Opportunities and Challenges of Creating an Infrastructure for Public Engagement in Nanoscale Science and Engineering

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The View From NSF

The workshop began with a working dinner on Thursday evening, September 2, 2004, and continued throughout the day on Friday. William Frascella, Director of NSF's Divison of Elementary, Secondary, and Informal Education, welcomed and introduced the participants. Dr Frascella then described the goals of the workshop, and presented background information on NSF's Nanoscale Science and Engineering Education (NSEE) program; the National Science Board "Broader Impacts" proposal review criterion; ongoing education initiatives at NSF-funded Nanoscale Science and Engineering Centers; current research initiatives in science museums; and existing collaborations between NSF-sponsored Nanoscale Science and Engineering Centers (NSECs) and museums. He emphasized the need for additional infrastructure within the museum community, and connecting the museum and nanoscale research communities, if collaborations are to have the most significant impact on public understanding and perception of nanotechnology.

Next Mihail Roco, NSF's Senior Advisor for Nanotechnology, addressed the group to give some general background on nanotechnology. He gave a history of the development of organized "nano" initiatives, and of the emergence of public awareness of nanotechnology. Dr. Roco pointed out that many people first hear of nano through high visibility visionaries and science fiction authors, rather than through mainstream researchers who are less well known. The Science Museum community, working with nano researchers, has an opportunity to combine high visibility with scientific accuracy and effective pedagogy.

The seeds of the nanoscience explosion were sown about 20 years ago with the development of scanning probe microscopes and the discovery of buckyballs, the first of the fullerene molecules. A host of new kinds of chemicals, materials, and devices has ensued from work involving many researchers from numerous disciplines, often by NSF grantees.

At NSF, nanoscience and engineering has tremendous support, including substantial investments within the core programs and cross-directorate activities within the NSE Priority Area. Including new starts in Fall '04, NSF supports 19 nanocenter efforts: 16 Nanoscale Science and Engineering Centers, the National Nanotechnology Infrastructure Network (NNIN), the Network for Computational Nanotechnology (NCN), and the initial Center for Learning and Teaching (NCLT). Several other federal agencies support large nanocenters. DOE is developing such centers at five of its National Laboratories. NASA sponsors four centers, and DOD supports three. All of the NSF centers, and many of the others, have large outreach activities, educational initiatives, or research on societal and ethical issues. All are potential collaborators for workshop participants and, perhaps, models for collaborative infrastructures.

NSF intends to play a role in ensuring that the resources of the nanocenters are available to the education community, and to facilitate connections with the many "nano-grantees" supported through core programs. The integration of education and research continues to be a strong theme throughout the agency.

The Foundation has already initiated efforts to bring nanoscience and nanoengineering to students at all educational levels. Graduate student training has been part of NSF's nano efforts from the beginning, and individual grants for nanoscience education at the undergraduate level started at least a decade ago. NSF developed the Nanoscale Science and Engineering Education (NSEE) solicitation in response to a challenge from the leaders of NSF's Nanoscale Science and Engineering Priority Area: *How can we bring nano ideas into science education more systematically?* The first NSEE awards were made in 2003. They extend nano education efforts to K-12, emphasizing middle school and high school. The 2004 solicitation was the first to include the NCLT program. The NCLT is tasked with facilitating the transfer and transformation of knowledge in grades K-16 while developing leaders in nano education – PhDs with credibility in both the educational community and a scientific discipline.

In developing the NSEE solicitations, the NSF staff realized that identifying deliverables was essential to developing strong programs. Educational research is a suitable deliverable, as are curricular materials, professional development programs, college course designs, films, and museum exhibits. The staff further recognized that NSF-sponsored research and related activities in NSEE will have the broadest possible impact—as mandated by the National Science Board's second review criterion for all NSF grants[1]—only if the Foundation works at the program level, not the individual grant level, to create an infrastructure which helps institutions develop successful outreach efforts. Societal issues have high visibility in fields like nano, so engaging public audiences should be a critical effort for NSF. Collaboration is implicit in the envisioned infrastructure, since narrowly constituted teams cannot not have *all* the skills and tools needed to develop the identified deliverables.

In the next decade, research and education will emerge as two activities on the same continuum. This workshop arose out of the realization that this emergence begins at a time when public awareness of nanotechnology is growing, and when multiple science and engineering disciplines are converging at the nanoscale. This presents a unique opportunity to the Foundation and to the communities represented here. One workshop goal was to suggest strategies for capitalizing on this opportunity in ways that respond to the Priority Area challenge by systematically introducing nano ideas in public settings. A further goal was to ensure that that these strategies target a wide and diverse audience, while addressing national goals. As an example, workforce training in nanoscience and technology is specifically called for in the authorizing legislation for the National Nanotechnology Initiative (signed into law on 3 December 2003). This is a matter of national competitiveness given the worldwide attention to nanotechnology. Strategies that bring new ideas into education, address social aspects of nanotechnology, and emphasize connections between disciplines—all with the above goals in mind—could serve as models for programmatic implementation of the NSF Broader Impacts Criterion throughout the Education and Human Resources Directorate.

Dr. Frascella noted that encouraging fruitful collaborations was an *a priori* reason for convening the workshop. The convergence of technologies, in nanoscale science and engineering as well as other fields, and the complexity of the emerging cyberinfrastructure are much too difficult to handle without collaborators. Many NSF-supported Research Centers are realizing that community and learning issues are central if they are to help the Foundation reach key goals like developing a diverse and integrated technical workforce. Scientists and engineers, local business and industry (already participants in many Research Centers), formal educators, and informal educators like Science Museums have an opportunity to form partnerships, based on mutual understanding of each others abilities and value propositions, to collaborate on these issues. Nanotechnology, with its strong interdisciplinary favor and growing public identity, seems to be an ideal testing ground for new collaborative models.

Over the course of the workshop, participants were asked to address seven broad questions:

1. What is the value of engaging public audiences in nano research?
2. Who are the target audiences for nano outreach efforts?
3. What deliverables would have favorable impacts?
4. What institutions should participate in collaborations to create and distribute such deliverables?
5. What models will it take to bring together these institutions?
6. What are the challenges and barriers to creating this infrastructure? How might they be overcome?
7. What role can NSF play in making this happen?

The first two questions were discussed by the entire group on Thursday evening and Friday morning. For the remaining questions, the participants broke out into three smaller groups. Each group contained a balanced mix of participants from the research and museum communities, as well as NSF staff who acted as facilitators. Prior to the breakouts, in addition to the remarks from Drs. Roco and Frascella presenting the Foundation's perspective on the issues, there were presentations from the two communities.

[1] Since 1997, all NSF proposals reviews have applied the following two NSB-approved criteria:
1) What is the intellectual merit and quality of the proposed activity?, and
2) What are the broader impacts of the proposed activity?

The view from the Science Museums

Alan Friedman, Director of the New York Hall of Science, gave the group some statistical background on Science Museums and the field of informal education. Dr. Friedman pointed out that even those who receive PhDs spend 92% of their life outside of classrooms, so informal education must usually be the predominant mode of lifelong learning.

Friedman described Science Museums as market-based purveyors of informal science education. Collectively, they are roughly a $1 billion/year industry in the United States. There are about 340 public-serving U.S. institutions in the Science Museum community. They entertain over 120 million unique visitors annually, for over 250 million visits. (Without correction for foreign visitors, this is about one-half the U.S. population.) Roughly one-third of the visitors are with school groups, the remainder are individuals or family groups.

Educational efforts at these museums have by now developed "a modest amount of rigor." Front-end assessments (testing ideas early on with representatives of target audiences) have become a routine part of the design process for new exhibits and programs. Large projects usually include formative evaluations (in-process, audience-based feedback) and summative evaluations (retrospective analysis). (See NSF's User-Friendly Guide... for more information on types of evaluation.)

Various community models have emerged from these educational efforts. The development of a traveling exhibition by a consortium of Science Museums, such as the NIH-sponsored AIDS exhibit, is one of the more complex examples.

Friedman cautioned the group that they should be aware of the limitations of museum-based informal science education up front. Not everyone goes to Science Museums. Some science topics are better suited to treatment by a book, on a TV show, or in a college classroom than in a museum exhibit or program. These limitations—which may be better recognized within the field than without—should be kept in mind when identifying target audiences and setting goals for Museum-based educational programs.

At the K-8 level, Science Museums reach a remarkably representative cross-section of the US population. Attendance drops (and simultaneously becomes less representative) through the teenage years. By young adulthood, sharp divisions appear. New immigrant groups are a strong presence, while established minority groups are underrepresented.

Friedman pointed out that science museums don't have captive audiences like films. Museum visitors choose what to see, how much time to spend on each part of an exhibit, and which programs to attend. That is, visitors themselves, not the museums, make visitor experience.

When asked whether he thought scientists, social scientists, educators, and museum staff could talk to one another, Friedman replied that collaborations must form supporting and encouraging such conversations. He noted that the community of Science Museums seems to recognize a need to organize and collaborate if it is to become a more important player on the educational stage.

Rob Semper of the Exploratorium made some comments about the scale of formal education to complement the previous remarks on the scale of nano and the scale of Science Museums. According to AAAS, US students now average less than 1000 total hours of science in grades K-12, and this number is decreasing. In grades 6-12, the figure is about 100 hours per year.

He then asked both the researchers and the educators to think about whether informal education should be viewed as one-way or two-way communication. In Europe, where there have been many projects to stimulate dialogue, the common phrase is "public dialogue about," not "public understanding of," science.

Semper described an "impedance mismatch" between scientists and the public. There is a shortage of scientists with the time or training to truly engage the public in dialogue about science. So you need a "transformer." Science Museums play that role as presenters, creators, designers, and producers of informal educational exhibitions and programs.

Semper reinforced a point made the previously, that the strength of a Science Musem often comes from its individuality and from special relationships to its local community. "With some trepidation," he suggested that the Science Museum community could probably be described as a scale-free network[2], and that this scale-free property could be exploited to ensure broad distribution.

The View from the Research Centers

Robert Chang gave the "informal world" an introduction to NSF's Research Centers and their outreach efforts. In recent years, the fraction of NSF grant money going to Research Centers or other large, long duration grants has been increasing. NSF encourages (often requires) collaboration between a Center's host and other institutions, and education is a common theme for collaborative activities.

Chang spoke of his own experience as the director of a Materials Research Science and Engineering Center (MRSEC), and in developing the Materials World Modules (MWM). The Modules are supplemental teaching units on materials science meant to enhance high school science curricula. MWM developers work with both teachers and cutting edge researchers. While the developers didn't initially realize the central importance of hands-on activities for "young kids," inquiry-based learning and design experiences became central themes as the project developed. The MWM program continues to develop; the next phase of MWM will involve Internet visualization and remote learning to broaden distribution.

Chang discussed his personal favorite among student projects, from a Module about cement and concrete. A group of three high school girls created a concrete block that glows in the dark for 12 hours following daylight exposure. He noted that at this age, girls seem to do better than boys in design projects. He feels they are more mature and understand the relevance of the modules better. Chang also discussed methods now being developed to extend the reach of the MWM, and outlined the structure of the then soon-to-be-announced Center for Learning and Teaching in Nanoscale Science and Engineering[3].

Many Research Center directors recognize that smaller players, including high school and college educators and museum staff, have a lot to contribute to center efforts, and are actively seeking ways to bring them in as collaborators. As always, the difficulty is in ensuring that collaborations are structured to serve the interests of both parties.

General discussions were held both Thursday evening and prior to the first breakout sessions Friday morning Some notable remarks follow:

> "Science Museums don't just do exhibits. Don't forget the professional development programs for teachers, programs for at-risk kids, and films presented in large format theaters."
>
> "The museum community is 'very sharing', both *ad hoc* and through ASTC (Association of Science-Technology Centers)."
>
> "I like Rob (Semper)'s transformer model. Teachers and professional societies can also serve as transformers."
>
> "Sustained connections (between researchers, transformers, and the public) are critical to success."
>
> "Tranformative activities take place most readily on neutral ground."
>
> "Art is the ultimate transformer. 100,000 people visited the NANO exhibit at the Los Angeles County Museum of Art, and PBS (Jim Lehrer) did a piece which reached millions more."
>
> "Journalists, playwrights, film directors, etc. might all be suitable transformers, each with strengths and abilities suited to different audiences and perhaps different topics."
>
> "Several people have mentioned the use of the web to reach a large audience. Don't think the web does everything. Skilled teachers, classrooms, and face-to-face engagement are still critical."
>
> "Nano is the field of the future, the public will and should be part of it."

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[2] Albert-László Barabási and E. Bonabeau
Scale-Free Networks , **Scientific American 288,** 60-69 (2003)

[3] see the press release NSF Funds First Nanoscale Center for Learning and Teaching at the NSF newsroom for more information.

Audiences and Potential Impacts

Teachers	K-16 Students	General Public	Workforce	Museum Staff	Community and Public Leaders	Scientists
Professional Development	Learn STEM view of nanoworld	Better Informed Public	Learn STEM view of nanoworld	Improve capabilities	Justify investment in science	
Nano content	Nano awareness	Nano awareness	Job awareness	Nano Awareness	Sustain research enterprise	Understand social issues
Process of Science	Process Of Science	Appreciation of science and scientists	Skill training	Access to scientists	Understand innovation, meet innovators	
Working with students	Portray passion of scientists	Learn value of Nano	Understand economics of nano			
	Nano Interest	Nano Interest				
	Nanoliteracy	Prepare for choices				
	See scientists as learners	Connect people to science				
	See scientists as observers	Reduce irrational fears				

Reports from Breakout Session on Question 3:

What deliverables would have favorable impacts?

and Question 4:

What institutions should participate in collaborations to create and distribute such deliverables?

The breakout groups created the following " long brainstorming list of potential deliverables, not prioritized":

- · traveling exhibits at science museums
- · public programs or demonstrations
- · large format films, books, TV
- · publicly available internet resources
- · internet-enabled distance collaborations
- · scientist-speakers at meetings, events, and forums, perhaps with additional dissemination electronically (web, TV, radio)
- · professional development activities for teachers
- · video games
- · nano camps
- · art exhibits
- · fashion
- · dance
- · media arts
- · new media, e.g., cell phones
- · experiences and activities centered on inquiry and design
- · microscopes or other nano instruments
- · haptic interface
- · theatrical portrayals of both nanoworld, or of "how we got there"
- · field trips
- · euro-style science cafes
- · public forums
- · engagement of leaders from business and knowledge communities on a neutral field.
- · tools for industry
- · tools for communicators
- · a public computing project like seti@home, protein folding@home, and similar ornithology or prime number search projects
- · graduate student and scientist participation in teaching at Science Museums
- · professional development opportunities for scientists, communicators, teachers.

In response to question 4, the breakout groups suggested the following potential players:

- · Museums
- · Government or university centers
- · Professional and trade associations
- · Publishers (education and trade)
- · Film/TV producers
- · Industry
- · Schools and districts

They recognized the need to identify stakes for each participant, but didn't have sufficient time to do so.

Some remarks from the discussion of the breakout session reports included:

"Culture and technology are melded in today's world. We should actively bring culture into science museums."

" Scientists should be aware that they are part of culture and shape future culture."

"Target? The broader the better."

"Compare nano to the space program and the human genome program. The space program emphasizes people, creating heroes. Possible disasters are less tangible. The genome program also put forth heroes like Crick and Watson."

"Public surveys indicate a high general interest in science and environmental issues. Nano as the core of life could be an engaging theme."

"A potential theme could be workforce and environmental impact 10 years out, and possibly shorter-term economic impact."

"Will the public profile of nanotechnology mirror solid-state physics, which has had tremendous impact with little public awareness, or the much more visible Human Genome Project?"

"There is an unusual opportunity here because of the degree to which the nanoscale science and engineering community has recognized the importance of social issues and public engagement."

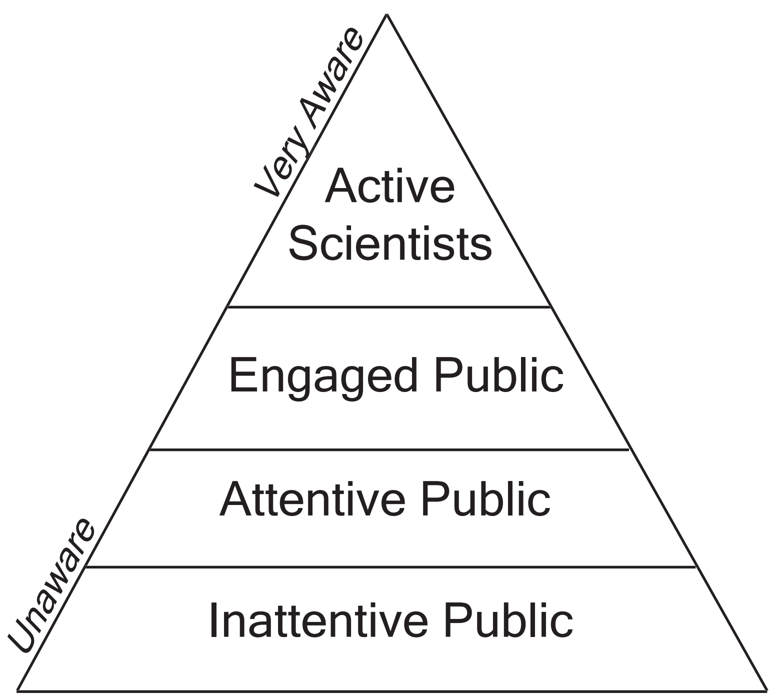
"Our group supported the idea of transformers, but there needs to be an awareness that they are driven by money, and only work if the communities on either side see a shared mission."

"The next 10-20 years will be a critical stage in the evolution of the Science Museum community. They seem to be coalescing into small, medium, and large centers with separate, evolving roles. The evolution of public service media and public broadcasting may be a model."

One group divided the public into a four-part pyramid as indicated in the figure below, and noted that:

"*The way we talk about nanotechnology and the depth at which we talk about it depends on the level of engagement of the audience.*"

They suggested that outreach activities should target the second tier up, the attentive public.



Awareness of Nanotechnology

Before breaking out again to discuss Questions 5 through 7, participants were reminded that the "vision on the table" is to facilitate and support collaboration on a level of seriousness and comprehensiveness that does not now exist. The workshop was intended to start a dialogue, not to affirm the ideas presented in the agenda but to expand on them. Developing a resource network that serves a single community may be part of the effort, but it's not enough. Also, the structures considered must address the particular needs of the nano community, although the infrastructure model itself may be much more broadly applicable. Specifics will have to come out in the deliverables and projected impacts of individual projects.

The workshop participants were asked to think of "the integration of research and education writ large," but to combine big ideas with practicality.

The following collaborative infrastructures emerged from the second set of breakouts:

1. A 3-ball model, with the research, museum, and public communities fully interconnected. SCALE-FREE connectivity within the groups implies that the path from any participant to another is short, even if they are in different groups. ("Six degrees of separation.") (See figures.)

2. A variation of the first model de-emphasizing the explicit connection between the public and research groups, and relying on the museum community to play the transformer role discussed earlier. In this "bow-tie," Museums as "transformers" sit at the center, with the research community and the public at each end.

3. The Roberts Foundation[4] (now REDF) model for social entrepreneurship. There is collective input and longitudinal assessment from all projects. NSF (or a designee) would compile measures of effectiveness. There are linear connections between clustered communities. This approach takes advantage of existing projects funded separately.

4. NSF and other agencies, foundations, or professional societies act as brokers, introducing parties in the research and museum communities to one another and facilitating interactions.

5. A brokered model (Gordon Conferences and summer institutes are examples) in which much of the interactions between the museum and research communities take place in short, intense periods.6. SWAT teams, with members from the three communities above, tasked to stimulate proposal ideas.

7. Non-directed retreats, which include artists, designers, and "kids from South Central"–a more diverse group than the workshop invitees.

8. Create a standing body that looks at "nanoattentiveness" over time, including outcomes of public surveys.

9. Form an oversight and idea-generation network. Thinking outside the box, could such a network have granting power or another funding mechanism?

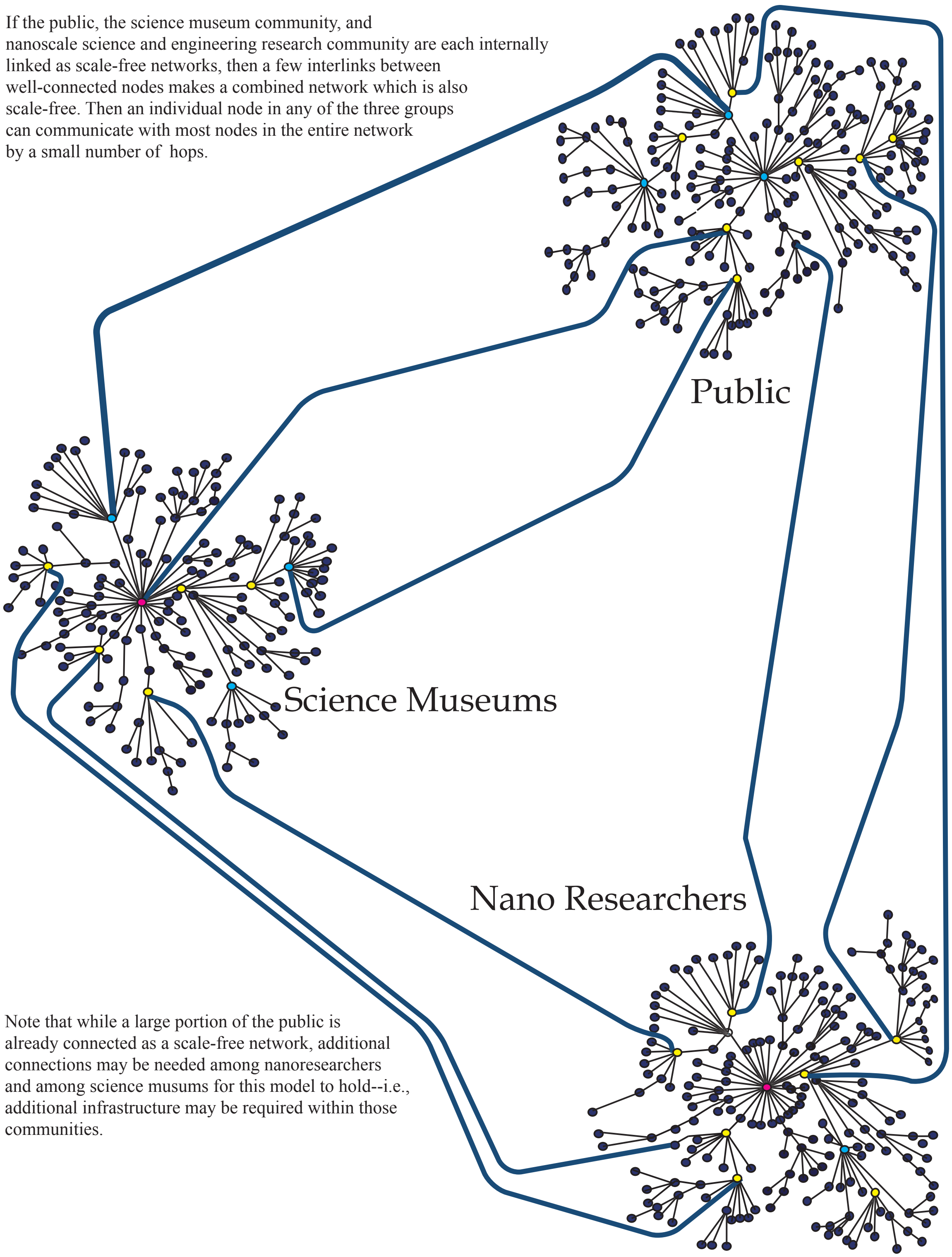
10. Consider two projects initially: a single major project using the existing museum community model for a multi-institution, multi-copy traveling exhibits, as well as a cross-community network that figures out what the next phase should target, stimulates new projects and partnerships, and tries to reinvent the infrastructure.

11. Establish an educational research consortium to figure out what strategies work for storytelling in the nanoworld. Include front-end evaluation, pilot projects, and a diverse group of creators and providers. The major output of this first stage would be a report. Consortium members or others would then develop projects implementing those strategies.

12. With the same mix of contributors as model 11, establish a fully formed network with a plan for its first major project. Network participants would undertake a series of staged implementations with ongoing evaluation and feedback.

[4] Social Return on Investment describes an approach to measuring the results of non-profit enterprises within the REDF "venture philanthropy" model.

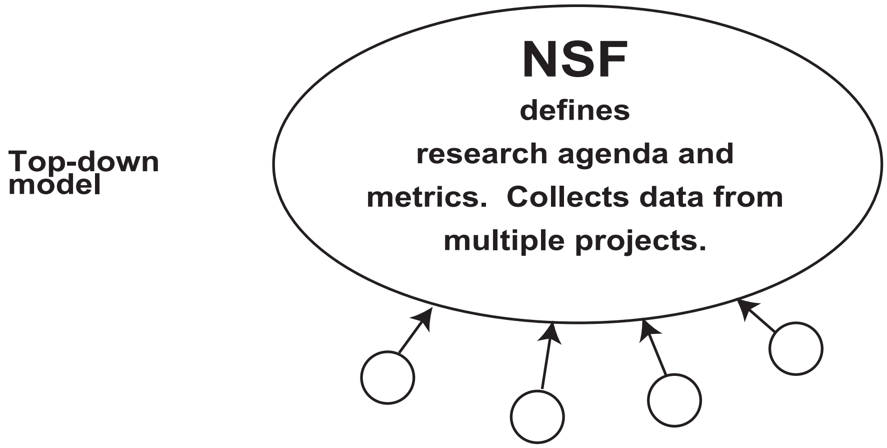
If the public, the science museum community, and nanoscale science and engineering research community are each internally linked as scale-free networks, then a few interlinks between well-connected nodes makes a combined network which is also scale-free. Then an individual node in any of the three groups can communicate with most nodes in the entire network by a small number of hops.

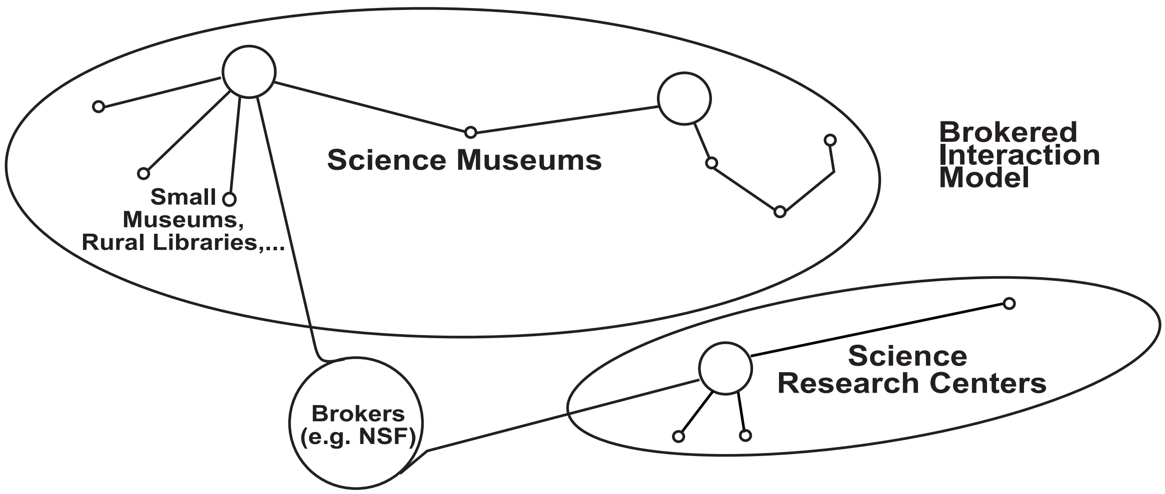


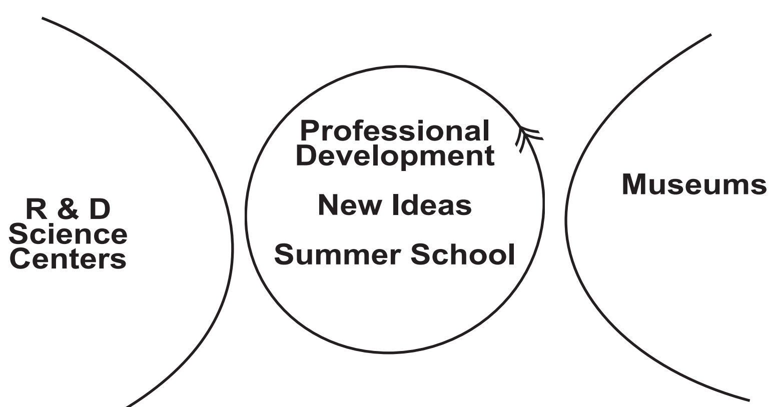
Note that while a large portion of the public is already connected as a scale-free network, additional connections may be needed among nanoresearchers and among science musums for this model to hold--i.e., additional infrastructure may be required within those communities.

A representation of Model 1

Representations of Models 3, 4, and 5







Gordon Conference Model