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PUBLIC ENGAGEMENT WITH NANOSCALE SCIENCE AND ENGINEERING

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> "Any sufficiently advanced technology is indistinguishable from magic." (Arthur C. Clarke [1, p.5])

> "Any technology distinguishable from magic is insufficiently advanced." (Gregory Benford [1, p.5])

Clarke's oft-quoted observation and Benford's more pointed corollary together express the paradox at the center of our public communication gap with respect to nanotech. The leading edge of innovation stretches beyond even the researcher's capacity to fully explain … or contain. We are tinkerers in a strange new world, poking around with atoms and electrons, making new molecules, testing how they will respond, finding plenty of odd behaviors to keep the quantum theoreticians burning the midnight oil. With new theory and new tools, a vast new frontier is now open for exploration and development, and eager homesteaders and gold-diggers are rushing in. This frontier exists on such a rarified level that few can view it in its entirety; others catch glimpses of this or that region; most rely on remote sensing; some go on trust alone. For the uninitiated, this territory is magical: access to it is far removed from the solid Newtonian world we know and trust. Magicians awe and entertain, but they also conjure up fear and *dis*trust. To whom does this magician answer? Will his amazing new powers be put to work for good or evil? Will he trick us with his hyped-up claims? Is a rekindled Frankenstein already stirring in the grave?

Like magic, nanotechnology thrives on hyperbole, of both the positive and negative kind. The need to market its potential to win support and funding fosters dramatic claims that spark equally dramatic counterclaims. Insiders describe an impending upheaval on the scale of the industrial revolution, but have trouble characterizing the anticipated watershed and pinning it down with timelines and predictable results. The message reads something like this: “We know we’re on to something really big here, but we’re not quite sure exactly what it will turn out to be, nor how or when it will occur.” This monumental uncertainty makes everyone nervous, from prospective investors to potential consumers.

Now there’s also the predictable Hollywood-style “nanophobia” to contend with, providing a kind of smoke screen hovering over more sober issues of concern: unintended impacts on health, personal privacy, environment, and movement of capital and labor.

Nanophobia as Sideshow

The new nanotechnology research enterprise, along with its government, industry, and venture capital boosters, voices serious concern over the potential impact of popular nightmarish fantasies of evil scientists and self-replicating technology run amuck: Could such a backlash have the power to derail public support for rapid, competitive development of this economically and militarily critical set of technologies? [2] Negative public reaction to nuclear power generation, to recombinant DNA, to genetically modified foods (especially in Europe), and to therapeutic cloning (especially in the United States) have all been cited as Luddite-breeding precedents that bear close scrutiny. Perhaps the chief similarity among these otherwise quite disparate historical models is the perceived susceptibility of the public to hyped-up claims and fear-mongering promulgated by special interest groups, as well as the media’s well-known tendency to pit extreme against extreme, aggravating the polarization of opinion—no doubt because careful and sober analysis does not win audience share. However, it is important to acknowledge the more significant common characteristic among these previous cases: in each one, the real fears centered on the ownership, control, and regulation of such advanced technologies, and whether government institutions could be counted on to uphold the public’s long-term interests over and above short-term commercial considerations.

One can plausibly argue that the nanophobic Drexler-Joy-Crichton apocalyptic scenarios are simply a sideshow—*not* the major threat to public support for nanotechnology R&D that some fear. The public is just not that naive. Most Americans know how to take the high-adrenalin Hollywood treatment in stride and to even use it to stimulate their further interest and curiosity in the science itself. Public attitude surveys show that interest in science fiction and interest in science and technology are highly correlated. (See, for example, the National Science Board’s *Science and Engineering Indicators—2002*, Section 7–35. [3]) Indeed, a recent visitor research survey conducted at Chicago’s Museum of Science and Industry concluded that fear was overrated:

> In most cases visitors [who were familiar with nanotechnology] said they were not troubled by any of the claims of nanotechnology. Most viewed it as a straightforward science with immediate positive benefits. Some visitors compared nanoscience to more controversial innovations, and said that in contrast to subjects like genetics, nanotechnology had no apparent dangers and seemed relatively neutral … .Very few visitors talked about science-fiction-related fears. Some made reference to science fiction as a way of joking about ungrounded fears. [4, pp.11-12]

On the other hand, public constituencies have repeatedly voiced legitimate concerns that appropriate safeguards be taken in the development and ownership of new materials and technologies, and have sought assurances that adequate regulatory procedures are provided and applied appropriately. It would be counterproductive to lump these reasonable concerns in with the science fiction fantasy fears and dismiss them all out of hand, falsely concluding that the public cannot meaningfully be engaged in reasonable discussion regarding appropriate safeguards for future research, development, and integration of nanotechnologies into our society.

Public Engagement

As has been pointed out many times, public engagement is a critical factor in the sustained development of new technologies and their successful integration into the lives of our communities, particularly if potentially negative health, safety, environmental, social, and ethical issues are involved. Public engagement also has the benefit of leading to faster uptake of commercial applications, broader investment, and increased involvement of young people in educational pathways that lead to further development of the new sector.

The term *public engagement* updates previous conceptualizations of the "public understanding of science" as a one-way street: white-coated scientists patiently lecturing on the brilliant products of their research to admiring but underwhelmed public audiences. The contemporary model of public engagement connotes interactivity and truly meaningful multidirectional discussion over the implementation of new technologies—discussions in which scientists, industry, investors and government regulatory agencies work together with citizen representatives of the diverse communities that are most likely to experience the impact of the new technologies and will need to deal with whatever unintentional fallout may occur. This notion assumes the presence of an educated and literate public essential to any functional democracy, and more particularly, the presence of a *scientifically literate* public essential to a 21st century techno-democracy. It also requires scientists, engineers, and CEOs to develop a broader perspective and a dose of humility. As *Public Understanding of Science* journal editor Bruce Lewenstein commented,

> It's really critical that scientists recognize that their assessments of what's "important" are not the only valid positions. It's also

> important for scientists to hear, truly hear, that the taxpayers who fund their work have a legitimate right to have some say in what questions they address and what levels of safety and uncertainty they accept as reasonable. Without that kind of MUTUAL respect and MUTUAL learning, any hope for true engagement is just a pipe dream. [5]

In Europe, the mishandling of science, technology, and society issues, most notably the Mad Cow disease debacle and the GM foods debate, led to a marked decline of public trust in science, industry, and government over the last decade [6]. In comparison, for better or worse, Americans tend to think optimistically of transformative technologies and tend to trust that risks will be handled reasonably well: more than 75 percent of Americans believe the benefits of technology outweigh the risks. This level of confidence is much higher than in Europe [7]. Americans also trust the institutions associated with research, expressing greater confidence in the leadership of medical and scientific institutions than in that of the Supreme Court, business, educational, financial and religious institutions, the press, and media [3]. Nevertheless, one has only to look as far as the recent debate in Congress over stem cell research and therapeutic cloning to know that as soon as technology gets personal, and begins to stretch the edges of the fabric of our social and ethical consensus, mechanisms for reasoned public engagement in dialogue and debate on the cost/benefits calculus and social and ethical implications of scientific or technical issues are, indeed, in short supply.

The idea of engaging the public in discussion of nanotechnology goes well beyond an interest in calming nascent fears of catastrophic consequences. This is a question of how we as a society move forward on behalf of *all* of us, with *all* of our short- and long-term interests on the table, as consumers, taxpayers, regulators, researchers, educators, politicians, investors, and CEOs. As Lewenstein commented "…questions of social justice, equitable distribution of risks and benefits, ethical concerns about privacy and about introduction of new materials (and even capabilities) into human bodies are questions that people can and should be addressing" [5].

We have much going for us in this endeavor. As already noted, we have little to fear from sensationalized science fiction fantasies. We have a public that thinks positively about the benefits of R&D, and is receptive to new technologies. We have investors willing to back R&D pioneers. We have an initial government commitment to deal forthrightly with the broader social implications and with potentially harmful health, environmental, and economic concerns. We have a regulatory system and a free press.

There are two key things we're short on, however: that previously mentioned "*scientifically literate* public essential to a 21st Century techno-democracy," and those "mechanisms for reasoned public engagement in dialogue and debate on the cost/benefits calculus and social and ethical implications of scientific or technical issues." Clearly, we cannot at this point rely on our formal education system to supply these necessities, although we ought to be working very hard in that direction. Neither are our commercial media up to the task.

Nanoscale science, with its convergence of fundamentals in physics, chemistry, biology, computing, and engineering, may well inspire, as well as require, a radical rewrite of the nation's K–12 science curricula, but this can occur only at a slow and uneven pace across the patchwork of independent school districts that make up the nation's formal education "system." In the meantime, science museums, and other informal science education institutions, may be able to make a substantial contribution in coming years to the quest for greater citizen engagement with this leading edge of current research.

Science Museums: Facilitators for Public Engagement

America's science centers and museums have the potential to reach significant populations with interactive exhibits and programming. A whopping 66 percent of American adults surveyed in 2001 reported that they had visited a science or technology museum at least once during the past year, the highest level of museum attendance ever recorded by the NSF survey. The figure has been rising since 1983. While traditionally regarded as destinations for school field trips and family weekend entertainment, science museums have also begun to emerge in recent years as venues well-suited for continuing adult engagement with science and technology, and as ideal educational outreach partners for university and institute-based researchers.

Science museums could also potentially morph into becoming those missing public spaces where researchers, policymakers, representatives of interest groups, and citizens can engage in forums, discussions, and facilitated consensus-building activities of the type advocated by Jane Macoubrie and others. Such activities have been prototyped at La Cite des Sciences et de l'Industrie in Paris, the Science Museum in London, and the Museum of Science, Boston, addressing issues of heightened public concern like genetics testing, GM food technology, and stem cell research. Granted, it is easier to find audiences willing to discuss these more accessible biotech issues, with their obvious personal and social implications, than it will be to involve audiences in the intricacies of non-biologically-oriented nanoscale science and engineering. We will need to work very hard at bridging that nanotechnology communication gap.

What the Heck is Nanotech?

Engaging public and school audiences in nanotechnology is challenging: even the most basic explanation seems to require a parenthetical statement (to explain the scale indicated by the prefix *nano,* for example, or that *atoms* are the building blocks of *matter*, whatever that is). Nanotechnology is hard to pin down in a brief non-technical description. It is everything, it seems—an umbrella term—but it is also nothing—nothing one can see, hear, or feel. The scale is incomprehensible, the language inaccessible. Effective communication of nanoscale processes—even with the aid of metaphors, analogies, and rich graphics—seems to require the assumption of a certain set of shared *a priori* experiences as well as extraordinary conceptual abilities. Yet these apparent cognitive barriers to nanotechnology communication mask an even more formidable threat, a widespread, but little recognized, phenomenon in our culture: physics phobia.

Most people believe that physics is beyond their reach: at best, a foreign country where only geniuses dare tread; at worst, an irrelevant and wasteful mental exercise. Popular culture tends to relieve the tension by elevating the very human Einstein to a pantheon of superhuman icons, revered as God-like savants, thus allowing the rest of us to stick to what we mere humans do best (i.e., *not* physics). As for the irrelevant and wasteful mental exercise strand of thought, here's former Senate Majority Leader Trent Lott, addressing an audience of high school and college students on C-Span in January 1997, and clearly winning their approval:

> When I was in high school, if you were in the so-called pre-college curriculum, you had to take four years of science and four years of math: a waste of *my* time, a waste of the teacher's time, and a waste of space. You know, I took *physics* … for *what?* (Cheers, laughter, applause). [8]

Indeed, the National Science Board's *Science and Engineering Indicators* show that few American adults know what an atom or a molecule is, nor which is composed of the other. Only 13 percent were able to provide a correct explanation of a molecule. Jon Miller, the principal investigator, commented:

> This result is both surprising and troublesome. The term "molecule" has become a part of journalistic discourse on television and is often used in newspaper articles without additional explanation. An analysis of the open-ended responses indicated that many adults knew that molecules are very small but did not know whether atoms were composed of molecules or molecules are composed of atoms. Some individuals knew that a molecule is a basic building block and is very small, but could not say anything else about it. [9, p.279]

In other words, forget physics, forget chemistry, and forget molecular biology. Miller concluded, "Minimally, it is essential that science communicators recognize the limited nature of public understanding of the structure of matter…" The Chicago Museum of Science and Industry survey also corroborated the finding of general public unease with terms like atom, molecule, and the term matter itself.

As a result, mentioning a fundamental nanotechnology notion like "building a transistor atom by atom" may result in a massive audience attention loss. What's an atom? What's a transistor? In this climate, one is quickly dissuaded from venturing on to interpret other key areas of nanotechnology research involving, say, quantum dots or scanning tunneling microscopy.

Dealing with Physics Phobia

Clearly, the challenge with nanotechnology is to find multiple pathways to penetrate physics phobia, provide entry points to this rarified world beyond the senses, and empower public and school audiences with the experience of constructing and testing their own inquiry-based conceptual models. The increased confidence this learning process may engender could go a long way toward making public dialogue on societal concerns a real possibility, and may also open the door to further individual engagement and learning.

Cognitive penetration of the nanotechnology world may require something beyond the normal textbook or classroom lecture experience approach. Because that world is so anti-intuitive, so contrary to practical experience and so inaccessible to the senses, new multidimensional approaches should be explored, possibly involving large-scale interactive models enhanced by audio-visual media, and kinesthetic, sensory, and motor experiences. We also need expert communicators, skillful at creating mental and physical analogs for atomic-scale processes and making them centrally relevant to diverse audiences.

Science centers and museums are beginning to serve as laboratories for testing innovative methods of teaching and learning nanoscale science and exploring cognitive connections. Most program and exhibit designers take visitor research very seriously. Front-end studies help determine what potential audiences already understand about any given subject and the associations those understandings hold for them. Typically, exhibit designers move slowly, in frequent communication with the target audience, carefully prototyping and making iterative adjustments of exhibit concepts and activities as they proceed through the development process.

Here is a partial list of recent U.S. science museum efforts to interpret nanoscale science and engineering for school and public audiences, all developed in close cooperation with university-based researchers:

- It’s a Nano World: Traveling exhibit developed by the Ithaca Science Center to introduce young children to the concept of scale; also debuted successfully at the Epcot Center
- NanoZone: Exhibit and multimedia project at the Lawrence Hall of Science at Berkeley, targeted at 8–14 year olds
- Nano: Art and science installation pieces offering experiential conceptualizations of nanoscale science and engineering at the Los Angeles County Museum of Art
- Nanotechnology: Extensive exhibit at Tokyo’s Museum of Emerging Science and Innovation

Current Science & Technology

At the Museum of Science, in Boston, we launched the Current Science & Technology Center in 2001 as an experimental model for providing in-depth programming on recent research. The Center offers daily live presentations and exhibits, cablecasts, current science theater/forum performances, and multimedia on a broad spectrum of science and technology topics. Often, staff can seize on a topic that’s currently getting a lot of media attention, and use it as a hook to bring our audiences into a more in-depth understanding of the science and technology involved, as well as the research process. Nanotechnology subjects are not often the stuff of front page news, and so we have improvised several other approaches.

Nanotech-related presentations developed by staff member Joel Rosenberg have titles such as The Wonderful (and Not So Wonderful) World of Carbon

Nanotubes, The Incredible Shrinking Transistor, Hooked on Photonics, and Quantum Computing. They begin with compelling ideas that link the subjects immediately to personal experience and include a little history, a core of science, a dose of personality, and a glimpse of future directions. Joel attracts a good teen and adult audience for these lively 20-minute, multimedia- and prop-rich stage events, which are often followed by more intimate audience Q&A and discussion.

The Museum's nanotechnology programming is produced in collaboration with our Nanoscale Science and Engineering Center partners, Harvard, MIT, and UCSB. The NSF-funded NSEC supports a full-time education associate in the Current Science & Technology Center. Joel has an engineering background and is well-informed on research across the entire nanotechnology field, and he develops and delivers presentations, cablecasts, and multimedia. He also curates a guest researcher speaker series, working closely with the researchers to adapt their more typical formal presentations to a style that works with our diverse audiences. We've had considerable audience interest in these encounters, and the researchers who have participated, including Eric Mazur, Eric Heller, Howard Stone, and Charlie Marcus, have been more than generous with their time. Some of the presentations have been videotaped and edited and posted on the Web site, linkable from mos.org/cst/nano. (Researchers who have the knack for engaging lay audiences with their excitement, accomplishments, and motivations in accessible language are everywhere to be sought out and emulated, as they provide a key link in the process. Graduate students ought to be encouraged to develop their communication skills—not only will it help us bridge this two-cultures gap, but it will also help them write grants, attract venture capital, and feel more at ease at cocktail parties.)

We are engaged in a three-year evaluation protocol of these various approaches with the Institute for Learning Innovation. Initial results from the formative studies show that the staff and guest presentations are on target with their approach, style, and content.

Future Applied Research: Public Engagement with Nanotechnology

We are currently exploring ways to network formal and informal science education institutions, pooling together their research, resources, and prior experience in nanotechnology education and forum activities and jointly developing and sharing new work. With education and outreach funding so scarce, none of us can afford to repeat failed experiments. Just as published research alerts scientists around the world to new findings that either discourage or encourage new avenues of investigation, so should education and outreach professionals, museum exhibit and program developers, and public engagement specialists develop and share a robust body of applied research as they further their efforts to move these fields forward.

Networking research and information about best practices among interdisciplinary collaborators can help us all take these practices to new levels of effectiveness and to new audiences, further stimulating innovation. Nanotechnology research is notorious for demanding interdisciplinary expertise. Developing effective practices for public engagement with nanotechnology may demand even broader collaboration. The current disciplinary divide between formal and informal educators robs each sector of valuable knowledge, tools, and resources. A conference bringing together museum exhibit designers, instructional material developers, K–12 education researchers, research institution outreach coordinators, and multimedia developers focused on potential synergies in nanotechnology research and societal implications for communication strategies might help break down the barriers and seed more creative interdisciplinary approaches. Such a conference might also facilitate broad dissemination of high-quality materials and catalyze greater market uptake.

Overall, it is important that government agencies, foundations, and R&D institutions deepen their commitment to the education, engagement, and dialogue that are integral to their funding for nanotechnology research. While this may include support for academic research on public opinion, ethical frameworks, and historic precedents, it may prove of greater and lasting value if a significant portion of the funding is invested in "applied research," devising and testing a variety of forms for engaging all citizens in the aspirations, substance, methods, risks, and benefits of this remarkable new world of nanoscale science and engineering. It doesn't have to be magic.

Conclusion

In this paper, I have argued that we needn't fear a hysterical public response to alarmist portrayals of nanotechnology dystopias disseminated through science fiction, feature films, or speculative science commentators. Our real concern should be addressing the public's fundamental interest in health, safety, environmental protection, and fair distribution of costs, benefits, and risk. Experience shows that new technologies integrate better into democratic societies when potential hazards are clearly and openly addressed and citizens can trust that adequate safeguards and regulations are in play. Communities need to be well-informed, and they also need to be listened to: it would be unwise and ultimately counterproductive to leave the regulation of such a potentially powerful new technology in the hands of a research and industry techno-elite or simply to market forces. Social consensus consistent with forward progress is better achieved in the presence of a scientifically and technologically literate citizenry. This is a key reason why we continually advocate for better K–16 teaching in STEM subjects, multiple public engagement strategies through science museums and media, and the development of "honest broker" forum spaces, for learning, listening, and coming to consensus. Nanotechnology education is particularly challenging due to its highly abstract nature and a culture of physics phobia in this country; it makes sense to fund innovative applied research in this area and stimulate more synergies between formal and informal educators. As a global community, we should support and vigorously fund the development of forum-style infrastructures for facilitating information sharing among the public and the various stakeholders, including joint assessment of risks and benefits and integration of societal values with science and technology research, with the goal of anticipating and resolving future conflicts.

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NANOTECHNOLOGY: MOVING BEYOND RISK

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Risk makes the world go around. Or, at least many of the social science studies about the management and public acceptance of new technologies seem to focus on risk. Social science literature is replete with books, articles, and monographs trying to define, analyze, measure, and predict various kinds of technological risk and to track popular perceptions about them.

Take virtually any word in the English language and place it before or after "risk." The result is the identification or creation of a whole field of social science study