SRI Education

Nano and Society

Case Study of a Research-to-Practice Partnership between University Scientists and Museum Professionals

July 2014

Patrik Lundh
Tina Stanford
Linda Shear

Developed for the NISE Network with funding from the National Science Foundation under Grant number 0940143, for Grant subaward #4549-SRI-06. Any opinions, findings, and conclusions or recommendations expressed in this product are those of the authors and do not necessarily reflect the views of the Foundation.

SRI Education

SRI Education researchers address complex issues in education, learning, and human services. Multidisciplinary teams of education policy researchers, sociologists, psychologists, political scientists, statisticians, and others study education policy issues and develop research-based solutions to improve productivity and quality of life at home and school and in the workplace.

Suggested Citation:
Lundh, P., Stanford, T., Shear, L. (2014). *Nano and Society: Case Study of a Research-to-Practice Partnership between University Scientists and Museum Professionals.* Menlo Park, CA: SRI International.

Contents

Executive Summary

This is a case study of how complex and potentially controversial science ideas are translated for the public through a research-to-practice partnership between university scientists and museum professionals, collaborating to address a problem of educational practice, with mutual benefits (Coburn, et al., 2013). The study explored how collaborators leveraged each other's expertise and priorities in order 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). The collaboration was part of the NSF-funded Nanoscale Informal Science Education Network (NISE Net), which has been working for the past nine years to educate the public about nano.

University social scientists from The Center for Nanotechnology in Society at Arizona State University (CNS-ASU) and museum professionals participating in NISE Net started the collaborative work with specific roles and assumptions that were negotiated over time. Through mutual recognition of each other's expertise and knowledge, the building of positive relationships, and the experience of learning and being challenged, the discussions resulted in workable ideas that were translated into real products for training museum staff to engage museum audiences.

We report on two main areas of findings. First, we address the question of what contributed to making the Nano & Society (N&S) team a successful collaboration. Primary keys to success were shared goals, institutional support, and the building of positive relationships between collaborators. The positive aspects of these emergent relationships helped the collaborators to leverage each other's expertise and different perspectives on the task they were addressing.

Our second area of findings addresses the question of how the collaboration shaped the creation of products for training museum staff to engage museum audiences about SEI in nano. Over the course of the collaboration there was a conceptual shift with regard to how collaborators thought about SEI, 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. Each of these conversations and outcomes was shaped by input from both scientists (a physical scientist and a social scientist) and museum professionals.

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

The collaboration began with an SEI framework focused on ethical issues and the need to weigh the risks and benefits of nanotechnology. N&S team members early on began to rethink this framework. The university scientists contributed an initial set of ten important ideas, and the museum professionals drew attention to the potentials and constraints of the museum learning environment, including visitors' experiences and staff capacity. Incorporating the different perspectives and expertise of both scientists and museum professionals, the participants shifted their thinking about SEI, focusing more on the visitors' own ideas and values about nanotechnology. Alongside this shift, workshop providers tried to balance a focus on nanotechnology with illustrations of familiar technologies. General technology examples were important for engaging workshop participants based on their own experiences with technology, in particular as they were asked to consider technology-related issues. These priorities were particularly strongly reflected in the products for training museum educators, including materials to help museum staff to have conversations with visitors that bring together the science expertise of the institution with the values and ideas of visitors.

This case study suggests some ideas for what makes research-to-practice partnerships work, both for scientists who are considering ways to translate complex and potentially controversial science ideas for the public and for museum professionals who are interested in seeking more expert resources to inform their public engagement work. It shows the value of combining these two perspectives and also sheds light on some of the key features of a successful collaboration.

Introduction

Nanoscale science, engineering, and technology (nano) is a highly complex interdisciplinary and multidisciplinary area with applications that involve notable benefits to society but also a number of implications – known as well as little explored - for ethics, human health, and environmental safety. The small scale of nanosized objects is particularly challenging in terms of engaging and educating the general public. Since the nanoscale is beyond human perception, it is more abstract than other science ideas on display in museums. The complexity and abstract nature of nano in turn means that engaging the public in conversations about the social and ethical issues around nanoscale science and its applications is no less challenging. NISE Net, with funding from the National Science Foundation, organized a collaborative effort between university scientists and museum professionals to tackle these challenges.

Communicating the Social and Ethical Issues (SEI) in nano was one of four areas of the content map, which defines the key areas of NISE Net's work. NISE Net had already developed exhibits, staff training modules, and educational materials for its three other areas. The Nano and Society (N&S) team was created in order to develop a set of workshops that also included products for museum exhibits, educational outreach, and staff training for communicating SEI in nano.

While bringing nano and society to the public was a goal shared by university scientists and museum professionals alike, the process of getting from goals to actionable products for training museum educators involved many months of creative productivity and negotiation among N&S members. Members were challenged to consider the numerous pitfalls of raising complex, highly technical, and controversial science issues with the public, and the numerous pedagogical and practical considerations of the museum learning environment.

The N&S collaboration resulted in workshop training materials and activities for museum staff, procedures to support the implementation of activities, educational materials, and scaffolds for museum staff to learn how to engage visitors. This is a case study of how N&S collaborators were able to negotiate and leverage their individual expertise and perspectives to produce viable products, and how they reconfigured conceptions of SEI in that process.

Theoretical Background

As a collaboration between university scientists and museum professionals, the N&S work addresses key issues in bridging the divide between scientists and informal science educators through research-to-practice partnerships. Physical scientists, social scientists[2], and museum professionals work with science issues at different levels of complexity and from different vantage points. Each can benefit from the expertise of the other, which requires a mutual understanding of each other's goals and approaches. Scientists and museum professionals also share the goal of improving ways to engage the public in not just learning established science facts but in dialogues and interactions around "unfinished" and controversial science knowledge and issues, something that each profession has in recent years begun to invest greater time and effort into (Chittenden, 2011). Raising public awareness, understanding and engagement about nano amounts to a salient research-to-practice problem. While research-to-practice partnerships have traditionally involved researchers who are directly involved in physical and biological scientific research, the issues of bridging the differences in expertise, culture, and discourse between research and educational practice are just as pertinent to social science research focused on policy, media representations, and public outreach issues in nano. In the case of the N&S work, the social science research of the CNS-ASU collaborators benefits from the educational practice-oriented expertise of NISE Net museum professionals, and vice versa.

Science museums have historically assumed the role of authority on science knowledge, with the public viewed as relatively lacking in science knowledge. Recent years have seen a shift away from this "deficit model" toward a more democratic model of public engagement with science (Elam & Bertilsson, 2003; Hagendijk & Irwin, 2006; Lehr et al., 2007). There has been an increasing focus in the field of informal science on the role of dialogue between science practitioners and the public (Davies, McCallie, Simonsson, Lehr, & Duensing, 2009; Lehr, et al., 2007). So-called Public Engagement with Science (PES) is particularly characterized, among other things, by mutual learning by members of the public and ISE practitioners, with a focus on dialogue (Chittenden, 2011; McCallie et al., 2009).

2 Physical scientists and social scientists will be referred to simply as scientists moving forward.

Given that science museums are situated within complex societal contexts where the implications of controversial issues in science are constantly present, limiting science museum exhibits to presentations of unproblematic scientific facts or "truths" can be considered insufficient (Cameron, 2005). Museum exhibits are often designed to combine formal science knowledge with visitors' prior knowledge and experiences in order to promote engagement with the exhibit and the natural phenomena it tries to explain (National Research Council, 2009). Visitors filter their engagement with and learning from museum exhibits through their own identities and motivational frameworks (Falk, 2006, 2009). The importance of interactivity in museum exhibits has long been known (Falk, Scott, Dierking, Rennie, & Jones, 2004), as well as that of technological novelty and open-endedness (Sandifer, 2003).

The area of nanoscience and technology poses a particularly salient problem in terms of connecting social science research to museum learning interactions, given the complexity and abstract nature of nano, the ubiquity of its applications in society, and the relative lack of knowledge about the ethics and the impacts on health, environment and society of these applications. Nano may have the potential to cause harm as well as to provide solutions to issues of social, economic, and environmental injustice, which amounts to an imperative for engaging the public in discussions about the societal implications of nanotechnologies (Sandler, 2007). This need is recognized within the nanoscience and technology field as well (Crone, 2008; Miller et al., 2007), but has not necessarily been adequately addressed. For example, the U.S. National Nanotechnology Initiative's articulation of responsible development of nanotechnologies mentions the importance of these issues but does not clearly define and substantiate what they are, who the stakeholders implicated are, and what concrete actions need to be taken (Sandler, 2007). The role of nano and society also potentially involves controversial issues. For a number of reasons, including the fear of inciting public mistrust of science and that they might challenge the institution's image as a scientific authority, science museums have often tended to avoid scientific controversies (Macdonald & Silverstone, 1992).

The learning environment of science museums places particular constraints on what is practical to represent. Science museum representations must attract and hold visitors' attention (Boisvert & Slez, 1994), as well as elicit visitors' curiosity (Koran, Morrison, Lehman, Koran, & Gandara, 1984). And while the museum space lends itself to intrinsically motivated learning in unique ways, it's also highly challenging to engineer learning experiences given the complexity of visitor behaviors (Allen, 2004). Given the highly complex learning environment that the science museum space constitutes, the design of exhibits and experiences needs to be based on strong research (Allen, 2004).

The emerging imperative for science museums to engage the public in multidirectional and participatory methods has dovetailed with the National Science Foundation's 1997 requirement

that its funded projects include statements about the Broader Impacts Criterion (BIC), regarding the anticipated impacts of the research on science, education, and society. There has, however, been both confusion about and resistance to BIC (Holbrook, 2005), which has in part been due to researchers' beliefs that they are not necessarily trained in outreach and education efforts, that the NSF requirement slows down research, and that it burdens early career researchers for whom such outreach efforts do not contribute to tenure (Alpert, 2009). In addition, science expertise is particular to specialized fields while communicating with the public requires more generalized knowledge (Davis, Horn, & Sherin, 2013). Scientists' deep expertise can also become a barrier, insofar as it can make it difficult for them to have insight into the experience of not knowing (Nathan, Koedinger, & Alibali, 2001; Nathan & Petrosino, 2003).

One notable response to the research-to-practice challenge was the formation of the Research Center — Informal Science Education Partnerships (RISE) by NISE Net in 2008 (Alpert, 2009). RISE was an effort to develop a model of ideas and strategies for how to build partnerships between researchers and museum professionals. An essential feature of the model is to combine 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 a major attempt to institutionalize the close collaboration between STEM researchers and museums across the nation (Alpert, 2009).

The benefits of collaborations among different educational organizations have long been recognized as beneficial (Mattessich & Monsey, 1992). Partnerships between scientists and museum professionals provide benefits for both types of practitioners. Educating the public about science benefits scientists in terms of building understanding for their work and even improving funding opportunities, while museums benefit from the content scientists bring and the services they can provide, such as lectures or demonstrations, among other things (Crone, 2008; Crone & Koch, 2006).

Even the best research-to-practice efforts to shorten the vast distance between scientists and the science lay person visiting museums can yield mixed results, testifying to the size of the challenge (Meyer, 2011). While considerable research has been conducted on partnerships between universities and schools, and on informal science educators and schools (Coburn, Penuel, & Geil, 2013), more research is needed on research-to-practice partnerships between scientists and science museums. This is the focus of the current study.

Context of Study

The National Science Foundation (NSF) funded NISE Net to engage the public in advances in nanoscale research, to capture the imagination of young people who may subsequently choose careers in nanoscale science or technology, and to foster new partnerships among research institutions and informal science centers. NISE Net's goals were to work toward:

1. Increased awareness of nanoscale science, engineering, and technology and its multiple potential benefits and impacts on lives and community

2. Increased understanding of the structure of matter and the forces at work on the nanoscale

3. Increased understanding of societal issues including risk assessment and abatement, and of the importance of broad citizen participation in discussions about responsible research and development of new technologies

The initial 14 membership institutions, many of which constitute the current leadership for NISE Net, began their work in 2005. Five years later, NSF awarded the network funding to continue their work for five more years. As of summer 2014, NISE Net is in its ninth year.

This report is specifically about the formation and evolution of the N&S team between the CNS-ASU scientists at Arizona State University and a group of NISE Net museum professionals. Eventually, the data from this report will be integrated into a larger one that encompasses all aspects of SRI's research on university scientist and museum professional partnerships.

The work of the N&S team provided an important chance to study in real time some of the challenges and opportunities involved in connecting research with practice in informal science education. The working group's focus, nano and society, also provided an opportunity to study the process of how both complex science and something as potentially contentious as values and relationships become translated into workshop materials that are digestible for museum educators working with lay audiences within the constraints of the museum learning environment. And while current science museum trends toward engaging the public in the construction of science knowledge pose their own unique challenges, staging exhibits around scientific controversies can raise the stakes even further. The N&S team work was situated within these important contexts.

Furthermore, we conceived of this collaboration as a research-to-practice partnership, in which the CNS-ASU scientists collaborate with museum professionals to address what researchers call a "problem of practice," with mutual benefits to both researchers and practitioners (Coburn, et al., 2013). The collaboration also had some features of a design-based implementation research framework, such as a focus on persistent problems of practice from multiple stakeholders' perspectives; a commitment to iterative, collaborative design; and a concern with developing capacity for sustaining change in systems (Penuel, Fishman, Cheng, & Sabelli, 2011).

Given these frameworks, our concern in this study was to understand how the collaboration around solving a practice-based design problem from multiple stakeholders' perspectives succeeded, and what contributed to that success. We set out to answer two research questions:

1. What key components contributed to the success of this research-to-practice collaboration?
2. How did the collaborative work between university scientists and museum professionals shape the workshops and products?

Methods

Single case study approach. This is a study of a single case, in which we set out to study and generate descriptions of and explanations for the dynamics within a particular situation (Eisenhart, 1989). We frame this as a paradigmatic case (Flyvbjerg, 2006), in which the single case serves as an exemplar to highlight specific features of a phenomenon. The paradigmatic case of the N&S team collaboration, in this sense, serves to highlight the features of the research-to-practice problem in a museum setting. The insights from such a case study approach provide descriptions and explanations that can generate hypotheses for further research but also inform understanding of other, similar research-to-practice problems.

Data collection. To gain as rich an understanding as possible of the N&S research-to-practice partnership, one researcher was assigned to follow the work closely in real time. After discussions of possible approaches, it was decided by the SRI research team that the researcher be embedded, to the extent that was practically possible, with the N&S team. The SRI researcher physically attended some key meetings related to the Nano & Society work, including the Center for Nanotechnology in Society conference in Arizona, the initial Oregon Museum of Science and Industry meeting, the pilot workshop at the Arizona Science Center, the filming preparation in Ithaca, and the Nano & Society workshop at Lawrence Hall of Science. The researcher also attended a Network-Wide meeting that occurred in Boston at the Museum of Science during December 2012, and two Subawardee meetings at the Science Museum of Minnesota. Finally, the researcher participated in Content Steering Group meetings and the N&S team meetings. These working group meetings took place mostly by teleconferences. Through these meetings, as well as informal conversations and formal interviews with meeting participants, the researcher developed relationships with key participants and gained important insights into the intricacies of the work.

To collect data from the meetings, the researcher took extensive notes as well as audio recordings, and collected notes taken by participants as well as written feedback from participants in the pilot workshop. The pilot workshop was preceded by a planning meeting, and followed by a debrief meeting. Four workshops took place, followed by debrief meetings. In each case, either the debrief meeting was attended remotely or notes from the debrief were collected.

To conduct interviews, the research team developed an interview protocol based on the research questions. The protocol was designed for semi-structured interviews with some of the key participants. Interviews were either audio recorded and transcribed, or documented through direct note taking. A total of six interviews were conducted with five different participants.

Finally, the research team collected a number of artifacts from the collaboration. These included agendas, PowerPoint presentations, and all the materials that were developed as a result of the partnership. More than a hundred documents were collected in all.

Analysis. We used a grounded theory approach to analyze the data (Corbin & Strauss, 1990; Glaser, 1992; Glaser & Strauss, 1967). All the data were reviewed, with memos created for key categories that were identified as related to the research questions. In this way, an emergent understanding was generated from the data itself about the key factors salient to the case. To further identify evidence for these emergent categories, interview and meeting notes were summarized in terms of goals, key actions, and outcomes. Based on these summaries, quotes and descriptive accounts were collected. Two researchers reviewed the data separately, generating descriptions and quotes. Their results were then compared and discussed and they came to a consensus about how to most accurately represent the events that had been documented. The focus then turned to generating explanations that answered the research questions and providing supporting evidence in the form of quotes and descriptions.

Nano & Society Work and Timeline

The N&S team formed in late 2011 in order to address NISE Net's fourth content area: "Nano is part of our society and our future." While the other three content areas were focused on educating the public about the science, engineering, and applications of nanotechnology, the purpose of the fourth content area was to educate the public about SEI related to nano. The N&S team was tasked with developing a set of workshops to raise museums' capacity around that content area, and to help them engage public audiences in conversations about the relevance of nanotechnology to their lives. The scope of the work was later expanded to also include product adaptation and development.

The N&S team was formed as a partnership between NISE Net's museum partners and two university scientists from CNS-ASU. The group was led by a museum professional from NISE Net.

The work began in late 2011. Nano &Society team members participated in a series of strategic face-to-face meetings hosted by the various participating institutions. This was followed in the spring of 2012 by the development of workshops and products. Participants met on a weekly basis on the phone to present their work, discuss, and offer feedback and suggestions for improvement. A pilot workshop was also conducted before the work culminated in a set of four workshops to train museum staff in the fall of 2012. The work of this team was presented to the entire NISE Net group in late fall of 2012.

Setting the stage with SEI. The initial ideas for the working group were formulated during the 2011 NISE Net regional hub meetings, which included discussions of SEI in nano. The regional hub meetings take place every other year at the regional hub institution, with participation from other institutions in the associated region. The goals of the regional hub meeting were to nurture and deepen relationships with existing partners in the NISE Network; to provide additional networking opportunities among workshop attendees, focusing on museum educators and outreach coordinators; to create opportunities for sharing experiences with using NISE Net products; to discuss ways to sustain the benefits of the NISE Network; and to present an update of NISE Net's resources, including new programs, tools and guides, mini-exhibition, and mini-grants. In the SEI-focused discussions, the museum professionals expressed their priorities for professional development and educational products. The professional development priorities included making sure that staff interacting with the public

would be comfortable with the SEI content. The priorities around educational products likewise involved a comprehensive treatment of nano, relevant topics such as medicine, and discussions about risks and benefits of nanotechnology.

Strategic Meeting 1: Forming the N&S team. Some of the members of the still-to-be-formed N&S team connected at the Third Annual Conference of the Society for the Study of Nanoscience and Emerging Technologies in November 2011, hosted by CNS-ASU. During two days, NISE Net presented to the conference attendees. After the conference, during an informal business meeting, the goals, strategies, and potential timeline of the N&S work were discussed. The ultimate purpose of the work was to create workshops to build museum staff capacity, which later was expanded to include laying the groundwork for adapting existing products to be implemented at science and technology museums. Participants discussed tentative goals for training; workshops; number, timing, and delivery of workshops; pilot plans; and other organizational issues.

Strategic Meeting 2: Formalizing the group and setting goals. The N&S team formally organized and began its work at the next meeting, hosted by the Oregon Museum of Science, in January, 2012. This was a 2-day meeting, in which the participants began to articulate what SEI would actually look like in practice. During this meeting, the focus on risks, benefits, and the ethics of nanoscience and technology was replaced by a focus on visitors' values and the role of technology in society, and on strategies for how to support museum staff in having conversations with visitors about their experiences, ideas, and values about nano.

Strategic Meeting 3: Deciding on content. The N&S team, including the CNS-ASU scientists, members from the NISE Net programs team, evaluators and improvisation professionals from the Museum of Science and Industry in Chicago, held a third strategic meeting at the Science Museum of Minnesota in February, 2012. The primary goal of this meeting was to determine the key content areas that the group was to develop products for. The ASU university scientists introduced the group to a broad set of content areas for the group to negotiate down to a short list of what it considered to be essential. The group's task was then to determine which were the most essential content to communicate to broader audiences. At the conclusion of this meeting, the working group had decided on three areas of content:

1. Values shape how technologies are both developed and adopted
2. Technologies affect social relationships
3. Technologies work because they are part of larger systems

Product Development. The N&S collaborators then proceeded to meet once a week over the phone, to gather feedback, discuss, and suggest changes to the in-progress public engagement products, workshop agendas, presentations, and training materials. The development work proceeded through the spring and summer of 2012, and resulted in the finished workshops and products described below.

Piloting and Implementing Products. In the summer of 2012, the N&S team had finalized the workshops and products. For two months, in September and October, the group implemented four separate workshops, which followed an initial pilot workshop. Each workshop lasted for two days. The workshops were structured as train-the-trainer professional development activities. In addition to the staff at the host museum, they also included museum staff from 50 Tier-2 partner institutions. In all, approximately one hundred people were trained directly by attending workshops through this effort. Each of the professional educators trained in the workshop was also responsible for taking the training products and materials to their own museum staff educators and training them. The workshops served the dual purposes of training staff and generating formative feedback for further improvement. Each workshop included a wrap-up session at the end, to collect feedback, address questions, and to document challenges and obstacles for further iteration on the products.

Feedback from the NISE Net Group. As the working group concluded its work, Nano and Society presented to other members of NISE Net at a Subawardee NISE Net meeting.

Final Workshops and Products

The collaboration resulted in four Nano & Society train-the-trainer workshops held in Minnesota, Berkeley, Houston, and Portland. The workshops:

> focused on preparing museum educators to engage the public in conversations about the relationship between nanotechnology and society to their daily lives. Workshop participants learned new hands-on activities, full-length programs, and ideas for facilitating visitor experiences in the Nano mini-exhibition. The workshop provided specific training and skill-building in nano and society content, conversation facilitation, and improving and learning from professional practice (Team Based Inquiry).[3]

The N&S team developed a number of training resources for museum floor staff, which included training agendas, slide presentations, a Big Ideas Guide, tips for having conversations with visitors, conversation goals, training videos, improvisation activities and team-based inquiry materials. Digital training materials are available for download online, in workshops, and in the Nano and Society kit materials. The training materials were developed for the museum workshop participants to learn from during the workshop and to use when they returned to their home institutions to train their own museum floor staff. A Nano & Society programs kit was sent to the workshop participants that included the training materials as well as some program materials to use with their visitors on the floor to engage them in conversations about nano and society.

3 http://www.nisenet.org/catalog/tools_guides/nano_society_training_materials

Findings Summary

Our findings are organized by the two research questions. To begin, we address the question of what key components contributed to the success of the research-to-practice partnership. We found that while collaborators had some differences in expertise, perspective, and approaches, they also overlapped in these areas, and, more importantly, they shared the same goals. Working toward a common purpose and building positive relationships meant that they were able to leverage each other's expertise. Rather than insisting on their own prior understandings and assumptions, the positive relationships collaborators developed helped each to listen and be open to the ideas of the others. By doing so, they could all leverage each other's expertise to inform the design process.

We next address the question of how the collaboration shaped the workshops and products that were developed. Here, we found that the negotiations exploring the different perspectives and expertise of university scientists and museum professionals shaped new directions that participants might not have taken on their own. As a result of their collaboration, there was, first, a notable shift from a focus from SEI in nano to a focus on visitors' values around nano. Second, the question of how to engage the public about the content, given the context, constraints, and affordances of the museum learning environment, was an essential issue that shaped the shift in content focus and development of workshops and products. This also related to how to build museum staff capacity based on nano and society content and the strategies for public engagement.

Key to Success: Shared Goals, Institutional Support and Positive Relationships

The N&S team members entered the collaboration with different, as well as overlapping, perspectives, levels of science knowledge, and practical informal education knowledge. As was apparent in the negotiations about content, public engagement, and museum staff capacity (which we discuss at length below), shared goals, institutional support, and the development of positive social relationships were essential for participants to make optimal use of one another's expertise, to critically re-examine their own ideas, and to work together to generate new ideas and directions based on collective insights. Notably, the first few meetings

in which participants discussed the content, the goals, and the basic approaches were conducted in person. The face-to-face personal interactions, facilitated through the working group process, aided in strengthening the relationships that participants relied on as they conducted the actual product development through weekly meetings on the phone.

While university scientists and museum professionals shared the overarching goals for the work as well as some perspectives and types of knowledge, they also came to play different roles in the partnership, informed by the focus of their professional work. The university scientists served as nano and society experts and the professionals from the museums provided the expertise in translating ideas and concepts into products that could be meaningfully communicated to public audiences with a wide range of ages and backgrounds. In addition, while NISE Net had already made nano and society a priority of focus, the university scientists also brought a vision for increasing the public's science and technology literacy.

Shared goals. A fundamental ingredient in making the collaboration successful was the fact that the N&S team members shared important goals for their work. They entered the collaboration with commonality in what they wanted to achieve in this area. University scientists and museum professionals were equally interested and invested in engaging the general public about nano. Reaching broader audiences with core ideas from their work was important to the scientists, personally and professionally.

In addition, NISE Net and CNS had aligned institutional interests: both organizations had missions that included fostering public awareness of, engagement with, understanding of, and dialogue about nanoscale science and technology.

Institutional Support. For both university scientists and museum professionals, N&S tasks were professionally related to their work: that is, the work was specifically funded and supported, or institutionally encouraged in their position. This included, for example, the flexibility and resources to meet face-to-face, and relief from teaching responsibilities in order to conduct workshops. One of the university scientists also pointed out on several occasions that participating in these types of collaborations is often difficult for untenured faculty members, since the work does not support tenure. He said he was in an unusual position to be able to participate in the collaboration, because of his institutional association with the CNS-ASU group. This insight was also echoed in a meeting attended by one of the museum professionals and coordinators from the National Science Foundation's Research Experiences for Undergraduates. Attendees pointed out that untenured faculty may not be motivated to work with museums to communicate with public audiences because that activity is not recognized on the path to tenure. Publishing research papers, book chapters, or books count

toward tenure, whereas educational outreach to public audiences does not. N&S collaborators said it would have been more difficult for the team to carry out its activities without these institutional supports for the work.

Positive relationships. One of the things that aided the N&S team collaborators in negotiating their different views on what and how to communicate to the public was the quality of the relationships they generated. In an interview in February 2012, one museum professional said, for example, "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. We all have our role." Echoing this sentiment and describing the positive quality of the face-to-face interactions and the growing relationships among participants, one of the university scientists said in an interview following one of the early strategy meetings:

> One of the reasons that we work so well together is that we really like each other. And these [NISE Net] people are great. They like to laugh; we like to laugh. We like to laugh in our classes with our students. How often can you go to an 8-hr meeting and walk away with your cheeks hurting because you have laughed so much. It is only in the NISE Net group that this happens. We really feel comfortable with each other.

In the process of building their working relationship, the various participants had to consider each other's roles and expertise with mutual respect. One of the university scientists said in the interview,

> There is an important first step… That is we go into our interactions with the idea they [museum professionals] know something that we don't. They have their expertise and if we were to pretend that we know how to do their jobs, we would fail.

This notion was accompanied by the expressed ideal of putting one's own interests aside, as he continued, saying, "Another thing is that we offer ourselves as selflessly as possible. For it to be useful, [a product] is going to have to be modified [for museum audiences] well beyond how we built it. We recognize that."

When reflecting back on these negotiations, one of the university scientists, in a discussion following the spring 2012 pilot workshop, also observed the benefit of having opened themselves up in this way, saying, "That was awful what we were coming up with. This [current products] looks nothing like that, because of the strength of everybody's ideas. Glad we are able to check big egos."

An important aspect of cultivating positive relationships - and potentially a significant motivator for engaging with the work - was that participants reported learning from each other and

pushing each other's thinking. One of the university scientists, when reflecting in an interview on the initial in-person working group meetings, said:

> It pushes us to address [the issues] far more than I'm comfortable with. That conversation that we had today, we would never have had [even] with our graduate student scientists... because the very concepts that we talked about are revolutionary in the very real sense of the word.

Notably, the personal relationships between museum professionals and university scientists did not begin with the N&S work. The university scientists had been involved earlier in NanoDays and some other related NISE Net activities, and they had also participated in developing the content map. When the N&S work began, therefore, many of the team members had already established a good personal relationship, which one museum professional said doubtlessly led to a much smoother collaboration than would have been the case if they had started from scratch. She also said that the fact that their relationship was already established helped all the team members be savvier in their discussions about audience engagement.

In a discussion after the close of the project, N&S members pointed out that the positive personal relationships that ensured the success of the project were not a given. In fact, earlier attempts to build a collaboration between CSN-ASU and NISE Net had been made, but had not found what N&S members considered the right context and the right mix of people. They pointed to how the N&S project and mix of people, by contrast, was right. One museum professional said, "we just clicked." He said that they "all became good enough friends" to give each other honest feedback. He also noted that the university scientists were familiar enough with informal environments to be good partners to the museum professionals.

The fact that the N&S team members were able to meet in person for the initial three strategy meetings also proved to be essential for the success of the collaboration. Some N&S members said, when reflecting back on the work, that it was during the face-to-face meetings that the big breakthroughs took place, and that being together helped them pull together disparate ideas into a coherent whole that was greater than the sum of its parts. While the numerous phone meetings that followed the strategic meeting were productive in their own right, they were largely dedicated to working through the details of the workshops and products, and negotiating how to realize them. According to one museum professional, the in-person meetings, by contrast, generated "amazing inspiration that came from being together."

Combined Expertise and Perspectives Influenced Workshops and Products

As university scientists and museum professionals cultivated their relationships, they also negotiated ideas based on each other's expertise. University scientists invoked their expertise in the relationship between technology and society. Museum professionals invoked their expertise in how to communicate science ideas to the public and how to construct the programmatic features of exhibits and learning activities. The result was twofold: First, there was a conceptual shift away from ethics, risks, and benefits, toward a focus on visitors' own values and ideas about the role of technology generally in their lives. Second, how to actually engage the public with nano and society ideas was a key consideration that influenced this shift and led to a focus on conversational strategies and questions about how to build museum staff's capacity to implement this approach.

Conceptual Shift - From Risks and Benefits to Values and Technology in General.
University scientists expressed their passion for educating the public about nano and society in nanotechnology and building technological literacy. They described how their work was partly driven by the mission to educate the public to be able to make informed decisions about the technologies that affect their lives. In an interview in February 2012, one of the university scientists said,

> For me it's about the democratic processes that continually ask us how we are going to use technology in our lives. It is a technological literacy issue. Not literacy in that you know which button to push to get a certain effect, but it is an understanding of how things fit into our lives. What I want is an increased capacity for making decisions.

At the same time, the scientists were aware that one of the challenges they faced was trepidation about SEI - in particular with regard to nano - among museum staff as well as visitors. One of the scientists said during a strategy meeting, "One of the first goals is to dispel nano and society myths. Nano and society is not scary. Everyone can, should, and does think about these things." University scientists were also aware of the potential ramifications of the public not having the right information, or inadequate information to be able to make informed decisions. One of them said during the strategy meeting: "You don't want to get stuck in the conversation 'are genetically modified foods safe'" (alluding to the widespread controversy and the consequences of misinformation about genetically modified foods).

The museum professionals, for their part, had also formed a consensus about the importance of addressing the ethical issues specific to nanotechnology in an early draft of the content map for the group, as well as a comprehensive treatment of nano with regard to how to communicate

it to the public. But early in the actual collaboration, they began to problematize the issue of risks and benefits. Controversial science issues have often been avoided by museums, in particular ethical issues relating to science, a concern that surfaced early in the collaboration. This sentiment was reflected in a conversation following the pilot workshop in spring, 2012, when one museum professional said, "Science museums were founded with the idea of avoiding these conversations." Another museum professional, in the same meeting, made the observation that her particular science museum tended to avoid political contention if possible:

> Our institution has a history of shying away from touchy issues. So that's in our closet. When it's evolution… we are not to talk about it on the floor. Certain people used to tell us not to talk about the really touchy stuff. Just the words 'social, ethical implications' is tough. We don't like to use that.

As museum professionals elaborated on this concern in their strategy meetings, they untangled the practical, pedagogical, and epistemological issues underneath. Discussing ethics and the risks and benefits of controversial science topics is complicated by the kinds of interactions that take place in museums, staff's level of comfort and confidence in taking these issues on, and the museum's role in the production of knowledge. An early concern raised was that a risks-and-benefits approach might not be appropriate for nano, since visitors can't absorb all the information needed for such reasoning. The N&S team discussed how the development of nanotechnologies is more or less inevitable, rendering the either/or approach of risks and benefits calculations inappropriate. Another museum professional raised the question of whether the exhibition floor was an appropriate space for having conversations about risks versus benefits and ethics, or if such conversations would be more appropriate for classroom settings. Museum professionals also pointed out that museum staff tends to be disinclined to take on issues of ethics, as they do not consider themselves experts in this area.

In a strategy meeting, one of the museum professionals on the N&S team also emphasized the importance of maintaining the museum's role of education the public about the science: "We welcome hearing people's values related to climate change, [but] we do steer conversation back to science and what it says…Respectfully say that here we're focusing on science." Museum professionals also described the role of the museum to make science fun and relatable, and the typical focus in museum work on explaining something that is already solidly known. At one strategy meeting, a museum professional raised the issue of visitors' capacity to adequately deal with these contentious issues:

> In this case, do we think we're going to get the visitors to actually balance the risks and benefits well enough that a visitor could actually weigh that evidence and make their

> own decision? The second option is getting people to recognize that we as a society are always going to be making decisions without the perfect information.

Museum professionals emphasized that the museum's role is to educate visitors about science knowledge and ideas that have been well established, not to adjudicate issues of values around science. Values, rather, are the purview of visitors, who bring their own ideas, values, and experiences to the encounter with museum exhibits. One museum professional said, in a strategy meeting,

> Think about these not as lessons but as exchanges; dynamic and fluid conversations with guests. Have had hour-long engagement with guests as they formulate their own opinions as you talk to them, related their lives and society. That's more important and more powerful.

The university scientists also embraced the idea of visitors' values being at the center of the learning experience. At one strategy meeting, one of the university scientists said,

> One way to do this is to share the opinions different people might have about technologies (nanosilver socks for a soldier versus hiker). Do guests come looking for answers? The shift here is demanding answers from visitors. Scientists are not the experts in this topic, and neither are visitors. Everyone has their own values, choices.

Alongside the emerging consensus in the strategy meetings to focus on visitors' own ideas and values, participants discussed whether to focus on specific nano research or applications, or on technology in general. Asking whether examples should be historical, hypothetical, directly related to nano, general, or a variety of other types, participants began to move toward general technology examples. This issue generated some ongoing controversy, and on a few occasions feedback on the pilot workshops and materials raised the issue about the importance of including nano-specific examples.

Finally, the issues of engaging visitors' values and the degree to which conversations should focus on nano or technology in general were couched within the debate of whether to make nano and society an explicit, separate focus or to embed nano and society issues in broader conversations about nano science. N&S team members began using the metaphor of baking cupcakes to elucidate the distinction, suggesting that nano and society could be "sprinkled on top" or "baked in." In one of the breakout groups in a strategy meeting, focused on nano days and the mini exhibition, the question was raised of whether to create entirely new products or to infuse the nano and society idea into existing activities. People suggested infusing it, with museum professionals suggesting "making [nano and society] SEI part of what the experience is about," and "baking in, not sprinkling on."

After the N&S team had made the conceptual shift in focus from educating museum visitors about the risks and benefits of nano to having conversations about their own values about nano and the role of technology in society, the focus on values ended up being embodied in the first of the three content Big Ideas that N&S team collaborators developed. The university scientists had initially developed a list of ten areas of nano and society content that they brought to the group, which the group proceeded to collapse and prioritize to a more concise list. The areas included technology-related issues such as the distribution of benefits and impacts of technology, goals, impact on social relationships, social norms, ethical questions, politics, and how people shape technologies. After negotiating the conceptual issues of nano and society, the group also decided to tackle the issue of educating the public about nano and society in technology in general, partly reflecting the consensus about integrating, or "baking in," the nano and society content. Participants settled on the following three goals:

1. Values shape technologies
2. Technologies affect social relationships
3. Technologies work because they are part of systems

Conceptual shift outcomes. These final content goals reflected the shift toward values rather than ethics and risks versus benefits, as well as the inclusion of a focus on the role of technology in society in general. The educational activities that were developed were directly based on these goals.

For example, the *Nano Around the World* activity (also known as *You Decide!*) was designed to involve visitors to think about how values shape technologies. This activity also embodied the "baking in" approach. In this activity, visitors are asked to apply different nanotechnologies to a variety of cultural and economic situations around the world, where issues around value and societal benefit are an integral part. Nano and society is an implicit aspect of the activity where visitors bring their own interpretations as they try to match nano applications to people who will benefit. One of the university scientists invented the game, with additional N&S collaborators providing input. The game consisted of several cards with pictures and explanations of a variety of people from different countries, cultures, occupations, jobs, and socioeconomic positions. The team also developed cards that introduced different kinds of nanotechnology products, either existing or envisioned for the future. The purpose was to engage public audiences in trying to see the world from different people's perspectives, as they selected a technology that may benefit that person. It was hoped that players would see that not all technology benefited everyone equally; that people, depending on specific circumstances in their lives, would have different needs of different nanotechnologies. The intended message is that technological products are not inherently good or bad; instead, their value depends on who benefits from their use. In Nano

and Society workshops, the cards were one of the participants' favorite activities, according to debrief comments at the end of the workshop session.

The Cell Phone activity, a training activity for staff, in which workshop participants think about how the use of cell phones play a role in their social relationships, was designed based on the second big idea. This is a quick 20-minute activity designed for small discussion sections. People discuss their rules for using cell phones in a variety of contexts, for example school, dinner table, library, or in theaters. They also talk about who came up with the rules and if they are permanent and why they were constructed.

The third big idea drove the design of another staff training activity, the Light Switch, in which workshop participants are asked to think about the underlying systems that make it possible to turn on a light switch. The light switch activity can be conducted as a whole group or a small group activity. It begins with the facilitator turning off the light, then turning it back on. Workshop participants engage the central question of "What just happened to cause the light to come on?" One person takes on the role of illustrator. The other participants suggest what else has to happen for the light to come on, in a facilitated discussion that helps them to expand their perspectives of the systems involved. Through this activity people grow to see how something as simple as everyday light involves connections to organizations for building power plants, transmitting electricity, having a billing system, and other aspects of the system.

The "sprinkle on top" versus "baking in" analogy was also used explicitly to describe to museum staff trainees the two different approaches to SEI in their programs. The "sprinkle on top" approach, as described in the training slides, meant that the technology and the societal aspects were discussed separately. But since they're not separate in reality, it is argued in the training, it makes better sense to discuss them together, to "bake in" the SEI aspects. "By putting the sprinkles inside you essentially infuse the nano and society throughout the entire program."

Museum staff capacity for engaging the public through conversation. With the shift toward thinking about the values that the public brings to their learning experiences, the N&S collaborators began to focus on the roles and expected expertise of staff and visitors. Museum professionals argued that the museum staff member should not act as the sole expert on nano and society since the expertise around ethics and values resides equally with visitors. Consequently, they suggested that nano and society is an emergent aspect of the exchanges between museum staff and visitors. This led some collaborators to note that the task is not to educate visitors in *what* to think, but *how* to think. A consensus began to emerge around the idea of how to support museum staff in having conversations with visitors that engaged their personal values. At one strategy meeting, a museum professional said:

> This is more of a conversation than a lesson: that's incredibly important. Center of expertise shifts when you're talking about individual and societal implications. Expertise belongs to the visitor, since they have the best idea of how something will impact their lives. They have an equal place at the table.

The idea of empowering staff to enrich conversations with various perspectives aligns with more recent trends in informal science education to move away from the historically didactic roles of science and natural history museums toward more dialogue and conversation (Davies, McCallie, Simonsson, Lehr, & Duensing, 2009; Lehr, et al., 2007). In these discussions, the university scientists envisioned museum staff engaging visitors through dialogue rather than more traditional demonstrations. Museum professionals, with their knowledge of the realities of museum interactions, were able to refine this idea to address their specific concerns about staff capacity and visitor backgrounds and expectations. In an interview in February 2012, one of the university scientists, reflecting back on this process, said that one of their goals had been

> to change the way people who work at museums think. The traditional approach that people in museums take is to think of themselves as the possessor of knowledge-to-share. They want people to come to museums, get turned on by the stuff [science] they are seeing and listen to how cool it is by explaining to them the facts. They are the keeper and sharer of facts….What we would like to see is the museum people move more into the arena of visitor engagement. We want the museum people to see that all people are experts in terms of their values. Everyone has values. We would like to see people from the museum enter into the conversation with visitors; help them understand that the conversation is relevant to their lives and their thinking about it is important.

When they came to a shared understanding about the need to empower staff to engage visitors differently, museum professionals addressed the ramifications for staff capacity and visitor expectations. One museum professional said in an early strategy meeting, "This is suggesting to me that we may want to research facilitation strategies. Are we creating solid learning environments, or is just a conversation enough? What are the outcomes when we use different facilitation strategies?" Another museum professional noted that, "In most of these situations we're not looking for answers. We're looking for responses, and prompting more conversations, and letting visitors talk, not the facilitator."

Museum professionals pointed out a number of challenges with regard to pedagogical approaches and content. For example, when deciding the best set of concepts to target in terms of salience, relevance, and import, museum professionals reported that they generally don't know the science background of the audience and that they work with audiences from multiple age groups. While considering these uncertainties, they need to know which grain size

of information to begin conversations with, keep comments simple and concise, find familiar terms to represent unfamiliar ideas, and create a dialogic environment. Dealing with different backgrounds and ages, museum professionals argued, is very difficult, particularly in an area like nanoscience.

In one strategy meeting, a museum professional drew attention to the delicate nature of these conversations, saying, "If you say it wrong people think you're pushing an agenda." There was also concern about the open-endedness of conversations. One of the university scientists said, in the same meeting, "But you can't cut that conversation off halfway through. This is a frightening space for me because of the vast range of responses you could get." And another museum professional made the observation:

> I think that it is going to be difficult to talk about this. We get people who are against evolution. It comes up as a glaring example…I have great conversations with guests but they rarely last more than 30 seconds. It is hard to get people to stick around. Even adults.

In discussions during the pilot workshop later in the spring of 2012, museum professionals also pointed out that challenges with regard to building capacity toward this end involved changing staff dispositions. One museum professional said that the "biggest deal is finding the difference between demonstrations and conversations. This is critical for the people on the floor." Another museum professional noted that, "staff doesn't always see the difference. They still try to be the expert in conversations. That stood out – how to separate and engage more in a conversation."

As N&S team members in the strategy meeting began to form a consensus around the idea of empowering staff to have conversations about nano and society, one museum professional said that they had identified two ways of empowering staff to learn to carry this task out by themselves, which included "products that are more structured experiences, intrinsically designed to scaffold a question/response conversation among visitors," and "training and tools to help educators initiate and frame more open-ended or flexible conversations and facilitate them." The N&S team members described possible scenarios during NanoDays interactions for example. One collaborator said:

> One of the common things visitors say as they approach is, 'What do you have here?' They're expecting you to show them something and/or give them instructions to try something, and then for you to explain it. So if you immediately turn that interaction into a question, rather than showing something or providing instructions, you're changing the dynamic and the expectation about the role of the facilitator and the visitor. The instructions for the activity can scaffold this for the facilitator, and the activity can be appropriate for that kind of exchange.

Conversation and staff capacity development. The N&S team's emphasis on a dialogical approach, combined with the museum professionals' rich understanding of the limits and potentials of museum interactions, resulted in a set of guides and supports for staff about how to conduct conversations with visitors, as well as the technique of improvisation, which became an integral part of the professional development package for museum staff.

To support museum educators to initiate and be thoughtful about the conversations they have with visitors, a number of products were developed. There were training slides that explain why conversations with visitors are appropriate, as well as Team Based Inquiry slides that museum educators use to track how conversations went with visitors so that they may compare their experiences with other museum educators. The N&S team also developed what was called Tips for Visitor Conversations. These were quick strategies that reinforce basic concepts, such as listening to what visitors are saying, making eye contact, encouraging questions about what the visitors think, remaining positive, thanking visitors, and so on, in addition to a set of tips that had already been developed for NanoDays kits. Finally, the group produced improvisational technique materials that were created to train the museum staff on enacting the activities, practice how to have conversations with visitors when responses are unpredictable, and overcome trepidation when having visitor conversations.

Collaboration Outcomes

This study did not collect data on the implementation of the final products that resulted from the N&S team collaborative work. These final products do represent a successful embodiment of ideas thoughtfully negotiated and developed over a long period of time as a result of consensus among the N&S collaborators. Feedback from museum staff who participated in the final workshops is also an important indicator of success. The feedback included statements such as:

> Some workshops present ideas that a small museum can't handle. Not this workshop. Surprising that it wasn't what I expected…changing the way of thinking rather than telling us how to teach nanoscience. There's so much to take back now.
>
> How do we get these ideas into the way we teach in science museums altogether? Now that's happened through this series of workshops. Maybe we'll get a grant to expand this? Great to see ideas about this conversational approach…Especially when we're talking about application of science to technology.
>
> These are things we can take back right now. We've been talking about them. Now we can move forward in a shorter time than trying to do it all ourselves.

> I'm looking forward to taking back strategies to a team that aren't scientifically trained. This took me out of my content-first comfort zone.
>
> [I'm] no longer intimidated by the idea of a steep learning curve. It's a different methodology than anything we've used before… will impact the whole institution. Something concrete to work together on.
>
> Appreciate getting lots of tools for talking about how science affects society and the world… social justice issues. Liked the opportunity to talk about that… that's why I like my job. What can you do with the science to make the world better for everyone? That's what drives me.

The N&S workshop participants also reported that the collaboration broadened their understanding of the potential reach of their respective work. One workshop participant said that her expectations had "evolved a huge amount. I thought it was going to be about information, but now I've learned to think about broader aspects of the world and information… the broader world of science museums…" This point was also made by a museum professional in the discussion following the pilot workshop in the spring, who linked the broadening of horizons to the overall trend of science museums to become more integral parts of society. He said:

> There were really important reasons for science centers not to engage in this. All the museums were supposed to be the same, because science is the same everywhere in the world. Science museums have cloned each other. But what happens now is we're not seeing the separation between the science and the culture…Inevitably there is going to be more of this. Science centers have been looking for a new identity for the last 15 years. Every… meeting we ask what is next? I think it's here. I think you've found something important. And the significance is going to be that this can be used in another context. That becomes institutionalized and then it's a different science center.

Finally, in meetings and in feedback on the workshops, participants pointed out that the products that emerged from the collaborative discussion resonated and were well aligned with the needs of museum staff working with the public. One workshop participant said, "[it's] uncanny how well the session planners know just what my staff needs. That might reflect a mindset in science centers across the country. It's incredibly useful information… great for our teacher professional development and civic professional development."

Summary and Recommendations

We found that shared goals, institutional support, and the building of positive relationships were key to successful collaboration – factors that have been noted in other research-to-practice partnerships as well (Coburn, et al., 2013). When N&S collaborators began working together, they reworked proposed nano and society content ideas based on key considerations with regard to museum staff, visitor dynamics and expectations, and the role and expected authority of the museum as a science education institution. The process began with addressing the ethical issues and the risks and benefits of applied nanotechnologies. As collaborators considered these concepts within the realities of museum work, they reworked them, focusing on empowering staff to have conversations with visitors, in which museum staff are positioned as representatives of the institution's science knowledge and visitors are positioned as the ones bringing their own values and questions to the conversations. Museum professionals voiced reservations about inserting themselves as experts on ethics, and about the difficulties of discussing risks and benefits with visitors given the depth of science knowledge needed and the relative dearth of information about actual impacts of nano- technologies on human health and the environment. As a result, the goals of the N&S team shifted more toward engaging workshop participants in conversations about the role of technology in general, with some compelling examples of nanotechnology applications.

The outcomes of the collaboration clearly reflected the combination of different areas of expertise brought by the N&S collaborators. They emphasized in interviews and discussions that their positive relationships enabled them to listen to one another, be open to critique and to learning from one another. This meant that the different perspectives and expertise each collaborator brought to the work could be leveraged for refining ideas and improving the workshops and products. For example, the university scientists brought content expertise and helped promote the idea of focusing on visitors' values instead of risks and benefits of nano, which was an issue that museum professionals were already feeling concerned about. Museum professionals helped advance the focus on a conversational approach and kept the discussions focused on the practical and pedagogical issues involved in museum visitor interactions. Reflecting back on the project, N&S collaborators said that they didn't feel that it mattered who had initially proposed an idea: many people contributed different pieces of an idea which ultimately gelled into a cohesive whole. They said that everyone felt a shared ownership of the process and the ideas, while still feeling that they were contributing from their respective areas of expertise. While the different

perspectives originated with collaborators' varying backgrounds and expertise, they said they did not experience contention, struggle, or frustration. Rather, they said, they had a common goal and they worked toward it to make it happen.

This case study demonstrates the benefits of bringing scientists and museum professionals together, working toward the shared goal of increasing the public's literacy and engagement with science and technology. While museums have long been reticent about engaging the public in science controversies (Chittenden, 2011), controversial issues can in fact be very engaging for the public (Mazda, 2004). And as this case study shows, paying careful attention to visitors' expectations and the roles and capacities of museum staff can yield products with the potential to engage the public in difficult and controversial science. We also believe that this study might contribute to alleviating scientists' trepidations about engaging the public. Research scientists have historically felt suspicious of what has been viewed as an oversimplification and intellectual impoverishment of science when it enters the public realm (Davis, et al., 2013; Latour, 1987), and they sometimes fear stigmatization when research is discussed publically (Goodfield, 1981). But as this case example of a successful collaboration shows, scientists can contribute in powerful ways to develop strategies for educating the public about difficult content and science controversies.

The findings of this study suggest some important aspects that contribute to the success of research-to-practice collaborations between scientists and museums. First, the partnership benefits from being built on a set of shared professional goals. Shared goals ensure that collaborators are motivated to engage, in particular as they encounter challenges relating to differences in perspectives and know-how. Second, for collaborators to meaningfully engage in the collaboration they need to have institutional support, of which time is paramount, but also in the form of the institution's recognition of the value of participating in research-to-practice collaborations. Third, it is essential for the facilitators of collaborations to create the conditions for participants to have positive interactions and develop good relationships. The development of positive relationships, trust, and the perception of mutual benefit, resulted from the connections people made early on in the collaboration. Fourth, face-to-face meetings enable participants to connect personally in ways not possible over the phone, which might be particularly important in the early phase of a collaborative partnership. The first few meetings N&S team collaborators attended were in-person. While much of the communication later on was conducted virtually over the phone, providing collaborators early opportunities to connect in person set the stage for developing sustainable relationships. Finally, it is important to consider deliberate ways to support collaborators in developing an appreciation for each other's expertise and establishing clear roles in the collaboration. This allows collaborators to leverage each other's strengths and complement each other's weaknesses, resulting in outcomes that are greater than the sum of the parts.

References

Allen, S. (2004). Designs for learning: Studying science museum exhibits that do more than entertain. *Science Education, 88*(S1), S17-S33.

Allen, S., & Gutwill, J. (2004). Designing with multiple interactives: Five common pitfalls. *Curator: The Museum Journal, 47*(2), 199-212.

Alpert, C. L. (2009). Broadening and deepening the impact: A theoretical framework for partnerships between science museums and STEM research centres. *Social Epistemology, 23*(3-4), 267-281.

Bell, L. (2009). Engaging the public in public policy. *Museums & Social Issues, 4*(1), 21-36.

Boisvert, D. L., & Slez, B. J. (1994). The relationship between visitor characteristics and learning-associated behaviors in a science museum discovery space. *Science Education, 78*(2), 137-148.

Cameron, F. (2005). Contentiousness and shifting knowledge paradigms: The roles of history and science museums in contemporary societies. *Museum Management and Curatorship, 20*(3), 213-233.

Chittenden, D. (2011). Commentary: Roles, opportunities, and challenges—science museums engaging the public in emerging science and technology. *Journal of Nanoparticle Research, 13*(4), 1549-1556.

Coburn, C. E., Penuel, W. R., & Geil, K. E. (2013). *Research-practice partnerships: A strategy for leveraging research for educational improvement in school districts.* New York, NY.: William T. Grant Foundation.

Corbin, J. M., & Strauss, A. (1990). Grounded theory research: Procedures, canons, and evaluative criteria. *Qualitative sociology, 13*(13-21).

Crone, W. C. (2008). Bringing nano to the public through informal science education. *Bulletin of the American Physical Society, 53.*

Crone, W. C., & Koch, S. E. (2006). *Bringing nano to the public: A collaboration opportunity for researchers and museums: Science Museum of Minnesota.*

Davies, S., McCallie, E., Simonsson, E., Lehr, J. L., & Duensing, S. (2009). Discussing dialogue: perspectives on the value of science dialogue events that do not inform policy. *Public Understanding of Science, 18*(3), 338-353.

Davis, P. R., Horn, M. S., & Sherin, B. L. (2013). The right kind of wrong: A "Knowledge in Pieces" approach to science learning in museums. *Curator: The Museum Journal, 56*(1), 31-46.

Eisenhart, K. M. (1989). Building theories from case study research. *The Academy of Management Review, 14*(4), 532-550.

Elam, M., & Bertilsson, M. (2003). Consuming, engaging and confronting science: The emerging dimensions of scientific citizenship. *European Journal of Social Theory, 6*, 233–251.

Falk, J. H. (2006). An identity-centered approach to understanding museum learning. *Curator: The museum journal, 49*(2), 151-166.

Falk, J. H. (2009). *Identity and the museum visitor experience.* Walnut Creek, CA: Left Coast Press.

Falk, J. H., Scott, C., Dierking, L., Rennie, L., & Jones, M. C. (2004). Interactives and visitor learning. *Curator: The Museum Journal. 47, 2*(171-198).

Flyvbjerg, B. (2006). Five misunderstandings about case-study research. *Qualitative Inquiry, 12*(2), 219-245.

Fry, R. (2002). Delightful sound and distracting noise: The acoustic environment of an interactive museum. *The Journal of Museum Education, 27*(1), 14-17

Glaser, G. B. (1992). *Basics of grounded theory analysis.* Mill Valley, CA: Sociology Press.

Glaser, G. B., & Strauss, A. (1967). *The Discovery of Grounded Theory: Strategies for Qualitative Research.* Chicago: Aldine Publishing Company.

Goodfield, J. (1981). *Reflections on science and the media.* Washington, DC: American Association for the Advancement of Science.

Hagendijk, R., & Irwin, A. (2006). Public deliberation and governance: engaging with science and technology in contemporary Europe. *Minerva, 44*(2), 167-184.

Holbrook, J. B. (2005). Assessing the science–society relation: The case of the US National Science Foundation's second merit review criterion. *Technology in Society, 27,* 437–451.

Koran, J. J., Morrison, L., Lehman, J. R., Koran, M. L., & Gandara, L. (1984). Attention and curiosity in museums. *Journal of Research in Science Teaching, 21*(4357-363).

Latour, B. (1987). *Science in Action.* Cambridge: Harvard University Press.

Lehr, J. L., McCallie, E., Davies, S. R., Caron, B. R., Gammon, B., & Duensing, S. (2007). The value of "dialogue events" as sites of learning: An exploration of research and evaluation frameworks. *International Journal of Science Education, 29*(12), 1467-1487.

Macdonald, S., & Silverstone, R. (1992). Science on display: The representation of scientific controversy in museum exhibitions. *Public Understanding of Science, 1*(1), 69-87.

Mattessich, P. W., & Monsey, B. R. (1992). *Collaboration: what makes it work. A review of research literature on factors influencing successful collaboration.* St. Paul, MN: Amherst H. Wilder Foundation.

Mazda, X. (2004). Dangerous Ground? Public Engagement with Scientific Controversy. Creating connections: museums and the public understanding of current research, 127. In D. Chittenden, G. Farmelo & B. V. Lewenstein (Eds.), *Creating connections: Museums and the public understanding of current research.* New York: Altamira Press.

McCallie, E., Bell, L., Lohwater, T., Falk, J. H., Lehr, J. L., Lewenstein, B. V., et al. (2009). *Many Experts, Many Audiences: Public Engagement with Science and Informal Science Education.* A CAISE Inquiry Group Report. Washington, D.C.: Center for Advancement of Informal Science Education (CAISE).

Meyer, M. (2011). Researchers on display: moving the laboratory into the museum. Museum *Management and Curatorship, 26*(3), 261-272.

Miller, C. A., Guston, D. H., Barben, D., Wetmore, J., Selin, C., & Fisher, E. (2007). *Nanotechnology and society: Ideas for education and public engagement.* Phoenix, AZ: Center for Nanotechnology in Society, Arizona State University.

Nathan, M. J., Koedinger, K. R., & Alibali, M. W. (2001). *Expert blind spot: When content knowledge eclipses pedagogical content knowledge.* Paper presented at the Third International Conference on Cognitive Science.

Nathan, M. J., & Petrosino, A. (2003). Expert blind spot among preservice teachers. *American Educational Research Journal, 40*(4), 905-928.

National Research Council. (2009). *Learning science in informal environments: People, places, and pursuits.* Washington, DC: The National Academies Press.

Penuel, W. R., Fishman, B. J., Cheng, B. H., & Sabelli, N. (2011). Organizing research and development at the intersection of learning, implementation, and design. *Educational Researcher, 40(7*), 331-337.

Sandifer, C. (2003). Technological novelty and open-endedness: Two characteristics of interactive exhibits that contribute to the holding of visitor attention in a science museum. *Journal of Research in Science Teaching, 40*(2), 121-137.

Sandler, R. (2007). Nanotechnology and social context. Bulletin of Science. *Technology & Society, 27*(6), 446-454.

SRI International

About SRI Education

SRI Education researchers address complex issues in education, learning, and human services. Multidisciplinary teams of education policy researchers, sociologists, psychologists, political scientists, statisticians, and others study education policy issues and develop research-based solutions to improve productivity and quality of life at home and school and in the workplace.

Contact SRI Education

Phone: 650.859.2995
Email: education@sri.com

SRI International
333 Ravenswood Avenue
Menlo Park, CA 94025

sri.com/education

About SRI International

Innovations from SRI International have created new industries, billions of dollars of marketplace value, and lasting benefits to society—touching our lives every day. SRI, a nonprofit research and development institute based in Silicon Valley, brings its innovations to the marketplace through technology licensing, new products, and spin-off ventures. Government and business clients come to SRI for pioneering R&D and solutions in computing and communications, chemistry and materials, education, energy, health and pharmaceuticals, national defense, robotics, sensing, and more.

Headquarters

SRI International
333 Ravenswood Avenue
Menlo Park, CA 94025-3493
650.859.2000

Additional U.S. and International locations

www.sri.com

Stay Connected

facebook.com/sri.intl
twitter.com/SRI_Intl
youtube.com/user/innovationSRI
goo.gl/+sri
linkedin.com/company/sri-international