Informal Science Education of Converging Technologies

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Abstract

The term "informal science education" is used to identify a wide variety of ways in which people learn about science outside of the formal educational process. While museums may have a tradition of preservation of objects for academic study, science and technology centers, which grew up everywhere in the second half of the twentieth century, focus on engaging the public in science. Driven initially by how phenomena could be put on display like objects in a museum, science museums developed a more explicit role in informal education, which has continued to evolve over time. Today's theoretic underpinnings of informal education in science museums are a convergence of the practices of the field with educational research and social science research. Educational research has identified the types of learning that are supported by informal educational experiences, and

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different theories of knowledge and learning have suggested different approaches in developing museums. With the emergence of educational challenges for science museums on topics of current scientific research and technological development that raise questions about the societal and ethical implications of the choices we make, research in the social and political sciences has converged with educational research and the practices of the field. This convergence enables informal education in science museums to grapple not only with core principles of science but also with the presence of science in society and with public policy issues related to science and technology. Emerging engagement in the science of science communication holds promise for further expanding and refining informal education approaches for building bridges between the world of science and technology and the many publics whose lives are influenced by it.

Introduction

Even as convergence of knowledge and technology has transformed the work of scientists and engineers in seemingly different disciplines for the benefit of society, a similar convergence has occurred in informal science education. In its broadest conception, the term "informal science education" is used to identify a wide variety of ways in which people learn about science outside of the formal educational process. The National Research Council report *Learning Science in Informal Environments*: *People*, *Places*, *and Pursuits*, published in 2009, noted that:

> Contrary to the pervasive idea that schools are responsible for addressing the scientific knowledge needs of society, the reality is that schools cannot act alone, and society must better understand and draw on the full range of science learning experiences to improve science education broadly. Schools serve a school-age population, whereas people of all ages need to understand science as they grapple with science-related issues in their everyday lives. It is also true that individuals spend as little as 9 percent of their lives in schools. (National Research Council 2009, p. 12)

The NRC report notes that scholars of informal education trace its roots in the USA to the late eighteenth century and institutions such as libraries, churches, museums, lyceums, and Chautauquas – all places where people gathered for learning, lectures, dialogues, debates, scientific experiments, and entertainment. In the mid-nineteenth century, people went to world's fairs to be exposed to a showcase of developments in science, technology, and industry. In the twentieth century, several world's fair sites provided permanent homes for science and technology museums – Chicago's Museum of Science and Industry, Seattle's Pacific Science Center, the New York Hall of Science, and San Francisco's Exploratorium among them. Early science museums in the USA drew inspiration from the Deutsches Museum in Munich, Germany, and were developed in Chicago, Philadelphia (The Franklin Institute), Boston (Museum of Science), and Saint Louis (Saint Louis Science Center). The great success of these and other early hands-on interactive science centers led to a worldwide explosion of science center development in the late twentieth century, and by the twenty-first century, the US-based Association of Science-Technology Centers listed nearly 400 such centers in their US database (www.astc.org) and another 100 from other countries, altogether hosting 95 million visits worldwide in 2013. Science and technology centers represent just one type of environment in which informal science learning takes place, but it is a significant one. The Association of Science-Technology Centers was founded in 1973, hosts an annual conference attended by over 1,500 leaders in the field from 42 countries, publishes a bimonthly magazine, and offers a variety of professional development and support services for the field.

While learning outside of school has taken place throughout human history, the field of informal science education was essentially defined by the creation of the Informal Science Education (ISE) funding program at the National Science Foundation in 1983. While funding for "public understanding of science" existed at NSF before that, the ISE program identified educational television, radio, and film projects; after-school programs; and science museum exhibits as components of informal science education. With grant funding came the requirement to use evaluation to assess and improve the impact of informal educational materials and activities (Robelen 2011). And with evaluation came the need to better identify learning outcomes consistent with research on learning in early childhood, particularly for children's museums and science museums with young audiences.

Informal science education is sometimes described as a craft because the community is seen as highly expert in what it does, but its "skills are rooted more in practice than in theory–a description that also fits formal education in schools" (Matterson and Holman 2012, 2.2). When you look across the wide range of practitioners of ISE, it is easy to see why this would be the case since the technical expertise needed for making television shows, designing exhibits, and running after-school programs for elementary school students varies considerably. Even in the specific case of developing an exhibit, a wide range of expertise is needed. Funded by the W. K. Kellogg Foundation in the 1980s, The Field Museum in Chicago developed a training program for exhibit development that identified three kinds of expertise and related responsibilities for an exhibit team:

Curator: The curator provides the scholarly expertise based on knowledge of the collection. As a subject matter specialist, the curator is responsible for establishing the overall concept of the exhibit.

Designer: The designer is responsible for the visual appearance and coherence of the exhibit. The designer's expertise assures that the material is set out in an appealing, understandable, and attractive manner.

Educator: The educator establishes the link between the content of the exhibit and the museum audience. The educator is a communication specialist who understands the ways people learn, the needs that museum audiences have, and the relationship between the museum's program and the activities of other educational institutions, including schools. The educator plans evaluation activities that will examine the exhibit's success in meeting its intended objectives and communicating with visitors (Munley 1986).

The Field Museum's training was instructive because the three team members they focused on had not only different expertise, but also different underlying values they brought to the development process, which sometimes, perhaps even often, resulted in conflicts during the creative process. Since the time of these Chicago trainings, science museum exhibit development teams have recognized a number of additional key players with different expertise to contribute to the work–project managers, fabricators, maintenance technicians, different types of designers (three-dimensional, graphic, and technical), evaluators, accessibility experts, and more, depending upon the nature of the project. It takes the convergence of skills and expertise from a variety of fields to develop a successful exhibition in which visitors will learn about science and technology on their own without additional guidance.

The informal science education field is itself diverse in the types of programs and institutions involved. Television and media projects may take similarly complex teams, but various programs that take place on the floor of a museum or in an after-school setting may be developed and implemented by a single individual or small group of individuals with similar expertise. In these cases, convergence may not yet be a reality but rather a future potential. Although an individul in this kind of position must often be a "jack-of-all-trades" with a wide range of expertise converging in a single person.

Real learning takes place in informal educational environments. Such environments are quite varied. Many of the practitioners of informal science education are highly skilled but work like craftspeople learning their methods from each other and improving their technologies on the job through both inspiration and trial and error. Some convergence with educational research has occurred since the 1980s, but new goals for informal science education to engage the public in new research areas like those associated with the convergence of nanotechnology, biotechnology, information technology, and cognitive science require twenty-first century informal science educators to engage also with knowledge from the fields of social and political science and with researchers studying the science of science communication. This convergence of these three areas of research – informal education, social and political science, and science communication – with the practice of informal education is the main focus of this chapter.

Convergence of Informal Science Education and Educational Research

In 2009, the National Research Council published *Learning Science in Informal Environments*: *People*, *Places*, *and Pursuits*. This report reflects on the theoretical perspectives on knowledge and learning that have guided an outpouring of research on the mind and the brain. These include behaviorist, cognitive, and sociocultural perspectives, each of which looks at learning differently. Behaviorist approaches focus on repetition and reward to support acquisition of simple skills that accumulate to become more complex concepts and behaviors. Cognitive theories may see learners as actively constructing knowledge and understanding in subject matter disciplines in connection with lived experience but primarily as individuals. Sociocultural theories focus on how knowledge and skills are developed in the context of the communities in which the learners are embedded. No grand convergence of these theoretical perspectives has guided the development of informal learning environments, but each has had influence in different areas and aspects of design.

The *Learning Science in Informal Environments* (*LSIE*) report constructs an integrated framework that brings about the convergence of learning theory with informal educational practices. Drawing principally from cognitive and sociocultural theories, *LSIE* proposed an "ecological" framework that integrates relationships between individuals and their physical and social environments. The framework uses people, places, and cultures as lenses to examine learning.

An example of convergence of theories of knowledge and theories of learning through a **people-centered lens** is the work of George Hein in the 1990s (Hein 1998). Hein saw behaviorist and cognitive theories applied across a range of learning experiences in ways that reflect a range of theories of knowledge – from seeing knowledge as objectively independent from the knower to the view that knowledge is individually and socially constructed. Mapping learning theories and theories of knowledge as two independent and orthogonal variables, Hein identified four quadrants with different approaches to informal education (Fig. 1).

If you think that knowledge exists objectively outside of the knower and that learning comes incrementally through repeated and progressive exposure to known content, you might organize a series of classroom lectures or the display of objects and information about them in what Hein calls a didactic, expository approach. The focus is on the knowledge and orderly presentation of it within the learning environment. This is typical of the traditional natural history museum in which minerals, shells, anthropological artifacts, stuffed animals, or other specimens are displayed in orderly and informative ways.

If you think that learning indeed happens in this way but that the knowledge learned is really a set of constructs in the mind of the learner, then you might take a more behaviorist approach providing rewards for progressive responses from the learner that are in line with learning goals. Programmed learning and computer games are examples that reward progression to higher and higher levels, and some museum exhibit and program activities have employed this question-answer-reward approach. It is quite typical for video and computer games to reward achievement with increasingly interesting and challenging levels of interaction.

If you think that knowledge does indeed have a reality external to the knower but that learners reconstruct that knowledge from their own experiences, then you might develop a discovery museum. This has been the dominant model in hands-on science and technology centers, in which exhibit developers construct experiences that will allow visitors to discover natural phenomena in the biological and physical world. Since the learner must construct knowledge that has objective

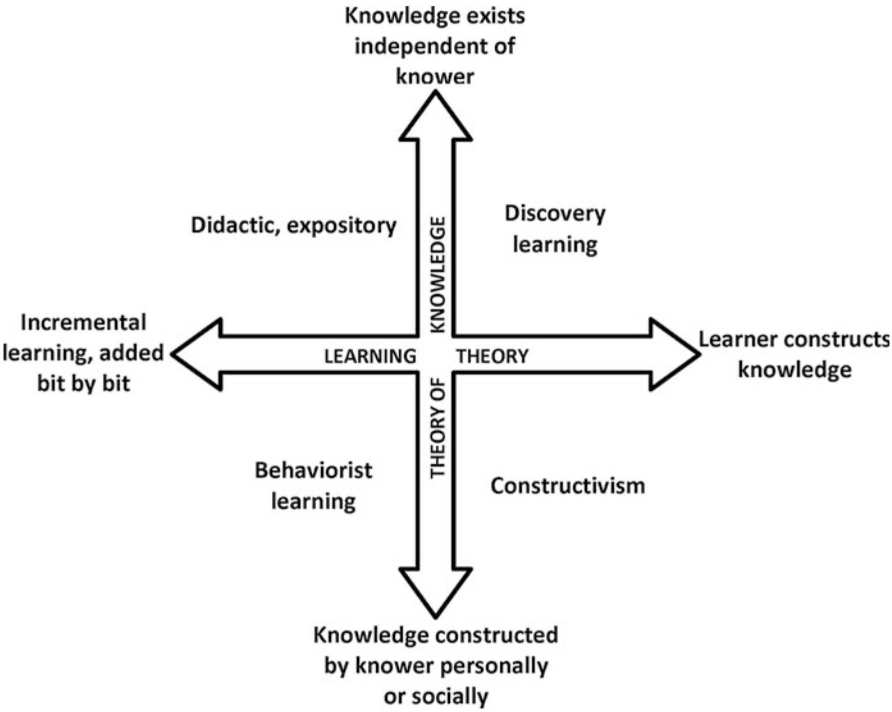

Fig. 1 Four domains of informal learning based on theories of knowledge and theories of learning (Redrawn with permission of George Hein)

reality, formative evaluation may be used to ensure that the designed learning experiences successfully lead visitors to the specific objective knowledge that is the goal of the learning experience.

If, however, you think that the knowledge that learners develop is really a set of constructs that are unique to the individual constructing it or to the social group with which individuals construct their understanding, then you might develop what Hein calls a constructivist museum. In such a museum, you might expect that different visitors will learn different things from the same experiences because they bring different knowledge with them at the outset. Open-ended, self-directed, multiple-outcome activities allow visitors to construct new knowledge that is most relevant to them. Hein clearly identified this quadrant as the one that reflects his views on the way that people actually learn and on the nature of what they learn.

Constructivist approaches are valuable for a wide range of learning objectives in science and technology, but they are inescapable for engaging the public in consideration of the societal implications of science and technology and especially in areas of new technological development where personal and societal values drive decisions as much as scientific evidence does. (The next section will discuss this further.).

Another component of the LSIE ecological framework, the *place-centered lens* (pp. 36–38), acknowledges the resources and practices associated with a wide variety of physical environments in which people learn. The awe of the Grand Canyon or Denali National Park, the night sky in the country far from city lights on a moonless night, a walk in the forest or along the rocky ocean shore at low tide, a plot of soil in the backyard or in a window box all provide unique opportunities for learning. Informal educators and naturalists make use of these unique opportunities all the time. Exhibit developers, after-school/out-of-school educators, media producers, and developers of online environments explicitly design settings to foster place-centered learning. Informal learning spaces have artifacts, materials, tools, practices, and supports that facilitate unique learning experiences. Such a space can be thought of as a "cabinet of wonders" – a world of fascinating scientific curiosities concentrated in a relatively small space eliciting one reaction after another and thereby constituting a unique place of learning and fun in the minds of the participants.

At the core of creating such learning spaces is the idea of experiential learning, which was most prominently proposed by John Dewey in his 1938 book *Experience and Education*. In 2012, George Hein documented how Dewey's ideas influenced museums, the 1973 establishment of the Education Committee of the American Association of Museums, and the 1981 launch of the Journal of Museum Education (Hein 2012). Science and technology centers are typically designed to be navigated freely – visitors choose their path and which activities they participate in. They may also be designed to serve a diverse range of visitors of different ages, backgrounds, and interests.

The *culture-center lens* described in the LSIE report reveals that all learning is a cultural process in which learners access and express their own ideas, values, and practices through their social affiliations. Out-of-school contexts can create social environments in which children become motivated and competent in areas in which they are failing in school. The Computer Clubhouse, for instance, which was originally developed at The Computer Museum in Boston and is now headquartered at the Museum of Science, is a creative and safe out-of-school learning environment where young people from underserved communities work with adult mentors to explore their own ideas, develop new skills, and build confidence in themselves through the use of technology. There are now 100 Intel Computer Clubhouses around the world. In a 2013 survey (SRI 2013) of Computer Clubhouse alumni, 97 % said the Clubhouse was the most important source of support in their lives for setting high goals and expectations for themselves. The Clubhouse has many success stories, and as one alumnus put it, "It was like a big family. My experience there made me more interactive with people. It's not only a great place for learning but for networking with great people while having fun" (http://www.computerclubhouse.org/alumni/steve).

The outcome of the NRC's work in 2009 to cut across various educational theories and to explore people, place, and culture lenses was to converge on a set of six interdependent strands that describe goals and practices of science learning (Fig. 2).

Strands of Informal Science Learning

Learners who engage with science in informal environments . . .

Strand 1: Experience excitement, interest, and motivation to learn about phenomena in the natural and physical world.

Strand 1: Come to generate, understand, remember, and use concepts, explanations, arguments, models and facts related to science.

Strand 3: Manipulate, test, explore, predict, question, observe, and make sense of the natural and physical world.

Strand 4: Reflect on science as a way of knowing; on processes, concepts, and institutions of science, and on their own process of learning about phenomena.

Strand 5: Participate in scientific activities and learning practices with others, using scientific language and tools.

Strand 6: Thing about themselves as science learners and develop an identity as someone who knows about, uses, and sometimes contributes to science.

Fig. 2 Strands of informal science learning (National Research Council 2009, p. 43)

These six strands have become a solid foundation upon which to plan, develop, and assess learning in informal environments. They represent the convergence of educational theory and research with the practice of informal education.

Knowledge of this convergence of educational research and informal educational practice was important to the development of educational experiences for the public on the topic of nanoscale science, engineering, and technology at the outset of the work of the NISE Net in 2005 because front-end evaluation showed that less than half of the industrialized adult population of the USA, Canada, and the UK had heard of nanotechnology and not more than 20 % could provide some sort of definition. Furthermore, interest in nanotechnology among the public was quite low compared with other emerging and current technologies. In addition, the informal science education community did not have decades of experience developing exhibits, programs, and media in the domain of nanoscale science, engineering, and technology, and there was no large extant base of such materials to learn from and to use as a basis for further designs. Hence, NISE Net developers had to find new ways to design informal educational materials to communicate new concepts to the public and to be attractive and feasible to the ISE and research communities. The larger ISE community itself had little expertise, experience, or incentive to do nanoscale education for the public. NISE Net was starting from scratch in developing institutional capacity and readiness to implement nanoscale education. So traditional informal educational practice needed to be supported by formative evaluation activities that measure educational achievement of new ideas, concepts, and approaches in the context of goals aligned with the strands of informal learning described by the *LSIE* report.

Convergence of Informal Science Education and Social and Political Science

In the late 1980s, the Museum of Science in Boston developed a series of exhibits that were organized around science thinking skills rather than traditional content areas. The underlying notion was to stimulate visitors in the construction of knowledge in ways similar to those used by scientists. In retrospect, this work can be seen as focusing explicitly on Strand 3 in the *LSIE* report (which had not been written yet) with the intent of generating pathways to the kinds of learning identified particularly in Strands 2, 4, and 6. The broad themes of this long-range exhibit plan and the associated scientific activities were the following:

- *Seeing the Unseen* (observation)
- *Finding the Pattern* (classification)
- *Making Models* (description)
- *Testing the Theory* (experimentation)
- *Putting It to Work* (application)
- *Playing with Ideas* (imagination)

When The Computer Museum in Boston closed in 2000 and organizationally merged with the Museum of Science, the latter organization began to examine the content and thinking skills that should be part of a new focus on technology. For technologies, thinking skills include innovation and engineering. With engineering comes a new set of issues noted in the 1989 report *Science for All Americans*, published by the American Association for the Advancement of Science (AAAS):

> Engineering decisions, whether in designing an airplane bolt or an irrigation system, inevitably involve social and personal values as well as scientific judgments. (AAAS 1990, p. 40)

"Social and personal values" are not among the typical content areas in most hands-on, interactive science museum exhibits, not in the list of science thinking themes adopted in Boston, and not in the six strands of informal science learning in the LSIE report. Furthermore, an experiment in building value-laden issues into science museum programming conducted by The Franklin Institute between 1991 and 1996 found that

> ...presenters were uncomfortable with issues-related programming, preferring "concrete" science that did not venture into politics. The changing nature of points of view on the subject also evoked some concern, as did the fact that the topic...raises questions that cannot be answered definitively. (Mintz et al. 1995)

Despite this reluctance, the need to venture into issue-related programming in science museums grew with the publication of the National Research Council's report *Technically Speaking* in 2002.

> As far into the future as our imaginations can take us, we will face challenges that depend on the development and application of technology. . ..To take full advantage of the benefits and to recognize, address, and even avoid the pitfalls of technology, Americans must become better stewards of technological change. Present circumstances suggest that we are ill prepared to meet that goal. (Pearson and Young 2002, p. 12)

Calling for widespread "technological literacy," the *Technically Speaking* report describes the need as comprised of "an understanding of the nature and history of technology, a basic hands-on capability related to technology, and an ability to think critically about technological development" (Pearson and Young 2002, pp. 11–12). The first two of the components of this definition of need were fully within the existing experience and toolset of science museums, but the third was not.

Dialogue and Consensus Conferences

Forum programs derived from Danish Citizen Consensus Conferences introduced a different type of programming into informal science education in museums. A solution to the conundrum of how to introduce social and personal values, and questions that cannot be answered definitively, into educational programs in museums came when three scientists (Steven Katz, Patrick Hamlett, and Jane Macoubrie) from North Carolina State University (NCSU) reported on their experiments with citizen consensus conferences about genetically modified foods at the annual meeting of the AAAS in 2002. Citizen consensus conferences were used by the Danish Board of Technology (DBT) to provide input to the Danish Parliament from citizens about new technological developments. DBT provided a panel of citizens with background information on the technology in question, access to experts for technical information, a deliberation process, and the opportunity to write and present a final report. The panel of ordinary citizens brought their common knowledge, personal experiences, and societal and personal values to the deliberations. The whole process was typically carried out over 2–3 months.

The team at NCSU had experimented with a similar process both to acquire the input the citizens could provide and to learn about the consensus process itself. Some in the informal education community saw the overall concept as a potentially engaging educational experience for their own audiences. The Museum of Science conducted a series of prototype forum programs on variations of the consensus conference format with total program times from 2 to 8 h. Attendees found it an interesting experience and enjoyed both learning about new topics and hearing the diverse views of different people on the issues raised.

While conducting this kind of deliberative dialogue with the public was new to science museum educators, there were other organizations that did it all the time. *National Issue Forums* (NIF) is a network of civic, educational, and other organizations and individuals, whose common interest is to promote public deliberation in America. The *National Coalition for Dialogue and Deliberation* (NCDD) is a network of nearly 2,000 innovators who bring people together across divides to discuss, decide, and take action together effectively on today's toughest issues. The *Public Conversations Project* (PCP) has worked in the USA and around the world since 1989 facilitating dialogues on a wide range of contentious issues in order to prevent and transform conflicts driven by deep differences in identity, beliefs, or values. These groups and others like them do not necessarily focus on issues related to science and technology, though science and technology often come into play, and they provided models of public engagement that science museum educators could learn from.

Public Engagement with Science

Public engagement with science emerged within the informal science education community in the USA as a different way of engaging the public, in 2009 when the NSF-funded Center for the Advancement of Informal Science Education (CAISE) developed the report *Many Experts*, *Many Audiences*: *Public Engagement with Science and Informal Science Education* (McCallie et al. 2009). That report notes that public engagement with science (PES) is an approach that developed during the prior decade within academic settings and the science policy arena.

> . . .Public Engagement with Science (in related) literature and practice has a specific meaning that is characterized by mutual learning by publics and scientists – and, in some cases, policy makers. This orientation contrasts with a one-way transmission of knowledge from "experts" to publics. Specifically, PES experiences allow people with varied backgrounds and scientific expertise to articulate and contribute their perspectives, ideas, knowledge, and values in response to scientific questions or science-related controversies. PES thus is framed as a multi-directional dialogue among people that allows all the participants to learn. PES activities in the context of informal science education may – but do not necessarily – inform the direction of scientific investigations, institutions, and/ or science policy. (McCallie et al. 2009, p. 13)

Many in the science communication and public policy arena have argued that to do this, there is a need to engage the public in multi-directional dialogue about science-related societal and public policy issues in a way that allows scientists to learn from the public as well as the public to learn from the scientists (Barben et al. 2008).

> We need to move beyond what too often has been seen as a paternalistic stance. We need to engage the public in a more open and honest bidirectional dialogue about science and technology and their products, including not only their benefits but also their limits, perils, and pitfalls. (Leshner 2003, p. 977)

ISE professionals are uniquely situated to inspire and mediate the types of interactions between scientists and publics that are critically needed today. Science centers already engage scientists as advisors and speakers, partner with them in outreach activities of all kinds, and provide training and opportunities to practice science communication skills. ISE institutions are skilled at communicating science to the public and are seen as trusted conveyors of controversial scientific topics. Thus, they are well positioned to facilitate conversations among diverse stakeholders about socio-scientific issues – societal issues that are informed by science. Despite this potential, ISE programming that explores the full benefits of PES is still limited (Kollmann 2012).

The Museum of Science conducted a survey in 2011 to explore the prevalence of PES activities in the work of the ISE community. Over 150 organizations submitted descriptions of 201 projects – ranging in format from art and theater to festivals to on-site research. Analysis of these case summaries found that most commonly, projects had public awareness, knowledge, or understanding goals and public engagement or interest goals to a lesser extent, but projects were much less likely to include goals for the scientists' involvement (Iacovelli et al. 2012). Despite high levels of interest in PES in the ISE community indicated by the responses to this survey and field-wide goals such as those in the Science Centre World Congress *Toronto Declaration* in 2008 ("We will actively seek out issues related to science and society where voices of citizens should be heard and ensure that dialogue occurs"), very little robust PES was happening in US science museums as of 2011.

Social Science Content

Informal educators for the most part were taught science concepts and processes in school, in a way that appears to have an objective, rather than subjective, basis. But when societal and personal values come into play, for many science educators the content is unclear. What values? Whose values?

In 2005, NSF funded the Nanoscale Informal Science Education Network (NISE Net) to increase public awareness, knowledge, and engagement with nanoscale science, engineering, and technology. The idea was to create collaborations between informal educational institutions and nanoscale research centers in order to raise the capacity of both types of organizations to engage the public in learning about nano. Tying all of these local partnerships together would be a national network infrastructure. The Museum of Science, the Science Museum of Minnesota, and the Exploratorium partnered to win the award from NSF to establish the NISE Net.

NISE Net developed a wide range of educational materials including tabletop and classroom hands-on activities, theater and stage presentations, media, exhibits, and a wide range of training materials, guides, and other resources. A group of five institutions worked together to develop, test, and deliver forum programs that engaged visitors in dialogue and deliberation about such topics as who should be involved in shaping future development and regulation of nanotechnology, under what conditions should nanotechnology applications in medicine and personal care products be made available to the public, and how should nanotechnology research fit into domestic energy policies in the near future. These forum topics went beyond even the novel physics and chemistry of nanoscale science and led informal educators to find social scientists, political scientists, and ethicists at their local universities to make presentations and help with the planning of the program content.

At the same time that NSF funded the NISE Net, it also funded two centers for nanotechnology in society, one at the University of California at Santa Barbara and one at Arizona State University. The latter became heavily involved in the work of the NISE Net and provided the critical missing component of the public engagement work – the science and society perspective and content drawn from the social and political sciences that is missing from the backgrounds of most informal science educators.

In 2007, a team of researchers and educators in the National Center for Learning and Teaching in Nanoscale Science and Engineering (NCLT) presented a draft of a document that was later expanded into *The Big Ideas of Nanoscale Science and Engineering*: *A Guidebook for Secondary Teachers* (Stevens et al. 2009). The draft primarily covered eight big ideas in physics, chemistry, engineering, and mathematics and only one big idea about science, technology, and society. Later that year, a team of researchers at the Center for Nanotechnology in Society at Arizona State University developed a parallel document *Nanotechnology and Society*: *Ideas for Education and Public Engagement* (Miller et al. 2007). This guide included ten big ideas:

- *People make nanotechnologies*
- *People live with*, *in*, *and through technologies*
- *Technological and social change are closely connected*
- *There are many ways to design*, *implement*, *and use a given technology*, *and many technological solutions to a given problem*
- *Technological systems are frequently highly complex*, *interdependent*, *and difficult if not impossible to predict*
- *Social and technological change can be incremental – or disruptive – and it can be hard to forecast which*
- *New technologies are often controversial and may create new risks*
- *Our technological imagination shapes our future*
- *People already play an important role in governing new technologies*, *and they can play an even bigger roles*
- *We need to be more reflexive about how we assess nanotechnology*. (Miller et al. 2007)

Researchers from the Center for Nanotechnology in Society (CNS) at ASU argued for societal and ethical implications content to be included not only into forum programs but also added to the more traditional educational formats used in science museums to communicate physical and biological science concepts. Forum programs require a longer time commitment that traditional museum experiences for both participants and facilitators, and so while highly impactful, they generally reach much smaller audiences than do short educational activities that take place in the exhibit halls as part of a normal museum visit.

So CNS researchers and NISE Net educators collaborated to develop a set of resources, educational activities, guides, training materials, and workshops centered on the theme of Nanotechnology and Society.

> The Nano and Society project of the Nanoscale Informal Science Education Network (NISE Net) is designed to empower museum educators and visitors to explore the relevance of nanotechnology in our lives. The project builds upon the fundamental scientific concepts, tools, and processes related to nanotechnology that are central to many of NISE Net's other educational materials and programs. It then considers how new nanotechnologies may affect people and the societies they live in and create. These technologies will open up new possibilities, shape our relationships, promote the values of those who build them, and through a variety of systems affect many different parts of our society and communities. This project is different from many other museum programs because it seeks to encourage visitors not just to think about science and technology, but to participate in the conversation. To achieve this, it encourages conversations that can help museum guests think through what their values are, better understand how other people think about values, recognize the expertise they have, and increase their confidence to contribute to the broader discussion about these technologies. At its core, this project aims to illustrate that while new nanotechnologies will help shape our future, people everywhere have opportunities to influence what that future looks like. (Wetmore et al. 2013, p. 5)

In developing educational materials for informal educators to use with museum visitors and training on how to use the materials, CNS researchers and NISE Net educators concentrated on three big ideas revising and combining elements from the earlier list of ten.

Nano and Society: Big Ideas

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

1. **Values shape technologies**.
   (a) Our values shape how technologies are developed and adopted:
      - Technologies reflect the values of the people who make them.
      - Individuals choose technologies to advance their goals, hopes, and dreams.
      - Companies build technologies that can be sold for a profit.
      - Governments fund technologies in an effort to benefit their economy and their citizens.

   (b) The adoption of technologies benefits some people more than others:
      - With any technology, no matter how useful, there are winners and losers.
      - Technologies can be used to promote one group's values and interests over other groups.

- Technologies can lead to conflicts over values, among groups, or even within an individual.
- Some of these effects are deliberate and some are unintended.

2. **Technologies affect social relationships.**
   (a) Technologies often change the relationships between people:
   - Technologies affect the way we interact with family members, people in our community, and people around the world.
   - People negotiate with each other and with new technologies to maximize their own values.

   (b) New technologies are often accompanied by changes in cultural norms:
   - We are all actively involved in developing acceptable behaviors related to technologies.
   - These new norms will not reflect everyone's values equally.

3. **Technologies work because they are part of systems.**
   (a) Technologies are part of larger systems that include technological, political, social, and environmental components.
   (b) Many people and groups are involved in the development and adoption of new technologies.
   (c) We affect the development and use of technologies through our actions and choices (as consumers, citizens, voters, workers, parents).
   (d) In order to understand the role that technologies play and the effects they have, we need to think about the ways they are connected to systems and people (NISE Net 2012).

Anticipatory Governance

Engaging the public in learning about and participating in dialogue and deliberation about future and emerging technologies is a reflection of a broader theoretical construct presented by David Guston of Arizona State University's Center for Nanotechnology in Society as "anticipatory governance." Guston defines anticipatory governance as "a broad-based capacity extended through society that can act on a variety of inputs to manage emerging knowledge-based technologies while such management is still possible."(Guston 2008) In pursuing anticipatory governance, Guston suggests activities that encourage and support scientists, engineers, policy makers, and other publics to reflect on their role in nanotechnology through an awareness of their own position as a participant with a specific set of roles and responsibilities in a field of other actors. Those roles call for the ability of a variety of lay and expert stakeholders, both individually and through an array of feedback mechanisms, to collectively imagine, critique, and thereby shape the issues presented by emerging technologies before they become reified in particular ways (Barben et al. 2008).

So the argument from the social and political science community to the informal science education community is that while few members of the lay public need to know about chemical bonds or planetary mechanics, they do need to know about how the decisions we are all making today or failing to make will impact our future, and we as educators need to know how we can help people develop the knowledge and skills the public needs to effectively play the roles that the future depends upon.

The Science of Science Communication

A new area of convergence for informal science education is the science of science communication. The NSF-funded NISE Net project created partnerships between science museums and university-based research centers. A central tenet of this arrangement was that the museum staff knew a lot about engaging the public but little about nanotechnology, and the researchers knew a lot about nanotechnology but little about engaging the public. The NISE Net project created a lot of educational materials that the university partners could use in their educational outreach activities, and it also provided training to NanoDays presenters and others from university research centers on how to use the materials. This led to a variety of activities throughout the network but most specifically at the Museum of Science and at the twice-annual meetings of the Materials Research Society (MRS) that focused on science communication professional development for mostly early career scientists.

At MRS, these professional development activities took the form of seminars on communicating through presentations, posters, working with the media, and in writing. These seminars were quite popular and became a staple of MRS meetings. The Museum of Science developed science communication training specifically for students in Research Experiences for Undergraduates (REU) programs and for graduate student participation in outreach events like NanoDays. Materials to conduct these two activities were developed and posted in the NISE Net library of educational materials at www.nisenet.org for all to use, and workshop helped to spread their use in the field. At the same time, the Pacific Science Center launched the Portal to the Public project, which was designed to assist informal science education (ISE) institutions as they seek to bring scientists and public audiences together in face-to-face public interactions that promote appreciation and understanding of current scientific research and its application. Starting with three science centers in 2007, the Portal to the Public network grew to 30 science centers by the end of 2013 (www.pacificsciencecenter.org/Portal-to-the-Public).

This work and the public engagement work discussed earlier drew the attention of ISE practitioners to two Sackler colloquia conducted by the National Academy of Sciences in 2012 and 2013 on the science of science communication. While informal science educators were aware of a body of research about science education, the research on science communication was fairly new to the field. Organizers of these colloquia and editors of the public volume of proceedings argued that beyond the discipline specific research field being communicated to the public and educational research that has informed informal education in the past, the research of psychologists, sociologists, decision scientists, and communication scientists can play a central role in informing successful science communication.

> Although scientists may know more than anyone about the facts and uncertainties, applications of . . . science can raise complex ethical, legal, and social questions, regarding which reasonable people may disagree. As a result, if scientists want to be effective in their communication, they must understand and address the perspectives of interest groups, policy makers, businesses, and other players in debates over decisions that require scientific expertise.
>
> . . .the stakes are too high to rely on intuitive theories and anecdotal observations about communication. It would be foolish to ignore the best available scientific evidence. The social, behavioral, and decision sciences have documented the many ways in which intuitions about others and about the effectiveness of communication can go wrong – and how those biases grow with the distance between the parties. The unique ways of looking at the world that make scientists such indispensable sources of information may also distance them from nonscientists. Making the most of what science has to offer society requires the give and- take of two-way communication with laypeople. . .. Ineffective communication can be costly to science as well as to society. (Fischoff and Scheufele 2013, pp. 14031–14032)

The extent to which science museums in the decades ahead see themselves as facilitating communication between scientists and a variety of publics, informal educators becoming familiar with and putting into practice the findings of research on science communication will become increasingly important.

Informal Education and Ubiquitous Information: Convergence of Education and Informatics

Informal science and education is enhanced not only by social sciences but also by the ability to communicate across fields, communities, and places using the Internet, large data bases crossing the fields, and methods of interaction between diverse groups. The evolution taking place in ISE would not be possible without modern means of communication and methods of finding information. ISE and social sciences are enabled quantitatively and changed qualitatively because of the new computer and informatics tools.

Educational media – television and radio – have been key contributors to informal science education. As early as the 1950s, *Watch Mr. Wizard* and *The Bell Laboratory Science Series* brought science to public audiences' homes across America, and numerous shows continued that work into the twenty-first century. *Cosmos*, *Scientific American Frontiers*, *MythBusters*, *3-2-1 Contact*, *Bill Nye the Science Guy*, and *Nova* are just a few television shows that have engaged audiences with science.

With the emergence of the World Wide Web in the 1990s and its subsequent growth, the public has a new major source of resources for informal science education. In formal education, universities have put entire curricula online and even offered degrees for online students. As of 2014, however, relatively little research existed on informal science learning through online environments. The Center for the Advancement of Informal Science Education (CAISE) Informal

Science Evidence Wiki is a source of information about current research in this area.

> For attentive, motivated, and knowledgeable audiences, science-related blogs likely enhance learning, build relationships with users, and visibility for a project or initiative.... However, blogs face many barriers in reaching younger audiences and unmotivated audiences, requiring dedicated resources, informed strategies, and staff to be effective.
>
> Over the past few decades, digital games on computers and mobile devices have grown in popularity as a teaching and learning tool....Research into digital games (however) is still in its relative infancy, and researchers' findings often conflict with those of others in their field.
>
> A large body of research exists on how to design formal educational software for non-mobile devices ... but there is considerably less information on how to design effective educational software for mobile devices, let alone informal educational software for mobile devices. The ways in which mobile devices are used differ along several important dimensions, which suggests that merely adopting lessons learned from more traditional desktop-based classroom software may not be effective.
>
> Recent research investigated the question of how learning from combined use of related, multiple media platforms (known as cross-platform learning) compares to learning from a single medium ....using the PBS school-age mathematics series Cyberchase, found that combined use of the Cyberchase television series and online games produced more consistent improvement in children's mathematical problem solving than use of either medium by itself....Moreover, the study found that, compared to children who played online Cyberchase math games without also watching the TV series, children who used multiple media also employed significantly more mathematically sophisticated strategies to play the online games....These points also suggest intriguing possibilities for convergent media, in which the narrative and explanatory power of video, the participatory strength of interactive games, and the in-person support provided in hands-on media can be combined in a single experience. (CAISE, Informal Science Education Evidence Wiki)

One early experiment with convergence between informal science education and informatics was the Science Learning Network project funded by NSF and led by the Franklin Institute in Philadelphia. The project involved six science museums and the global information technology company Unisys.

> With the goal of integrating the resources of informal educational institutions with the power of telecomputing, the (Science Learning Network's) theory of action incorporated a multi-pronged approach to supporting inquiry science teaching and learning in K-8 public schools.... SLN (provided) important images of the ways that museums, schools, and teachers move forward with integrating technology into their educational missions. (Blanc et al. 1998)

When the Experience Music Project (EMP) opened in Seattle in 2000, developers showed an unusually high regard for information in the context of artifacts and hands-on interactive museum environments. Perhaps this is not surprising with the realization that Microsoft co-founder Paul Allen was at the center of the project. In addition to the artifacts, labels, and hands-on activities, EMP provided all visitors with headphones and a digital audio tour guide worn over the shoulder. Recorded exhibit tour guides were not uncommon at the time, often providing narrative explanations of exhibit artifacts. (Charlton Heston who played Moses in the film

The Ten Commandments narrated the recorded tour for the Ramses the Great Exhibition.) But the data base for EMP's tour guide was more extensive than a recorded narrative. You could access audio recordings made with the various instruments on display in the galleries or by the artists whose personal artifacts were on display. You could also bookmark items in the EMP Digital Collection that you want to access later in your tour or at home on the museum's website. A seeming world of information was at your fingertips throughout the tour.

With the explosion of handheld mobile technology both in terms of capacity and distribution, visitors today can indeed have a world of information at their fingertips. For instance, *DIY Nano* is an iPhone app created by the Lawrence Hall of Science for the NISE Net (www.nisenet.org) that connects visitors to a variety of videos, hands-on activities, and the whatisnano.org website.

In 2013, the Museum of Science in Boston opened a new exhibition about health and human biology called the Hall of Human Life (HHL). Emphasizing that research in human biology and health was being revolutionized by the convergence of biology and information technology, the exhibition is built upon a base of information provided by its visitors. Visitors get bar-coded wristbands as they enter the exhibition and use them to activate a series of link stations in five themed environments – Communities, Time, Organisms, Food, and Physical Forces – where they collect or enter data about themselves anonymously into the exhibition database. Visitors' experiences are personalized as they see the shape of their own foot arch and compare it to others or measure how many calories they use up while walking at different paces and with different strides. They test their ability to recognize faces, to balance themselves, to pay attention, and to explore how they relate to their families and how their circle of friends changes their brains. Visitors to the HHL can then later access their data online at home or in their classroom.

In addition to the kinds of information resources that science museums, media, and community programs might use directly with their public audiences, online information systems now form the backbone for online collaboration, mutual learning, and distribution of educational resources throughout the professional communities of informal science educators. Here are just a few examples of the many that exist in 2014:

http://informalscience.org The Center for the Advancement of Informal Science Education (CAISE) works in collaboration with the National Science Foundation (NSF) Advancing Informal STEM Learning (AISL) program to strengthen and advance the field of professional informal science education and its infrastructure by providing resources for practitioners, researchers, evaluators, and STEM-based professionals.

www.howtosmile.org is an online tool that allows educators to search, collect, and share high-quality, hands-on science and math activities.

www.nisenet.org houses an online library of 500 informal educational resources focused on various aspects of nanoscale science, engineering, and technology.

www.ngcproject.org provides extensive resources aimed at encouraging girls to pursue careers in science, technology, engineering, and mathematics.

Impacts of Convergence on Informal Science Education

Informal education identifies its domain of impact as outside of school time learning, meaning beyond the hours of 9 AM to 3 PM (or whatever normal school hours are), beyond the months of September through June (or whatever the school year is) and beyond the ages of 5–22, or however long an individual continues in formal education. The audience includes preschoolers, children of all ages with or without their families, and adults for whom formal education is a distant memory. There is a wide range of goals associated with informal education and these audiences, but at the outset of the Nanoscale Informal Science Education Network, two that emerged that have ongoing relevance for all fields of science and technology, but especially for those that are emerging and show great promise for the future, are the following:

- To help youth and their families see a role for themselves in the future that is unfolding in the new and emerging fields of scientific research and technological developments
- To help adults make informed decisions about the development and application of future technologies that are not clouded by misperceptions and unwarranted fears

The convergence between informal educational practice and educational research has helped guide the development of out-of-school experiences that are engaging and stimulate many types of learning, while at the same time has broadened our concept of what learning includes. This has been particularly effective in providing engaging learning experiences for children that stimulate their curiosity, generate a sense of excitement about learning science, and help them think of themselves as someone who can know something about and contribute to science and technology.

The convergence between informal educational practice and social science research has broadened the content for informal education from basic physics, biology, chemistry, astronomy, geology, engineering, and other fields of science typically taught in school to issues of the impacts of science and technology on people and society more broadly as well as the corresponding impacts on science and technology of people and society. This has been particularly helpful in supporting the needs of adult audiences in understanding the relevance and implications of technological development.

The emerging convergence between informal educational practice and research in a collection of disciplines related to the science of science communication is yet to be fully realized. The promise it holds is to support informal education organizations like science museums in facilitating fruitful dialogue between members of various scientific communities and members of various publics. The form of that facilitation might include organized engagement events, training for scientists in communication practices, or other mechanisms to support two-way communication and to build mutual respect and trust.

The convergence between informal education practice in science museums and research in education, in the social and political sciences, and in the science of science communication has changed the roles that museums can play within society: from the cabinet of curiosities to the informal learning environment, from science content to science thinking skills, from public understanding of science to public engagement with science, and from a venue for informal learning to a facilitator of increased capacity for public engagement with science within the scientific community.

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