feature article

The larger world of nano

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Research in the social sciences and humanities can help scientists and policymakers to better understand the nanotechnology enterprise and to make it more transparent to an enthusiastic but cautious public.

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The field of ethical, legal, and social issues (ELSI) in nanotechnology barely existed before 2003. Today it has a journal, *Nanoethics*; a professional society; and a presence in many nanotechnology research institutions. It is now possible to pull together research by sociologists, economists, historians, philosophers, and others to address such basic questions as, How is the nanotechnology enterprise organized? What do various publics think about nanotechnology? What do nanoscientists think about the public? One result thus far is that the US and European publics' attitudes toward nanotechnology differ from what nanoscientists and policymakers believe them to be. Policies that do not acknowledge that discrepancy could be self defeating.

Integrating the social dimension

Research on ELSI was envisioned as part of nanotechnology even before the founding of the US National Nanotechnology Initiative in 2001. In part, that was because a similar program within the Human Genome Project was seen as having headed off potential public concerns—for example, that the project was a cover for eugenics. Proponents of the NNI also believed nanotechnology's effects would be so transformative that social scientists and humanities scholars would have to help society prepare. The NNI billed nanotechnology as the "next industrial revolution" and "as socially transforming as the development of running water, electricity, antibiotics, and microelectronics."[1] Social scientists, according to the NNI, could help government and industry take advantage of nanotechnology discoveries and forestall public resistance to the resulting profound changes.

The above justifications for ELSI research focus on nanotechnology's impact on society. Indeed, most ELSI research thus far has looked outward to gauge or shape public perception, media coverage, and the regulatory environment of nanotechnology. But ELSI research was never envisioned as directed solely outward. Such early proponents of the NNI as Richard Smalley, James Murday, and Joseph Bordogna believed that nanotechnology's impact on the sciences themselves would equal its impact on society.[2] They hoped the NNI would create and coordinate new institutions that would eliminate barriers between disciplines, promote commercialization of academic nanoscience, and educate a new high-tech workforce with a greater representation of women and minorities.

If natural scientists and engineers deem those goals worthwhile, then they should be open to contributions from the social sciences and humanities. After all, organizational sociologists know about building new institutions; historians

Figure 1. Before introducing Crayola crayons in 1903, Binney and Smith was a manufacturer of carbon black, a nanoparticle used as a pigment in industrial crayons and incorporated into the rubber matrix of car and bicycle tires. (Courtesy of Binney and Smith Inc Records, National Museum of American History Archives Center, Smithsonian Institution, Washington, DC.)

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Figure 2. Nanospecific waste practices are more likely to be implemented by organizations that perceive nanomaterials as risky. Here a researcher from the National Institute for Occupational Safety and Health measures the degree to which a nanomaterial powder enters the atmosphere as it is collected. (Courtesy of Charles L. Geraci, NIOSH.)

have researched past attempts to make science more interdisciplinary and inclusive; economists and economic sociologists understand tacit knowledge, technology transfer, and commercialization; labor economists and education scholars analyze the relationship between higher education and the high-tech workforce; and so forth. ELSI research can thus help natural scientists and engineers to better understand and organize their efforts.

Of course, the social sciences and humanities need funding and institutional support if they are to contribute to nanotechnology. The NNI has targeted about 4% of federal nanotechnology funding for a mixture of ELSI research efforts and education and outreach activities. The largest patron of ELSI research in the US has been NSF through its Nanoscale Science and Engineering Centers (NSECs) and its National Nanotechnology Infrastructure Network (NNIN). Prominent features in NSF's ELSI landscape include the Center for Biological and Environmental Nanotechnology at Rice University; the Nanoscale Informal Science Education Network, coordinated by a consortium of science museums; the National Center for Learning and Teaching in Nanoscale Science and Engineering at Northwestern University; and the Network for Nanotechnology in Society, comprising centers at Arizona State University and the University of California, Santa Barbara, a small research group at the University of South Carolina, and another small group divided between UCLA and Harvard University.

NSF encourages its NSECs and NNIN facilities to support research projects on societal dimensions of nanotechnology. Some NSECs have not engaged constructively with social scientists and humanities scholars, but others, such as the Center for Hierarchical Manufacturing at the University of Massachusetts Amherst, have integrated societal-dimensions research into their organizations. In Europe, social scientists commonly participate at nanotechnology centers and initiatives, including the Cambridge Nanoscience Centre, the Dutch NanoNed consortium, and Belgium's IMEC microelectronics research laboratory.

Risky business

Some nanoscientists are concerned about downsides of ELSI research. I have heard natural scientists and engineers who direct NSECs and NNIN facilities say, for instance, that it is challenging for someone with their disciplinary background to oversee and evaluate social science projects housed in their centers. Other directors have reportedly worried that societal-dimensions research could create a backlash by attuning the public to potential risks from nanotechnology rather than informing about the technology's benefits. ELSI researchers also regularly hear nanoscientists say that nanotechnology is not so new as to warrant special examination by the humanities and social sciences (see figure 1).

A study by Maria Powell, of the University of Wisconsin–Madison's NSEC, lends texture to such anecdotes. In interviews conducted three years ago with nanoscientists—mostly physicists and chemists—Powell heard

> considerable frustration that, as they perceive it, the public and media view nanotechnology as something new and therefore risky. Given that nanotechnology has been going on for many years, they do not understand why it is being singled out now. None said they are particularly worried about the risks related to nanotechnologies personally or for the public, and several asserted that "most scientists they know" or "we" (referring to scientist colleagues) are not very concerned about it.[3]

Potential risks from nanomaterials have loomed large in ELSI research, and it is legitimate to ask whether ELSI scholars focus too much on the topic. At this point, however, toxicological data on nanomaterials are too ambiguous to offer a clear view of potential risks. Current concerns may turn out to be overblown—or they may not. The data, though, certainly do not support the chemists and physicists Powell interviewed who "were adamant that concerns about nanotechnology risks are without scientific merit and are being generated by fearful activists and/or ill-informed Luddites who have something to gain by promoting the idea that nanotechnology is new and risky."

Other studies show that differences in risk perception are correlated to differences in risk practices (see figure 2). In a survey commissioned by the International Council on Nanotechnology, a team associated with the Center for Nanotechnology in Society at UC Santa Barbara polled 82 nanomaterials-producing research labs and manufacturers worldwide and obtained feedback concerning environmental, health, and safety attitudes and practices.[4] They found that "when asked if they believed there were any special risks associated with nanomaterials that they either handled or produced, 35 (43%) organizations reported that there were none, 25 (30%) described risks, and 12 (15%) reported either not knowing or not having enough information." Those differences had real consequences, since "organizations reporting a belief in nanomaterials' special risks were more likely to monitor the workplace [and] implement nanospecific waste practices."

The perception that nanomaterials are not risky is often no more rooted in empirical data than the perception that they are. The nanoscientists Powell interviewed had virtually no familiarity with or interest in toxicological studies of nanomaterials. Nearly all of them got their information on nanotoxicology from mass media outlets such as the *New York Times* and CNN, and only one had read peer-reviewed articles on the topic. Yet they were absolutely certain that the public, basing its fears of nanomaterials on information from the same kinds of sources, was behaving irrationally. This seems, to me, a rather unscientific double standard. Scientists who worry about threats to the nanotechnology enterprise should ask themselves what is the bigger risk: that the public, despite a lack of evidence, will conclude that nanoparticles pose a health hazard, or that the public will be incensed that a significant number of nanoscientists believe, despite a similar lack of evidence, that the public is ignorant and irrational?

Fortunately, many leading nanoscientists understand that dismissiveness and ridicule of public concerns are counterproductive. Many government-funded nanotech centers have public-engagement programs to bring some transparency to nanoscience. In building new research institutions that incorporate public engagement from the outset, policymakers and nanoscientists can make nanotechnology a model for future research areas. Now is the time to experiment with various methodologies for public engagement.

Those methodologies include citizens' schools like the South Carolina Citizens' School of Nanotechnology, in which local community members learn about nanotech over several weeks while quizzing nanoscientists on issues of concern, and undergraduate courses on nanotechnology in society—for example, Rice University's Nanotechnology: Content and Context, taught since 2004. In citizens' juries such as Nanojury UK, members of the public hear expert evidence and then make policy recommendations. The Madison Area Citizen Consensus Conference on Nanotechnology and similar activities enable stakeholders to work toward common ground. Less formal events include science museum programs and NanoDays, such as those coordinated by the Nanoscale Informal Science Education Network, usually held at research centers. Figure 3 shows a NanoDays project designed for children and conducted at a science museum. At informal science cafés like those sponsored by the Center for Nanotechnology in Society at Arizona State, nanoscientists interact directly with the public, in a café or other informal setting.

Folk theories

Unfortunately, many nanoscientists come to public engagement carrying notions about the public that are largely unsupported by evidence. Sociologist Arie Rip terms those no-

Figure 3. Science campers built a model nanotube at the Lafayette Natural History Museum and Planetarium in Lafayette, Louisiana. The camp was one of many NanoDays events held throughout the US in 2008. **(a)** The tube takes shape a few days after the camp begins. Eventually more than 300 students would participate. **(b)** When it was completed, the nanotube was three stories high. (Courtesy of the Lafayette Natural History Museum and Planetarium, Lafayette, Louisiana.)

tions folk theories of nanotechnology—practitioners' beliefs about nanotechnology's role in society, warranted more by ideology than empirical data.[5] Probably the most influential folk theory is that nanotechnology will run a course similar to biotechnology's and will therefore inevitably face a backlash like that in Europe and some developing countries against genetically modified organisms (GMOs).

Admittedly, some aspects of nanotechnology explicitly take into account lessons from the development of the life sciences. Yet the question of whether nanotech will unfold like biotech should be subject to social science investigation, rather than simply assumed as a guide to policymaking.[6] Moreover, the parallel-development folk theory is accompanied by several questionable corollary beliefs about what the lessons from biotech are.

One pervasive misreading is that opposition to GMOs centered on public perception of toxicological risks to the environment and human health from bioengineered foods. Historical and sociological studies of the GMO controversy indicate that it originated much more in anxieties about globalization, lack of corporate transparency and accountability, and an institutional distrust built up from previous episodes such as the mad cow disease scare of 1996 and the hoof-and-mouth epidemic of 2001.[7] Toxicological worries were an important vehicle for the controversy, but more because risks from GMOs were unfairly distributed than because the public perceived the risks as compelling. The benefits of GMOs were seen as going to large corporations, whereas whatever risks GMOs posed accrued to consumers and the environment. Nevertheless, nanotechnology policymakers seem determined to believe that perceived toxicological risks will be the wedge for public opposition and that the only way to prevent that opposition is to educate the public about the technology's benefits and lack of toxicological harm.

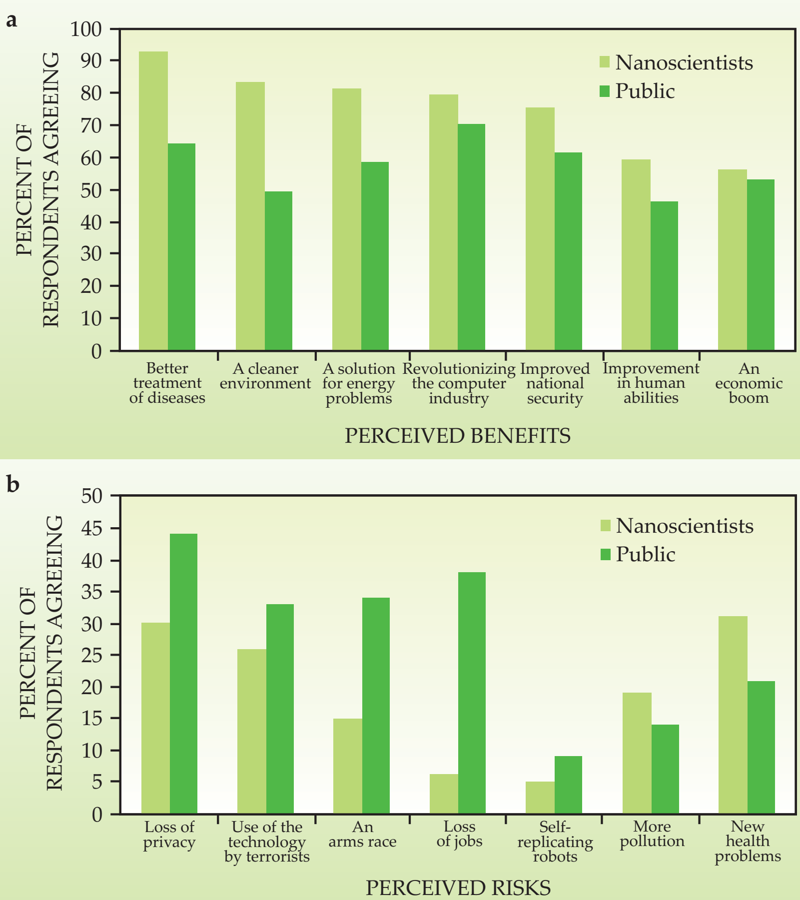

Figure 4. Benefits and risks of nanotechnology are often perceived rather differently by nanoscientists and the public. As these histograms show, **(a)** nanoscientists tend to be more optimistic about nanotech's benefits, and **(b)** the public is often more pessimistic about nanotech's risks. Particularly striking is the discrepancy between nanoscientists' and the public's perception with regard to job loss. (Adapted from ref. 14.)

It is perhaps not surprising that when natural scientists think about perceived risks from nanotechnology, they focus on those risks amenable to natural science investigation. Perhaps as a result, environmental health and safety issues dominate the policy debate at the expense of societal risks that are of greater concern to the public—surveillance and job loss, for example—but not easily elucidated through laboratory experiments. In the US the NNI targets some $76.4 million in environmental, health, and safety research for 2009, compared with $40.7 million in all other education, outreach, and societal-dimensions research. Don't get me wrong: Funding for EHS research in nanotechnology is money well spent. But that funding is a good investment because the science itself is important and interesting, even if it is not likely to be decisive in overcoming potential public opposition to nanotechnology.

Risk concerns in context

Public engagement projects offer good evidence that simply showering the public with research findings about nanotoxicology will change few minds. As Robert Doubleday of the University of Cambridge notes, citizens arriving at such events report an "excitement about the potential of nanotechnology."[8] His finding is consistent with several previous surveys showing that while large majorities in North America and Europe have heard little about nanotechnology, those same majorities have positive or neutral evaluations of nanotech's potential.[9] Doubleday also finds, though, that once participants in public engagement projects "learned more about specific nanotechnology products and how they work, participants become concerned about [the] possibility of negative unintended consequences." Surveys conducted last year show that giving respondents more information about nanotechnology simply exacerbates preexisting inclinations: Those who are mildly optimistic to start with become more so, while those who start out cautious become even more wary.[10]

Doubleday finds that knowing more did not sour participants on the technology itself; indeed, "participants were enthusiastic about the possibilities." Rather, once participants learned about nanotechnology, they placed it in the context of their distrust of bureaucratic institutions. "Public concerns about safety are couched not in terms of the technology itself but almost wholly in terms of the social structures in place to ensure that hazards will be identified and products regulated. . . . There was concern that the direction of innovation is being overly shaped by short-term economic interests . . . [and] dissatisfaction with the current relationship between publicly funded research and commercial application."

Merely telling the public about potential benefits of nanotechnology will not change minds that, Doubleday notes, are "skeptical about whether these benefits will be achieved under current conditions." Likewise, telling the public that studies show nanotechnology is not risky will not change minds that are skeptical that the institutions sponsoring such research have public, rather than commercial, interests at heart.

Indeed, the accountability of nanotech institutions is already in question. An inventory by the Project on Emerging Nanotechnologies at the Woodrow Wilson International Center for Scholars found that the NNI's claim of $68 million in federal money spent on EHS research in 2006 was exaggerated by $55 million. The Wilson Center also found an additional $8 million that did fund EHS research but that was not properly reported by the NNI.[11] The inability of US nanotech funding agencies to be transparent even to the NNI will hardly reassure the public that scientific institutions deserve the benefit of the doubt.

Nonetheless, as Powell's interviews showed, many nanoscientists assume that if the public does come to oppose nanotechnology, it will not be because the institutions of nanotechnology have failed to build trust. Rather, it will result from the negative influence from the media and organizations like the Wilson Center. Indeed, nongovernmental organizations such as the ETC Group have received significant press coverage for their vocal opposition to nanotechnology. But as a blanket portrait of media and organizational attitudes, the belief expressed in Powell's and other interviews is inaccurate and unhelpful. Some of the most powerful environmental NGOs, such as Greenpeace and the Environmental Defense Fund, have taken cautiously optimistic attitudes toward nanotech's potential to ameliorate environmental damage. Similarly, studies of media coverage consistently show that most mass-media articles about nanotechnology simply celebrate new discoveries. Only about half of them mention societal implications at all; of those that do, positive presentations outweigh negative ones by more than 3 to 1.[12]

Still, many nanoscientists and policymakers fear that a major publicity disaster could push the public into opposition. Indeed, the societal-dimensions mandate in the 21st Century Nanotechnology Research and Development Act of 2003 was meant, in large part, to help nanoscientists counteract a well-publicized 2000 anti-nanotech screed by William Joy in *Wired* and Michael Crichton's sensationalist 2002 anti-nanotech novel, *Prey*. But fears that Joy and Crichton would spark public outcry appear to have been another dubious folk theory. One survey found that exposure to *Prey* is strongly associated with more positive views on nanotechnology, not less.[9] Exposure to *Prey* did, however, correlate somewhat with respondents' unwillingness to "trust business leaders within the nanotechnology industry to minimize potential risks to humans."

Some PHYSICS TODAY readers may object to Rip's and my labeling of nanoscientists' beliefs as folk theories. Just to be clear, all stakeholders in nanotechnology have their own folk theories. Social scientists and humanities scholars engaged in ELSI research have folk theories that color their interpretations of data. Historians, including me, tend to be knee-jerk skeptical of claims that nanotechnology or any human endeavor is wholly new and revolutionary. Economists seem obsessed with the notion that all nanotechnology springs from the invention of the scanning tunneling microscope, which they see as an "entirely *new method of inventing*" (emphasis in original), capable of unleashing a "creative gale of destruction" that could sweep away existing firms and industries.[13] Yet economists' own data show nanotech's debt to electron microscopy, x-ray diffraction, and other tools that predate or are only occasionally used in conjunction with scanning tunneling microscopes. Communications scholars and political scientists too often speak of the inevitability of a "risk event" that will lead to a crisis in public confidence in nanotechnology. Many assumed that the 2006 recall of Magic Nano, a German cleaning product, would be that triggering event.

No one is exempt from the power of folk theories. But engagement with the public and sustained collaboration between nanoscientists and ELSI researchers should help keep such theories based in reality.

Wider worries

A 2007 survey of 1015 US adults and 363 leading US nanoscientists highlights the significant mismatch between the public's and nanoscientists' folk theories of nanotechnology.[14] Conducted almost two years after Powell's interviews, the study, surprisingly, shows that nanoscientists have internalized public policy anxieties about nanotoxicology much more than the public has. Some 30% of nanoscientists believe that nanoparticles could lead to new health problems, compared with only 20% of the public. Yet, as figure 4 shows, in areas ignored by the public policy debate, the public sees much bigger risks than nanoscientists do. Some 44% of the public see nanotechnology leading to loss of privacy, compared with 30% of nanoscientists; 33% of the public worry about a nanotech arms race, compared with 15% of nanoscientists; and a whopping 38% of the public fear a loss of US jobs, compared with a mere 6% of nanoscientists. Other surveys corroborate the finding that the US public's greatest worry about nanotechnology is not toxicological or environmental risk. In Michael Cobb and Jane Macoubrie's survey, for instance, respondents feared that nanotechnology will lead to loss of personal privacy (31.9%) or an arms race (23.8%), but only 18.6% worried about "breathing nanoparticles that accumulate in the body."[9]

If nanoscientists want to meaningfully engage the public, they need to engage on the issues the public is actually interested in, in addition to issues such as toxicology that have loomed large in policy debates. Of course, public interests will evolve, and different sectors of the public will focus on different issues. If nanotech is to draw any lesson from biotech, it is that the public imagination about a new technology wanders. Since the dawn of the biotech industry in the 1970s, the public has gone from worrying about recombinant DNA to genetically modified foods to stem cells to cloning. Even within the narrower GMO debate, public concerns, at least in Europe, migrated from health risks to environmental and biodiversity harms to informed consent for consumers. It is important, therefore, that ELSI research on nanotechnology cover a broad spectrum of topics. Like other nanoscience research, it should also cover a spectrum of time horizons. That is, ELSI research should range from investigations that can be applied immediately to policymaking to those contributing to background knowledge that will be applied over a much longer term.

Thus far, ELSI research has been a mixed bag in looking to the longer term and covering a wide variety of topics. Surprisingly little research, for instance, has addressed the three

Figure 5. An open-source nanotechnology recipe for magnetite nanocrystals requires only such simple ingredients as olive oil, vinegar, crystal drain opener, and rust. For details see reference 16, or 18 (from which this figure is adapted).

issues the US public is most concerned about: job loss, privacy, and national security. The work that has been done in those areas once again indicates the weak empirical basis for some common folk theories. For instance, a preliminary study by Paula Stephan and colleagues shows that NSF's projection that nanotechnology will result in the creation of 2 million jobs worldwide by 2015 is belied by statistics that indicate only a small and slowly growing market for highly skilled nanotech jobs.[15]

A role for qualitative exploration

Job loss may be understood through quantitative data, but nanotech-based risks to privacy and national security are less amenable to quantitative analysis. For those issues, nanotechnology presents opportunities to experiment with new qualitative techniques for exploring the societal dimensions of science. One promising technique is scenario development—essentially, writing stories that project futures for different nanotechnologies and the ways they will interact with society. The exercises are usually meant not to generate literal predictions but rather to train nanoscientists in how to think about the ways in which technologies develop and what different parts of society will make of them. In that sense they are much like the Rand Corporation's political war games from the cold war era.

Some scenario development closely resembles fiction writing. Indeed, Rosalyn Berne of the University of Virginia and researchers at the Center for Nanotechnology in Society at Arizona State have encouraged practicing scientists to write speculative fiction as a way to think about where their laboratory work might end up. But scenario development is not just about individual self-cultivation, though that goal can be important. Well-written scenarios for issues like privacy and national security are prerequisites for telephone surveys, focus groups, consensus conferences, and other societal-dimensions research. A notable example of scenario application is three seminars on societal dimensions of nanotechnology, aired by the Public Broadcasting Service earlier this year (see http://www.powerofsmall.org). In those gatherings, panels of experts from various disciplines were given scenarios relating to soon-to-be-real nanotechnology. The resulting mix of perspectives offers a useful starting point for any class or small group looking to discuss ELSI topics.

Scenario development, interviews with nanoscientists, consensus conferences, and other qualitative techniques are powerful tools because they offer both a snapshot of nanotechnology as it currently is and an occasion for discussion of societal dimensions that can shape what nanotechnology will be. There are and should be limits to that shaping, and scientists should retain a great deal of autonomy. Yet current ELSI research shows that some degree of public shaping of nanotechnology is necessary. As I've discussed, the public is relatively optimistic about nanotech products but concerned about making the development process more transparent and accountable.

Public engagement efforts are one way to speak to public concerns, but they risk coming across as superficial and insincere if they are not accompanied by real changes in the decision-making process in the lab, the boardroom, and the courtroom. The inclusion of social scientists and humanities scholars in nanotech research centers is a proven way to facilitate such changes.

To report an example from my own campus, Rice University's Center for Biological and Environmental Nanotechnology has for several years supported in its laboratories ethnographic research by Christopher Kelty, an anthropologist. That was basic research with no intended short-term application. Yet the presence of Kelty and his graduate students in the center sparked wide-ranging discussions among the center's nanoscientists about social justice and intellectual property. Those in turn led to a new research direction: an attempt to devise alternative chemical processes by which nanomaterials could be concocted by their end users, rather than solely by multinational corporations. Figure 5 shows one such "open-source technology" that could, for example, help make nanotech-based water treatment systems more responsive to local needs and less prone to suspicion that they have been foisted on the industrializing world by greedy Western interests.[16]

Changing the process of nanotech research will be difficult. It will make research more time-consuming. It will require that disciplines overcome vast differences in methodology and communication. It will require all nanotech researchers—natural scientists, engineers, social scientists, and humanities scholars—to ask tough questions about their own practices. But today's political moment demands introspection. Nanoscientists who, as citizens, want greater accountability and transparency from governments, corporations, trade unions, religious denominations, and other institutions must recognize that their fellow citizens demand similar accountability and transparency from science. Nanotech researchers must become comfortable narrating how and why they pursue knowledge to a larger audience than just their colleagues. As physicist Richard Jones explains, the process of explaining and listening can be tiring but ultimately rewarding:

> For the scientists, it is a chance to speak to the public in a very direct way, unmediated by the press or by pressure groups. There is a tendency for scientists sometimes to feel embattled and underappreciated, and they can be pleasantly surprised that most members of the public, in the UK at least, do hold science and scientists in high regard. Many members of the public, for their part, welcome the chance to learn and to make their voices heard.[17]

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