has been reviewed by at least one scientist for accuracy and by museum professionals for appropriate wording and interest level for their audiences, in addition to going through a universal design review that ensures accessibility and inclusiveness for multiple and diverse audiences. In other words, the concept of bridging the science-centered culture of the university and the pedagogy-centered culture of the museum was also embodied in the products and strategies that they worked together to create.

Across the activities the communication goals of the NanoDays materials reflected one of the key issues that both NISE Net at large and the partnerships we studied have grappled with: How to distill the essence of nano science and technology ideas into nuggets of insight that the public can reasonably engage with and learn from. For example, one activity involved children playing with sand and water. The facilitator of the activity engaged young visitors in an examination about what happens to water when dropped on sand. The visitors watched and talked about the water sinking into the sand. The facilitator then showed them a different batch of sand covered with nanoparticles. The visitors expressed delighted surprise when they observed that the water would bead up and roll off the sand. The facilitator leveraged the visitors' experience to engage them in a conversation about how, even though the nano-coating is not visible, the sand interacts differently with the water, and was able to guide visitors through the conversation toward an introduction to scientific ideas of hydrophobic and hydrophilic properties.

Based on our observations of NanoDays activities and interviews with facilitators about their experiences interacting with visitors, we identified three key aspects of how the materials and facilitation together were implemented across the activities that we observed in ways that made the science accessible and leveraged visitors' own ideas and experiences: 1. Initiating visitors; 2. Connecting to visitors' knowledge and experiences; and 3. Engaging visitors with nano content.

Initiating visitors: First, the NanoDays activities initiated visitors into the activity through demonstrations, artifacts, or prompts from the facilitators that were intended to be fun, generate interest, and/or resonate with visitors' own experiences. For example, when facilitators introduced the Hydrogel activity, which demonstrates how a material's nanoscale structure affects how it behaves on the macroscale, they had visitors pour a small amount of sodium polyacrylate powder into a cup of water. The way the water/power mix almost instantly turned into a beady, gelatinous mass was so surprising to visitors that they were immediately engaged; they wanted to see it again, stirred and explored the material, and began to ask questions and be open to questions from facilitators about potential applications (such as diapers). One young visitor exclaimed, when stirring the hydrogel, "I want to keep this forever!" Another said, "I want to put it in my bathtub!"

Connecting to visitors' knowledge and experiences: Second, activities connected to visitors' knowledge and experiences. For example, they drew analogies or elicited ideas and experiences that many people are familiar with, both to engage visitors and to help them relate to the ideas in the activity. One activity built on the idea that magnets and magnetism are familiar to most people. The Ferrofluid activity conveys the idea that a fluid containing nano-sized particles of magnetite can behave as either a fluid or a solid, the latter when the substance interacts with a magnet. In one example, two visitors thought the solid-acting ferrofluid looked like black sand and began offering ideas about where they had seen other examples of black sand. They talked about a recent trip to Hawaii, and the facilitator explained that those sands are of volcanic origin and don't contain magnetite. In the course of this conversation, one of the visitors asked why this was related to nano, which provided the facilitator an opportunity to explain the ferrofluid's behavior at the nanoscale, and also point to applications of this phenomenon, such as using it when printing money as a counterfeiting measure.

Engaging visitors with nano content: Third, activities engaged visitors with nano content. After visitors had become interested, and started asking questions as a result of the hands-on activities and the prompts and questions from the facilitators, the activities transitioned to introduce visitors to the underlying science. The facilitator used artifacts and/or built on visitors' engagement and ideas to begin to ask visitors about the science, and helped explain the phenomena showcased through the hands-on activities. For example, there were several demonstrations built around the way that light interacts with nanoscale materials in surprising ways (Stained-Glass Windows, Thin Films, Invisibility, etc.). The big idea in science is that light comes in wavelengths that are seen as a color, depending on the size of the wavelength. When materials interact with wavelengths of light, they absorb certain wavelengths and reflect others. In these different activities, visitors were provided opportunities to observe how the different materials' sizes impact the colors of the materials. Visitors played with materials and watched the effects. As they did so, they asked questions and engaged facilitators in conversations. For example, one girl doing the Thin Films activity asked, "how can it have all the different colors if the film is the same thickness?" which prompted the facilitator to talk about how the thickness varies at the nanoscale, which is too small to see. He then elaborated on how that thickness interacts with light of different wavelengths, using the figures in the guide to help illustrate.

Thin Films at The California Academy of Sciences

The goal of this activity was to communicate how materials at the nanoscale interact with light to produce effects that can be seen in everyday experience and that can be harnessed into different technological applications. In the activity, the facilitator first initiated a conversation, based on some simple materials. Visitors were then asked to place a strip of paper in water, followed by a drop of nail polish, on the water surface. The nail polish immediately turned into a thin film on the water surface, creating shimmering colors. Visitors pulled the strip of paper out of the water, which took with it the thin film, so that they could examine it further. The facilitator had materials to show additional examples of the shimmering colors phenomenon. He also had a laminated sheet with images and information about the underlying science to explain the phenomenon.

Visitor initiation: To initiate visitors into the activity, the facilitator showed solar panels or feathers to visitors and asked them what they noticed. In one instance, visitors noted that these had different colors and that they were shiny. The facilitator asked them why they were shiny. One visitor responded by talking about differences in light. The facilitator made a connection to applications of the phenomenon and said there are technologies that take advantage of this, like solar cells. He showed them the sheet of solar panels and asked them what they noticed about them, why there were different colors. To introduce the activity, he said they would find out by doing the activity why these materials generate different colors. The visitors' entry point into the activity was thus framed both by the science and by some of the visitors' own ideas.

Connecting to visitors' knowledge and experiences: After the visitors had pulled out the paper and thin film, they had a discussion in which the facilitator asked visitors what other examples they had seen of the phenomenon of shimmering colors. The visitors brought up several examples, such as butterflies and beetles, and in particular noted that they had seen it with gasoline or oil on the surface of water. In this way, visitors made a conceptual connection between what they saw in the activity, the science phenomenon modeled, and their own experiences.

Engaging visitors with nano: After the visitors had observed and discussed the phenomenon of shimmering colors, the facilitator, following the laminated guide, explained how it was related to the nature of light. For example, one facilitator asked, "have you heard about light having different colors?" In some instances, the facilitator asked visitors to think about why the colors were different. Visitors offered different explanations, such as "because…maybe the black paper brings out colors?" or "maybe they have more room to space out?"

The facilitator went on to explain how light is a wave, and that different wavelengths result in different colors. Some visitors were familiar with this idea, in particular youth in middle and high school grades. The facilitator then explained that the thickness of the film interacts with the light waves, and said, "The red and yellow have far space and blue and purple are close together."

The facilitator pointed to illustrations in the guide that show how light with different wave lengths interacts with the material, and how the thickness of the materials impacts different wavelengths of light differently. He also used a dry sponge to show where light of different wavelengths would reflect off or be absorbed by the materials in different ways.

The facilitator then asked visitors to think about the phenomenon they had seen, and to try to explain the relationship between material thickness, light, and the color shifts they had observed.

When one girl wondered about the thickness of the film, the facilitator responded, "we can't see it, because it's nano size." A few minutes later at the end of the activity, the girl built on this idea when she said, "Just because we can't see the wind, it doesn't mean it doesn't exist!"

Research Question 3

How do museum-scientist partnerships build the capacity of each partner?

INTRODUCTION

Increasing capacity in the field of informal science education to educate the public about nano is one of the key goals of NISE Net. A number of outreach and professional development efforts have been implemented over the years toward this goal. A NISE Net evaluation found in 2009 that NISE Net participants have reported significant increases in their ability to take leadership for nanoscience education, interest in doing so, and confidence in explaining and advocating for NISE Net's work (St. John et al., 2009), in particular as a result of participating in NISE Net-supported workshops and other professional development initiatives (Pattison, et al.Benne, & LeComte-Hinely, 2011). There has also been some evidence suggesting that collaborations between museums and universities increase capacity for individuals who participate (Pattison et al., 2011). In SRI's study, we also examined whether and how close partnerships between museums and universities result in increased capacity for individuals and institutions.

FINDINGS

Capacity building was closely tied to the personal, rather than institutional, dimensions of partnerships: In our focus on how partnerships contribute to building capacity for collaborators, the main thread that emerged in collaborators' descriptions of capacity building was how it related to the insights collaborators had into each other's fields, areas of expertise, and institutions. Having bridged differences and found ways to listen to and learn from each other, scientists and museum professionals were able to strengthen their own professional practices. For scientists, this meant having a deeper appreciation for the value that museum professionals bring to the design of exhibits and activities that engage visitors with science. It also meant gaining a better appreciation for both the opportunities and the limits of the pedagogical space. Museum professionals reported that their eyes had been opened to an area of science they were previously unfamiliar with, but also more broadly that they gained an appreciation for the science content that many who facilitate encounters with visitors are often not entirely comfortable with. In other words, the types of capacity building that collaborators reported on tended to be tied to the personal, informal nature of the partnerships more than institutional aspects. Some collaborators did report institutional capacity building as well, as will be described in a later section.

University scientists grew professionally in terms of increased understanding and appreciation of public outreach

The university scientists reported on a number of outcomes they believe will outlive the partnerships. In particular, they reported that they and their colleagues personally and professionally had changed their attitudes toward outreach and that the quality of their outreach efforts was stronger as a result of what they had learned in the partnership. One university scientist described how his ability to present his professional work to a museum audience had

> *"Level of quality of our outreach has gone way, way up. Because museum people will not accept poor quality, poor design, poor graphics."*
>
> – Scientist

improved, and that the quality of his outreach efforts had improved. He also said that the personal impact for him as a professional was profound: "I would say that for me it's been career defining." Another scientist said that the partnership raised the quality of her university department's work tremendously, saying that she learned the value and need for a cross-disciplinary team, that it broadened the horizon of what she thinks is possible to do, and helped her "grow up" professionally.

One of the scientists also pointed to potential plans as a result of their experiences in the partnership to educate additional staff about their insights, and the possibility of diffusing insights across other disciplines in the university as well, which would be a way to institutionalize the personal capacity building that took place.

> *"I'm starting a whole series of mixers in the fall to help them understand what science centers are interested in and how to engage with them in interesting ways, to show them how they can benefit even if they are just checking the box… So people from anthropology, social sciences, applied ethics and bio ethics, etc., getting them to think about communicating with the public."*
>
> – Scientist

Museum professionals grew professionally in terms of deeper understanding of the science and the perspectives of scientists

Museum professionals talked about how working with scientists and their institutions provided them access to expertise, equipment, materials, and knowledgeable people to help with facilitation of activities. For example, one museum professional said that they would not have had access to equipment without the partnership with the university. Another museum professional said that they could not have created the nano-themed interactive space without the partnership with the university scientists.

> *"We are at a point where we are comfortable with this topic, our whole staff is."*
>
> – Museum Professional

> *"It helped me see the complexity of a network approach, and the sustainability of a network. [It] has given me pause as a professional."*
>
> – Museum Professional

Beyond these immediate benefits, museum professionals described how the deeper understanding of the science and the perspectives that scientists brought to the partnerships were significant contributions to their personal and professional growth. For them personally, they reported, they and their colleagues who were involved in the partnership gained better understanding of the science, more confidence in creating and facilitating exhibits and activities, and broader horizons in terms of their thinking about the potentials of the museum space.

> *"I don't think we would be where we are, thinking the way we are. We have been fertilized like crazy by NISE Net…Doing things in totally different ways that you had never thought of before. I never knew about nano technology, and now that I do it's very interesting."*
>
> – Museum Professional

While museum professionals primarily emphasized the individual, professional benefits of the partnerships, they did point to some ways in which the partnerships had led to growth in institutional capacities as well. One museum professional, who had orchestrated multiple partnerships as part of her participation in NISE Net, said that these experiences had influenced the practices at the museum as a whole. For example, the museum adapted training approaches to other areas, all museum staff members shifted their thinking about possibilities for science activities in the museum, and they continue to build on lesson plans that were developed.

One simple way in which the partnership increased institutional capacity was the materials that they developed together that would continue to benefit the museum regardless of the individuals involved. Museum professionals also said that ideas and concepts from the developed materials influenced other materials and exhibits in the museum.

When asked to describe other capacity-building impacts at the institutional level, museum professionals described such impacts in less concrete ways than when they talked about individual impacts. For example, one museum professional said, "Capacity building in the museum has certainly improved. It's complex, evolving so rapidly, and I think that the capacity building for tackling the topic, in my imagination should have improved dramatically across these institutions." Another museum professional said that the partnership (which she described interchangeably as "NISE Net") changed how they do business in the museum and also that the NISE Net trainings are transferable to other work they do. She said the biggest impact is that "NISE Net has improved us as an organization."

> *"Having these resources that I can go back to again and again, that also is a huge asset."*
>
> – Museum Professional

> *"I was a champion in our organization. Those champions move on to other things, and does somebody else pick it up to be an advocate?...How do you institutionalize the work?"*
>
> – Museum Professional

> *"Most of our partners don't leave. Sometimes because of staffing and budget cuts, they still stay involved in advisory roles, then reappear when things change."*
>
> – Museum Professional

Some museum professionals also noted that even with strong motivations for partners to continue collaborating or building new partnerships, they would need additional funding to realize those ambitions. But even without funding, they would sometimes do what they could to maintain the relationships and support each other in whatever ways they could. One museum professional also pointed to the issue of ideas and initiatives for partnerships being vested in particular individuals, which meant that as staff turns over, the ideas and initiatives turn over as well.

Scientists and museum professionals benefitted from increased social capital

Both university scientists and museum professionals reported capacity building in terms of social capital. Social capital refers to the way that relationships to other people and institutions can help individuals gain access to knowledge, skills, and other resources that enable them to do things they might otherwise not be able to do, or do in the same way (Coleman, 1988). Many aspects of NISE Net follow a social capital framework. As NISE Net evaluations have found, the NISE Net's

> *"We'll continue to ask questions, I'll continue to work with that relationship as long as I possibly can, to keep it fresh. It has been great."*
>
> – Museum Professional

> *"Having a national network of trusted collaborators has many barely tangible but very significant advantages."*
>
> – Scientist

regional hub structure, for example, has provided individual members more mechanisms for connecting with others within NISE Net (St. John et al., 2009c), as well as simply having a "bank of people to be able to call upon" to support them in their work (St. John et al., 2009b, p. 11). Almost all of the interviewees mentioned having made connections that they believed would endure beyond the partnerships, connecting collaborators with individuals and institutions across the country. One university scientist said she had seen a "huge address book increase." She said that she has "contacts in museums across the country now" that she calls to ask for help, and that one new contact had led to a presentation in South America and another led to learning about a new project.

> *"The relationships will continue."*
>
> – Scientist

> *"We now have these partners that we call up when we have questions; the connections are invaluable."*
>
> – Museum Professional

Increased social capital can lead to new grants and partnerships

Some of the museum professionals said that the partnerships had led to additional—or at least potential—grants and partnerships. For example, one museum professional said that their NISE Net partnership led to a new partnership with a nano-focused research center at a university. One of the museum professionals, whose institution had engaged in several partnerships with university scientists, described a range of new opportunities for partnerships and funding that had emerged as a result of the connections she and her colleagues had made. A number of the museum professionals interviewed reported on partnerships that were still ongoing or that ended relatively recently, which meant that additional opportunities were not yet apparent. But for those that did report such opportunities, the common thread was that they emerged as a result of the personal connections the collaborators had made.

While none of the scientists mentioned any concrete ways in which the partnerships had led to additional partnerships or grants, one of them said there was a potential for some: "I think we have a bunch in the hopper right now which will answer that question." In addition, one of the museum professionals opined that the partnership would be advantageous for their university partners in their grant writing process, because the experiences were "the sort of things that federal grant agencies are looking for more and more."

> *"Our partnership has helped us get other grant funding, for example a state grant."*
>
> – Museum Professional

> *"And we have recently, because of connections to NISE Net and doing nano tech, formed partnerships with industry that uses nano tech. Also we formed, because of the NanoDays, partnerships with other museums, such as the Smithsonian Electronics Museum."*
>
> – Museum Professional

> *"Every grant we have right now is the result of the NISE Net work… We were more local before that… The scientists now see us a viable resource or partnership in our area. Before we called them, now they call us to partner with them on grants."*
>
> – Museum Professional

Children's Museum partnership that made science possible

This children's museum, like many other museums, first included nano in its programming with the NanoDays kits. The museum's first partnership was with a local university, which provided scientists who facilitated activities during NanoDays. The partners expanded their collaboration to include nano in the museum's summer camp programs, during which scientists visited once a week to facilitate activities from the NanoDays kits. The partnership grew further, to include trainings for scientists to do play facilitation with children and youth. As the partnership grew, staff from the museum visited the science labs at the university and accompanied them at field sites.

The museum professional said that because it's a children's museum, none of the staff are STEM experts, so they rely heavily on their scientist partners to develop or vet activities. "We are a children's museum, the folks here are not STEM experts, so we rely on our partners…We bring the play expertise and they bring science expertise."

The museum's partnership with the university led to further collaboration on several NISE Net mini grants and also led to a state university grant to support their STEM programming. Staff have continued to model other activities and exhibits in the museum on what they have learned in their NISE Net partnerships, and they have made numerous professional connections that they continue to rely on for support.

The museum professional said that without the partnerships, providing science and other STEM-related activities and exhibits would not have been possible. In particular, she said, "without the support of NISE Net I don't think nano would be a focus; we would probably spend more time on other content areas."

Conclusion

This study sought to understand how university scientists and museum professionals collaborate in close partnerships, how they use products of some of those collaborations, and how their collaboration builds capacity. The partnerships SRI investigated have faced challenges common to other cross-institutional partnerships, in particular with regard to differences in organizational and professional cultures and different orientations toward and perspectives on the problems they have partnered to solve. For these particular NISE Net partnerships those problems have been related to understanding of science and of how to communicate science to the public, a problem made particularly salient for an area as complex as nano.

Our findings with regard to how university scientists and museum professionals collaborate successfully focused on the importance of high quality personal relationships between collaborators, the importance of communication, and the inter-personal trust that resulted—as well as sharing authentic goals. These aspects enabled collaborators to listen to each other, hear and offer critique, understand each other's practices and institutions, and ultimately be able to leverage each other's expertise and perspectives for meeting the outcomes they were committed to.

These findings complement other kinds of recommendations and findings that focus more on the organizational aspects of how to create successful partnerships involving museums and/or universities. NISE Net's own partnership guide points to the importance of "partnership stewardship," which emphasizes, for example, having designated liaisons, accountability to what partners have committed to doing, mutual efforts to help represent each partner well, time management and other forms of courtesy, cultivating cross-cultural insight and understanding, as well as some other structural and organizational aspects (Alpert, 2013). Organizational aspects have been emphasized in other types of partnerships as well. For example, in partnerships between universities and K-12 schools, recommendations include anticipating challenges, devoting resources to the partnership, weighing the pros and cons of starting small or big (Coburn et al., 2013). Others have pointed to the need for champions in each institution (Carr, 2003), careful planning, establishing clear guidelines, thorough time management (Bobick & Hornby, 2013), and having a third party facilitator (Somerville, 2013).

Having strong relationships and trusting each other meant that partners were able to find ways to distill the best of both the science and the public outreach areas that they each represented and advocated for. This common ground between science and outreach pedagogy was also the key insight for our second research question, which focused on NanoDays events. Here, we saw evidence of how the museum professionals and university scientists that developed the materials and facilitation guides for the NanoDays activities had succeeded in creating museum visitor experiences that built key science and science application ideas into powerful pedagogical approaches, leveraging the expertise from both scientists and museum professionals.

Finally, the focus on inter-personal dynamics was also key to capacity building for partners. In other words, the main capacity building university scientists and museum professionals reported was linked to what they personally learned in their interactions with their collaborators; insights into each other's fields and increased capacity to do public outreach and to incorporate science into exhibits and activities.

NISE Net's efforts to build and support partnerships between university scientists and museum professionals have been an important component of the Network's approach to informal science education. These partnerships have enabled scientists to connect with the general public in ways not possible before. While this has been an important resource for scientists to meet their broader impacts requirements of their grants, it has also facilitated their own interests in sharing and advocating for their research. Museum professionals have gained access to more science expertise and opportunities to create exhibits and educational outreach efforts in their institutions. They have learned about a field many were not familiar with before. Both scientists and museum professionals have learned from each other, and built capacity in a number of ways. NISE Net's various initiatives have meant an increase in social capital for participating partners, with the result that they have gained access to more expertise, materials, and personal relationships, as well as opportunities to form additional relationships and partnerships benefitting their professional work.

While NISE Net has demonstrated the positive impacts of collaborations between university scientists and museum professionals, this type of partnership has not been studied much in the research-to-practice field. Gaining greater insights into the critical ingredients in how such partnerships work, as well as how they contribute to capacity building for individuals and institutions will therefore be an important contribution to the ISE field. At the same time, we hope the final outcomes of our research effort will provide important feedback to NISE Net, as the Network continues to build successful partnerships and educate others on how to do so.

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