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Societal Dimensions Research in the National Nanotechnology Initiative

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Abstract

The National Nanotechnology Initiative (NNI) has incorporated the support of research on the societal dimensions of nanotechnologies into its core mission to promote responsible innovation. This agenda is the consequence of both NNI's own vision as well as the 21st Century Nanotechnology Research and Development Act, passed by Congress in 2003 to authorize NNI. This report offers comments on the progress of societal dimensions research under NNI in four areas: 1) *General progress in societal research on nanotechnology*, which has made significant strides under NNI sponsorship; 2) *Size and composition of the societal research portfolio*, which is inadequate to the size, diversity and dynamism of the NSE community; 3) *Integration of societal research in NSE activities*, which shows promise but has not been implemented as broadly as it should be; and 4) *Public engagement with nanotechnology*, which likewise shows promise but has not been pursued with sufficient purpose. This report concludes with a discussion about the societal challenges of nanotechnology and some recommendations for NNI regarding research, training and outreach on societal issues in nanotechnology.

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Introduction

The Center for Nanotechnology in Society at Arizona State University (CNS-ASU; www.cns.asu.edu) was created in October 2005 under a $6.2 million grant from the National Science Foundation (NSF), and it has been favorably reviewed by NSF for a $6.5 million renewal for October 2010 to September 2015. It is affiliated with the Consortium for Science, Policy and Outcomes within ASU's College of Liberal Arts and Sciences. CNS-ASU pursues a strategic vision of "anticipatory governance" of nanotechnologies (Barben et al. 2008; Guston 2008) in which capacities for *foresight*, public *engagement*, and *integration* of social and natural science work are collectively developed to encourage a broader societal capacity to manage emerging nanotechnologies for the public interest while such management is still possible. This pursuit reflects CNS-ASU's understanding of the 21st Century Nanotechnology Research and Development Act (2003 Act), passed by Congress in 2003 (Public Law 108-153), which authorized the National Nanotechnology Initiative (NNI), and it is an important component of NNI's goal to support the "responsible development of nanotechnology" (NSET 2009).

Most of this report is derived from the author's experience directing CNS-ASU and from research, training and outreach activities that CNS-ASU itself has conducted. The report generally refers to "societal" activities, which is meant to encompass ethical, legal and social dimensions, and not environmental or workforce issues unless specifically mentioned. The report also uses the term "nano-scale science and engineering" (NSE) to refer to the broad research area, the plural "nanotechnologies" for the material outputs of that research, and the term "nanotechnology" for the broader enterprise or innovation system around nano-scale activities that includes both research and material technologies as well as related policies and other dimensions.

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General Progress in Societal Research

Research, publishing and professional activities in the societal aspects of nanotechnology supported by NNI have made significant progress over a short period of time. When NNI began, there was very little attention to nanotechnology in the community of scholars that studies science and technology from a societal perspective (Bennett and Sarewitz 2006). Shapira et al. (2010) have found that only about one-quarter of social science articles on nanotechnology found in Web of Science and Scopus indices published in 2007 or prior were published between 1998 and 2004, while nearly two-thirds were published between 2005 and 2007.[1] The United States is the world leader in this research: Of the 308 articles they identify, nearly half have at least one author from a U.S. institution (compared with the approximately one-quarter of NSE articles published in the same period). Shapira et al. (2010) also describe, through a co-citation analysis, how this literature has blossomed over time from being dominated by "science visions" – of the sort articulated by visionary NSE researchers (e.g., Smalley, Whitesides) as well as by less established and more prophetic voices (e.g., Drexler, Joy) and by fiction writers (e.g., Crichton) – to a more diverse set of areas that includes empirical treatments of "science mapping" and "technological trajectories" as well as important attention to "public perception and deliberation," "governance" and "ethics," among other areas.

While the study did not attempt to identify the origins of funding for this minor explosion of research (such a project could be done), it seems clear from the timing, the presence of some particular authors, and the development of general areas of attention that NNI funding – particularly that through the NSF's first Nano-scale Integrated Research Team (NIRT) projects – was involved in this development.

Just about the time of this inflection point, the first report by the National Nanotechnology Advisory Panel (NNAP 2005: 38) exhorted NNI to "engage scholars who represent disciplines that might not have been previously engaged in nanotechnology-related research" and ensure that "these efforts should be integrated with conventional scientific and engineering research programs." This call echoed language in the 2003 Act to integrate societal concerns into NSE research for the benefit of all Americans. The Centers for Nanotechnology in Society announced by NSF in fall 2005 – including ASU (at $6.2 million) and the University of California, Santa Barbara (CNS-UCSB; at $5 million) – embodied this dual agenda of broadening the array of scholars engaged in research on the societal aspects of nanotechnology and integrating with NSE research programs. At CNS-ASU, for example, the original fourteen scholars who were co-principal investigators or leaders of research thrusts represented thirteen different doctoral disciplines ranging from electrical engineering, math, biology and the geo-sciences to political science, philosophy, sociology and anthropology. CNS-ASU has trained students across a similarly diverse group of disciplines as well.

The two centers for nanotechnology in society joined with the earlier NIRTs (which together received in 2005 another $3.1 million) to constitute a "network for nanotechnology in society," and for several years the principal investigators maintained regular telephone contact and discussed and planned events, including the launch, in fall 2009, of a new professional society: the Society for the Study of Nanoscience and Emerging Technologies (SNET; www.thesnet.net), spearheaded by NSF grantee Davis Baird at the University of South Carolina. In addition to this nascent society, other markers of the successful professionalization of research on the societal aspects of nanotechnology include the creation of new peer-reviewed journals, such as *Nanotechnology Law and Business* and *NanoEthics: Ethics for Technologies that Converge at the Nanoscale*, the forthcoming publication of an *Encyclopedia of Nanoscience and Society* (Guston 2010), and the acceptance of research on the societal aspects of

[1] Because the sample period ends in 2007, and the centers for nanotechnology in society at ASU and UCSB did not commence activities until October 2005 and January 2006, respectively, the bulk of their work is not included in Shapira et al.'s analysis.

nanotechnology by both the broader social studies of science and technology community (e.g., Barben et al. [2008], published in the field-defining *Handbook of Science and Technology Studies*) as well as by the NSE community (e.g., *Journal of Nanoparticle Research* and *Nature Nanotechnology*, which regularly publish both empirical research and commentary on societal aspects of nanotechnology). The 2008 Gordon Research Conference on Science and Technology Policy, co-chaired by CNS-ASU director David Guston, was dedicated to the topic of "Governing Emerging Technologies."[2]

Size and Composition of the Societal Research Portfolio

However promising this trajectory of research in the societal aspects of nanotechnology may be, it has not fully matched the earlier vision of a society better equipped to deal with emerging nanotechnologies, largely because the speed and scale of NSE research continues to rapidly outpace research on its societal aspects. Karinen and Guston (2010) argue that, while the 2003 Act and other developments may have positioned nanotechnology to take better advantage of societal research than programs like the ethical, legal and social implications (ELSI) research on the Human Genome Initiative, it is still the case that the centers for nanotechnology in society were not funded until nearly five years after the first of their counterpart nanoscale science and engineering centers (NSEC) was funded, and not until NNI had established a long-term, interdisciplinary and inter-agency agenda for NSE research on which it already had spent $4 billion cumulatively.[3]

In the recent budget report from NNI, the education and societal dimensions program component area ("PCA 8") are disaggregated from environment, health and safety research ("PCA 7") for fiscal years (FYs) 2006 to 2010. During this period, NNI agencies spent $182.2 million on PCA 8, or about 2.3% of the more than $7.8 billion spent on all NSE research over these five years. This share is less than the reputed 3-5% share of the Human Genome Initiative dedicated to ELSI research, even while it includes educational activities such as the NSEC/National Center for Learning and Teaching (NCLT; $15 million initial award), the Nanoscale Informal Science Education Network (NISE Net; $20 million initial award) and other educational endeavors. While it would be hard for an outsider to disaggregate educational spending from societal dimensions, it seems likely – given that the institutions contributing to the nanotechnology-in-society network are funded cumulatively at a level akin to the NCLT and significantly less than the NISE Net – that societal dimensions research would not constitute any share greater than one-third of PCA 8 funding, and likely much less. Societal dimensions research is thus likely less than 1% of the entire NNI portfolio, and probably closer to 0.5%.[4]

One reason for this tiny share is that agencies participating in NNI, other than NSF, have made almost no commitments to societal dimensions research. The recent NNI budget report disaggregates the PCA spending by agency: Of the $182.2 million in PCA 8, NSF commits $168.1 million, or more than 92%; the National Institutes of Health (NIH) commits $10.1 million, the Department of Energy (DOE) commits $2.5 million, and the Department of Agriculture (USDA) commits $1.5 million. These sums may, of course, be

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[2] See http://www.grc.org/programs.aspx?year=2008&program=scipolicy.
[3] See NNI Investments by Agency and PCA, FY 2001-2010, available at www.nano.gov. Caveats about the quality of the budget data are necessary.
[4] This estimate would not even include discounting shares of the budgets of societal dimensions centers, teams and projects that are dedicated to education or, for that matter, supporting interdisciplinary work by supporting NSE students.

entirely dedicated to education, or may have research components. But the Department of Defense (DOD), which has the largest cumulative share of NNI spending, reportedly has committed nothing to PCA 8.[5] Likewise, the National Institute of Standards and Technology (NIST), the National Aeronautics and Space Administration (NASA) and the Environmental Protection Agency (EPA) have committed nothing, while they have spent cumulatively more than $1 billion on NSE. If one looks only at NSF, the share of PCA 8 funding is about 8% in the period, but again education is likely two-thirds of that sum, putting even NSF's respective share of societal dimensions of nanotechnology research lower than the low end of the ELSI share of genomics research.

There is some irony in that NSF, which is expected to focus on fundamental research, supports the lion's share of societal dimensions research while the mission agencies – which are supposed to be more concerned with translational issues for which societal dimensions research may be helpful – neglect it. This neglect occurs even in the context of several agencies other than NSF having identified PCA 8 as a primary or secondary nano-related activity in the 2007 NNI Strategic Plan (NSET 2007: 9). But the more important point is that potentially critical areas of societal dimensions research have gone wanting, in areas directly related to these missions. Despite the profound potential implications for weapons systems, the role of the warfighter, espionage, asymmetric warfare, chemical and biological defense, dual-use technologies, and other security issues, there is no sustained research program on the societal aspects of nanotechnologies in the military and security context.[6] Similarly, there is little societal dimensions research on the implications of nanotechnologies for public health outcomes, the role of standards and standardization in advancing NSE research and governance, or on the kinds of knowledge systems that regulatory agencies like EPA and the Food and Drug Administration (FDA) require to best grapple with emerging technologies and the kind of data that newly increased budgets for environment, health and safety (EHS) research will generate (but see Wolf et al. 2009).

Integration of Societal Research with NSE

Even if all the agencies sponsored societal research to NNI at the level of NSF, let alone at the level of genome ELSI, there would still be a question of the integration of that research with NSE research as both the 2003 Act and earlier NNAP reports envision. The relevant passage from the 2003 Act, 2(B)(10)(c), authorizes:

> insofar as possible, integrating research on societal, ethical, and environmental concerns with nanotechnology research and development, and ensuring that advances in nanotechnology bring about improvements in quality of life for all Americans.

While there may be reasonable disagreement over what integration means in practice, CNS-ASU has taken it to mean the close collaboration of social scientists and humanists with NSE researchers and

[5] There are likely reporting issues here, as at least one activity, a 2007 workshop organized by the Chemical and Biological Defense program on nanotechnology, would fit into PCA 8. See Kosal (2009). It would, however, be hard to imagine any sizable amount of funding in PCA 8 being completely overlooked, and if it were, that in itself would be suggestive of other forms of neglect.

[6] One new activity is the Consortium for Emerging Technologies, Military Operations and National Security (www.cetmons.org), which involves researchers from ASU, Case Western Reserve University, Georgia Tech, and the US Naval Academy.

students in research, training and outreach activities. Among the signature "integrative" activities CNS-ASU has developed as constituent elements of its anticipatory governance agenda are:

- Socio-Technical Integration Research (STIR; www.cns.asu.edu/stir), which places a social science or humanities researcher in an NSE laboratory for an extended period to explore the possibilities for "midstream modulation" – that is, the considered broadening of research decisions and directions (modulation) in the context of the laboratory (midstream, as opposed to upstream in legislative authorization or downstream in technology assessment; see Fisher et al. 2006; Fisher 2007; Schuurbiers and Fisher 2009);

- Real-time assessments, based both on the analysis of large-scale databases as well as close collaborations with NSE researchers, that have probed how EHS research knowledge is used by nanoscientists (Youtie et al. 2009) and the extent to which NSE research is shifting toward a focus on active nanostructures that may pose intensified EHS concerns (Subramanian et al. 2010);

- Scenario development workshops and other futures-oriented projects, including a workshop on the future of pre-symptomatic diagnostic technologies (Selin 2008) and a forthcoming workshop on nano-enabled renewable energy technologies;

- Graduate training for NSE students, including

    - PhD Plus program (www.cspo.org/outreach/phdplus/), in which CNS-ASU partially supports NSE students and involves them in societal research and outreach activities, such as developing technically grounded scenarios for the Nano Futures project (http://cns.asu.edu/nanofutures/aboutproject.html) or working with the Arizona Science Center on Science Café events, table-top demonstrations and other public activities;
    - Science Outside the Lab program (http://www.cspo.org/outreach/scienceoutsidethelab/), a highly experiential, two-week curriculum in Washington, DC, to expose NSE graduate students to the ways and means of science outside the laboratory; and
    - Coursework, including societal dimensions training for doctoral students in ASU's new, interdisciplinary Biological Design PhD program as part of that program's required core seminar and a stand-alone, two-credit course on Nanotechnology and Society that meets requirements in ASU's new Professional Science Master's degree program in Nanoscience; and

- Undergraduate education for students from various backgrounds, including

    - A Learning Community, in which a small number of ASU undergraduates take three inter-related courses (for nine credits) on both the technical and social sides of "Nanotechnology in Society;" and
    - InnovationSpace (http://innovationspace.asu.edu/about/), a nine-credit capstone course in ASU's School of Design Innovation, in which designers, business students and engineers work in cross-functional teams to design, proto-type and develop business proposals for new products (in this case imagined nano-enabled products).

While NSEC/CNS-UCSB also has made integrative activities a research and training priority, it is not clear that the other NSECs, the National Nanotechnology Infrastructure Network (NNIN), or the other NNI centers have done so. In systematically searching NSEC Web sites, CNS-ASU researchers coded a large number of activities and found evidence of few integrative research activities among them (Garay and Fisher 2008). While Web sites are not the best sources, CNS-ASU was unable to easily obtain a comprehensive set of annual reports from the NSECs.[7] CNS-ASU has since applied for and received funding from NNIN to travel to six NNIN nodes and NSECs to perform in-person interviews about integrative activities, with completion of field research by May 2010.[8]

Evidence about the implementation of integrative activities also comes from a catalogue of degree-granting programs in NSE compiled by CNS-ASU. The research (Van Horn et al. 2009),[9] which created the most comprehensive list to date of post-secondary programs that grant degrees in nanoscience or nanotechnology, identified forty-nine qualifying programs. Of these forty-nine, thirty-two are associate's degree programs; of the remaining seventeen, one is a bachelor's program, eight are master's programs, and eight are doctoral programs.[10] Of the seventeen non-associate's degree programs, only four describe any concrete, integrative activities:

- ASU's Professional Science Master's degree in Nanoscience (as mentioned above) incorporates a two-credit "Nanotechnology and Society" class into its required curriculum.
- Rice University's Professional Science Master's degree in Nanoscale Physics lists "Science Policy and Ethics" as an available elective.
- University of New Mexico lists "Social and Ethical Issues in Nanoscience" as a core course in its Nanoscience and Microsystems MS and PhD programs.
- University at Albany, State University of New York offers several nano-business and -economics related courses in conjunction with a set of MS, MS/MBA and PhD programs in nanoscience and nanoengineering.

While it would take further research to discern what specific role NNI funding might have had in creating these programs or supporting their faculty, it is clear that integration of societal dimensions into NSE education is not commonplace. It might, however, be related to federal and (in one case) state investments in interdisciplinary activities. The program at ASU would not have offered the "Nanotechnology and Society" course were it not for the educational programs developed by CNS-ASU. Rice not only hosts the NSEC/Center for Biological and Environmental Nanotechnology (CBEN) but also has done serious work in societal dimensions (previously with Christopher Kelty, now with Cyrus Mody, who also works with CNS-UCSB). University of New Mexico not only has an NNIN user facility but also has an Integrative Graduate Education and Research Traineeship (IGERT) program in Nanoscience and Microsystems. Albany boasts the College of Nanoscale Science and Engineering, with large-scale state and private investments in the Center of Excellence in Nanoelectronics and Nanotechnology (CENN).

[7] NSEC annual reports are not available online in a systematic and public fashion.
[8] NSET (2009: 23) cryptically refers to "a study is being conducted to assess and compare the capability of research centers in nanotechnology and other emerging technologies to integrate broader societal considerations and social sciences into their work. This study is coordinated with a European effort using the same methodology." Neither I, nor CNS-UCSB director Harthorn, nor my relevant researchers at CNS-ASU can identify this study, unless it is an oblique reference to the STIR study itself (NSF # 0849101).
[9] This research was conducted through a subcontract to the Heldrich Center for Workforce Development at Rutgers University.
[10] Such numbers are subject to constant fluctuation as new programs come into being and old programs are discontinued. The total number of programs identified is larger than any other single source at the time of the report's publication in May 2009.

This emphasis on integration is not to argue that all societal research should be integrated with NSE research, any more than an emphasis on technology transfer would argue that all research should be oriented at commercialization. But it is to suggest that – after a decade of NNI and seven years since the 2003 Act – appropriate models for integrative research, training and outreach activities exist and should be disseminated further throughout the community.

Public Engagement with Nanotechnology

In addition to calling for integration of societal research, the 2003 Act mandated public input and outreach and, like integration, an agenda for public engagement has not been implemented in as robust a fashion as it might have been. The relevant passage from the 2003 Act, 2(B)(10)(d), authorizes:

> public input and outreach to be integrated into the Program by the convening of regular and ongoing public discussions, through mechanisms such as citizens' panels, consensus conferences, and educational events, as appropriate.

NNI offered a promising, if tardy, start with its large workshop in May 2006 on public participation, organized by the National Nanotechnology Coordination Office (NNCO) and sponsored by the Nanoscale Science, Engineering and Technology (NSET) Subcommittee. The two-day program generated considerable excitement among the larger-than-expected number of participants. Yet, while the presentations from the workshop are available online,[11] no report on the workshop seems ever to have been finalized for distribution on the NNI Web site.

The major messages of that meeting, as well as almost all relevant scholarship in public engagement in science and technology over the last decade and a half, are that:

- Communication between the lay-public (which is not monolithic) and the scientific community (which isn't, either) needs to be two-way.
- Such communication needs to be not just about scientific facts but also about technological applications and social values.
- The purpose of this communication must not be limited to the faulty formula of "more knowledge on the part of the public will mean more support for research and technological applications."

Previous NNAP (2005:38) reports have come dangerously close to this latter formulation, e.g.:

> To sustain this [high level of public] support, the scientific community and the Federal agencies that fund scientific research must communicate more directly with the public, not through surrogates such as the entertainment industry…. Through the NNI website and through outreach activities at the NSF-funded centers and DOE user facilities, the NNI has established channels to communicate with members of various stakeholder groups, including the broader public.

[11] See: http://www.nano.gov/html/meetings/p2/index.html.

Similarly, recommendation 6.1 of NNAP (2008:34-35) was to: "[d]emonstrate more clearly to the public the value of nanotechnology and NNI-supported research and development."

NNAP (2005:38) did recognize that public input was important, as it reported that "[f]or its own part the NNAP has held open meetings focusing on nanotechnology issues, which have provided the public with several opportunities to provide input." But the ability of the general public – as opposed to organized and special interests – to participate substantively and provide input at "open meetings" of executive agency committees is highly constrained, which may be in fact why the 2003 Act calls for more open and interactive public forums such as citizens' panels and consensus conferences.

Taking guidance from this specific language of the 2003 Act and from its own vision of anticipatory governance, CNS-ASU has made public engagement, like integration, a centerpiece of its activities. In addition to small-scale activities such as regular Science Cafes[12] held in conjunction with the Arizona Science Center and the inclusion of diverse stakeholders and potential user groups in scenario workshops and lab integration activities, CNS-ASU organized in spring 2008 the most ambitious public engagement activity around nanotechnology in the Unites States, the National Citizens' Technology Forum (NCTF). Modeled after the Danish consensus conference but distributed across six locales across the United States, the NCTF on "nanotechnologies and human enhancement" demonstrated that a high-quality deliberative activity can be organized at a national scale in the United States, and that a representative selection of lay-citizens can come to discerning judgments about nanotechnologies while they are still emergent (Hamlett et al. 2008). While there are reasonable concerns about the quality of the particular online component of the process (Delborne et al. 2009) and the demands that such intensive activities place on citizens (Kleinman et al. 2009), the NCTF process is a sound demonstration upon which to build future citizen deliberations (Philbrick and Barandiaran 2009).

NISE Net also has made an important and creative start in public engagement. While the focus of NISE Net activities is communicating technical ideas about NSE and nanotechnologies, it has struck up an increasingly intensive collaboration with CNS-ASU around integrating societal perspectives into its informal science education. This collaboration was born from mutual self-interest: CNS-ASU was interested in expanding the audience for dissemination of its research results, and NISE Net was interested in using societal content and perspectives to complement its outreach activities. Early aspects of the collaboration included a draft of "ten big ideas" in the societal dimensions of nanotechnology (Miller et al. 2007) that CNS-ASU produced for NISE Net, as well as NISE Net's drawing on CNS-ASU's strategic vision of anticipatory governance (Guston 2008) to provide a further rationale for its forum programs, which are oriented toward public deliberation (Bell 2009).

The relationship is growing to allow CNS-ASU to contribute its expertise to reach hundreds of museums and science centers in the expanded NISE Network through such activities as "hacking" NISE Net's NanoDays kits with societal dimensions materials and collaborating on the development of a film script and table-top demonstrations that would communicate societal dimensions research. CNS-ASU and NISE Net also are planning longer-term collaborations to identify key learning goals for anticipatory

[12] The science café "movement" has been gathering steam. The Web site www.sciencecafes.org – sponsored by Nova Science Now and Sigma Xi, The Scientific Research Society – locates scores of these informal, open gatherings of citizens with scientists across the country. At least several of these are affiliated with NNI-related activities, including the cafes organized by CNS-ASU, CNS-UBSB, and the University of Wisconsin NSEC.

governance and how those goals may be pursued in formal and informal educational settings, as well as how anticipatory governance may be materialized in full-scale museum exhibits.

Nevertheless, a significant challenge remains for public engagement: In aggregate, public understanding of nanotechnology has been static, but it has improved in a small but significant increment among the most educated segments of the population while it has actually declined in a small but significant increment among the least educated (Corley and Scheufele 2010). A great deal more attention to the particular kinds of public engagement mechanisms and the particular audiences they reach will be necessary.

Discussion: The Social Challenge of Nanotechnology

The earlier NNAP reports evinced concerns over the relative novelty of the social and ethical issues raised by nanotechnologies. The second report, in particular, maintained that "[i]t is not clear whether the concerns raised are exclusively related to nanotechnology or, more likely, to the generally increasing penetration of technology into the fabric of our daily lives" and that "there is no apparent need at this time to reinvent fundamental ethical principles or fields or to develop novel approaches to assessing societal impacts with respect to nanotechnology" (NNAP 2008:30). This opinion was shared by President George W. Bush's Council on Bioethics, which NAPP consulted, and also by some voices in the relevant literature as well (e.g., Grunwald 2005; Keiper 2007; Litton 2007).

One presumes that NNAP investigated this question of novelty because the presence of unique ethical concerns would make NNI remiss in not attending to them. But this logic is not instructive if there are no unique ethical concerns. Among the scholars, the major concern evinced is for the distribution of scarce resources and scholarly attention – to advocate for less attention to, in their view, the trendy but not novel societal dimensions of nanotechnology, which is more concerned with the hypothetical challenges of an inchoate technical field than with concrete challenges of science and technologies that already are upon us. These scholars argue that if nothing is new ethically – by which they mean, along with NNAP, that no new ethical principles are necessary – then nothing needs to be new financially or organizationally.

Without addressing the issue of whether there is anything ethically novel about nanotechnology,[13] there are four reasons to believe that an ethics of nanotechnology is important to develop.[14] Since each of these reasons is related in some degree to nanotechnology's status as an emergent technology, a brief digression that will explain something more about "anticipatory governance" is warranted.

The intuition of the argument about novelty and resources is that it makes sense to minimize time and effort on the ethics of utter fantasies, which many observers have declared rampant among nano-proponents and nano-opponents alike.[15] However, Keiper's sentiment (2007:57) that "our ability to

[13] Many knowledge-based technologies have what could be called a politics of novelty. On the one hand, advocates represent them as novel in order to garner them attention and funding while, on the other hand, they represent them as merely incremental improvements over previous technologies in order to secure public support and favorable regulatory treatment. See Rayner (2004).
[14] Registers have been switched here to ethics in order to match earlier NNAP and scholarly concerns, but it is clear from context that these usages include the full array of societal dimensions.
[15] This intuition is itself disputable, as hypothetical examples and extreme cases are often quite useful in ethical and normative debate, if only to delimit particular concepts and arguments. It also is the case that many NSE researchers themselves draw on

anticipate the societal and ethical consequences of nanotechnology will plainly be conditioned on what turns out to be possible" is troublesomely imprecise. The only definition of "anticipation" that renders this sentence logical (and consistent with his whole article) is as "prediction." But for many social science and humanist researchers working on NSE, as well as for the dictionary, anticipation is a less concrete and causal concept than prediction. Anticipation is more of a distributed capacity than an actual ability; it is not to be evaluated by the congruence between the stuff predicted and stuff materialized, but rather by reducing the difference between how one prepares to face imagined challenges and how one faces the challenges that actually present themselves.

There are three operative concepts here, and an extended analogy might help:

The first concept is prediction, or saying before it will happen what in fact will happen. If one could *predict* the manner of one's death, then one could (in all but the most fate-ridden perspectives or the worst horror movies) avoid it. But one's ability to predict even the contours of an emerging technology are poor, especially when trying to account for its interaction with other emerging technologies like synthetic biology, information technology and robotics, and neuro-technology.

In some cases, one can probabilistically *forecast* one's chances, for example, of dying of heart disease or cancer or an automobile accident. In such cases, one could alter one's chances greatly through precautionary action. But such probabilistic knowledge is hard to come by – it is only after counting a great many deaths that one knows how probable it is to die of something, and it might in fact be a moral imperative to search for ways around waiting for deaths.

Finally, one could *anticipate* that one's health will be taxed by a variety of challenges related to infection and aging, for example, and could attempt to sleep well, eat right and exercise in anticipation of these challenges. The decision to sleep is not because of a suspicion that lack of sleep will kill one, and lifting weights is not prompted because of a belief that being able to bench-press a certain number of kilos will enable one to avoid being crushed to death beneath a fallen beam. But doing these tasks is in anticipation of the physical challenges – whatever they may be – that one does know one's body will face.[16]

Similarly, it is not known which specific challenges emerging technologies such as nanotechnologies will offer – this is their nature as emergent. But those challenges can be anticipated generally and strategies devised – which involve, among other things, ethics – for confronting them.

To return from the digression, the first reason in favor of specific ethical and social attention to nanotechnology is that NSE as a large enterprise on which billions of dollars of R&D funds – not to mention billions more on commercial products – are committed worldwide on an annual basis, has followed a trajectory different from nuclear and genomic big science (Jasanoff 2007). First, nano has no canonical moment like the mushroom cloud or the determination of the structure of deoxyribonucleic acid (DNA). While nano aficionados may point to Feynman's 1959 speech or IBM's logo written out in xenon

science fiction as part of their moral vision (Berne 2005) and that science fiction can play an important role in technology assessment (Miller and Bennett 2008).

[16] Scenario planning of the type advocated in the NNI Strategic Plan (NSET 2007:31) is a standard way to approach the challenge of anticipation without forecasting.

atoms, NSE seems more beset by alternate histories of its emergence (McCray 2007; Kim 2009). NSE also articulates *ex ante* no clear endpoints akin to sequencing the human genome or building an atomic weapon. NSE insiders themselves stress the heterogeneity of nanotechnologies and the plurality of its potential applications. Coherence comes to NSE via breakthroughs in our ability to observe, intervene and manipulate at a scale of operation rather than in a particular substance or system. There is not one nanotechnology but a suite of nanotechnologies, and thus a suite of potential ethical and societal inquiries. Indeed, while this incoherence is seemingly part of what disturbs some critics of developing nano-ethics, it is not warrant for lack of attention but rather evidence that nanotechnology is not just ripe for critical reflection but demanding of it.

Second, the framing of issues, including and perhaps especially ethical issues, is dependent heavily on context, and nanotechnologies are developing in a context necessarily different from other recent technologies. Empirical research on NSE is accumulating evidence of potentially important contextual differences from even its oft-associated biotechnology cognate. For example:

- The funding context of nanotechnology versus, e.g., genomics, differs to the extent that the DOD rivals NSF as the most significant public sponsor of NSE in the United States, while NIH and DOE sponsored genomics research. For many ethicists, as well as for many researchers, the agenda of a research sponsor is a relevant fact for the ethics of research.
- Nanotechnology offers a different array of disciplines and thus a different set of interdisciplinary challenges for ethics. For example, what is not risky to some “upstream” researchers may in fact be risky to “downstream” ones (Powell 2007). The consequent ethical issues raised are not novel as such, but they are likely to play out differently than previous attention to laboratory safety and public policy issues.
- The contexts of geographic and regional development of nanotechnology are different than previous technologies. At the international level, NSE offers a different profile than biotechnology, with a much more prominent presence of developing countries such as China and India and some small nations such as Israel (e.g., Youtie et al. 2008). Thus, there are likely to be different issues emerging based on the particular cultures and circumstances of key NSE countries, but also different ethical aspects to rationales for NSE investment (e.g., competitiveness, development, military) in individual nations. In the United States, the array of emerging nano-districts is overlapping with, but distinct from, those associated with biotechnology (Shapira and Youtie 2008), raising questions about models of research-led economic development and its ability to make durable contributions.
- Strong evidence suggests that nanotechnology is developing as a general purpose technology, and is thus poised to contribute to societal transformation on the scale of the transformations facilitated by electrification and information and communication technologies, rather than genetic technologies (Youtie et al. 2007).

These are only some of the novel contexts within which NSE is developing, and it is not unreasonable to constitute research programs around them that involve ethics.

Third, advances in nanotechnologies provide a greater “technical imminence” for some ethical issues, thus rendering them more critical to study now even if not novel as such. Questions of human enhancement stand out in this regard.[17] To some extent, all technologies may be viewed as human enhancements. To conclude, however, that the ethical issues attached to reading glasses are the same as for dialysis machines, and thus the same as for implantable brain-machine interfaces seems at least a bit preemptory. A prominent promise of nanotechnology is to craft many if not all human assistance technologies at the right size and level of interactivity to integrate them within the human body. While society has been confronted already with ethical issues of internalizing enhancement technologies in areas of competitive sports (e.g., anabolic steroids and other performance-enhancing drugs and now gene doping) and competitive academics (e.g., use of Ritalin to enhance the concentration of students who do not have attention deficit disorder), it very well may be confronted with ethical issues of internalized enhancement technologies in competitive arenas, like the marketplace and politics, that raise issues more fundamental to social and political organization (Guston et al. 2007) and would require a great deal more social organization to manage. Moreover, nanotechnologies make the imminence or temporal proximity of such enhancements more apparent. Arguments dismissive of the need for ethical and social inquiry into emerging technologies often point to the gap between current knowledge and practice on one hand and fantastical visions concocted by opponents of progress on the other hand (e.g., Zonnefeld et al. 2008). Yet, a cross-section of “real-time technology assessment” methods (Guston and Sarewitz 2002) applied to the question of the NSE research related to the human brain reveals a great deal of interesting activity worth of ethical inquiry (Miller and Robert in preparation).[18]

Fourth, public policies and NSE researchers themselves have called ethicists and other scholars of technology to participate in the development of nanotechnologies in ways that they had not participated heretofore. The 2003 Act called for the creation of a research program in the societal implications of nanotechnology (Fisher and Mahajan 2006). The legislation helped smooth the way to the awarding by NSF of the two centers for nanotechnology in society. These centers have tended to eschew the term nano-ethics, and yet they each have many participants who “do” ethics, with many projects having distinctly normative components and dealing explicitly with values. Their research programs, while newly composed by their respective teams and ambitious and even potentially over-reaching, were each formulated in response to requests for proposals and were not merely creatures of an over-active social scientific imagination (as Keiper and Litton would have it). This behavior on the part of policy makers is not limited to the United States, as the United Kingdom and the Netherlands, in particular, have launched similar programs. Further, this demand is articulated by NSE researchers themselves and not just by the Congress or executive agencies. Since CNS-ASU has been established and engaged in its integrative agenda, numerous colleagues in NSE research (and other areas) have approached the center seeking its collaboration in research, training and outreach activities across technical areas from nano EHS to emerging energy technologies to synthetic biology. These collaborations are sustained because researchers themselves have the need to anticipate future developments, engage the public and integrate their own work with social scientists and humanists.

Finally, even if nanotechnology were:

1. similar in its origins, trajectory and ends to other big science projects;
2. replicating the institutional and geographic contexts of other emerging technologies;

[17] The 2003 Act also called out human enhancement as an area of particular concern.
[18] Another area ripe for such inquiry would be geo-engineering, as many of the proposed solutions for engineering away climate change involve the deliberate release of climatologically active nanomaterials.

3. unpromising in lending greater imminence to issues raised by previous technologies; and
4. uninviting to social scientists and humanists;

such questions would still deserve attention because they have proven persistent if not intractable. Given this persistence, disavowing the need for a new approach would be like disavowing a hammer when a screwdriver has failed again and again to gain traction.

We have no future facts, but we are in the process of making them. We cannot forecast their precise contours or consequences, but we can anticipate them and prepare intellectually and materially for the kinds of things that we can imagine occurring. Because the future is so uncertain, the present needs to be populated with more discussion about technical possibility, consequences, and purpose – and ethics – rather than less.

Despite NNAP's earlier (2008:30) disavowal of the need for "novel approaches for assessing societal impacts with respect to nanotechnology," NNI has been authorized by the 2003 Act to engage in novel approaches and it has in fact been supporting them, albeit modestly. These approaches are characterized by anticipatory governance as developed at CNS-ASU but exemplified in other ways involving *foresight*, *engagement*, and *integrative* activities at CNS-UCSB and other NNI-funded societal activities (e.g., the NIRTs at the University of Minnesota and at Northeastern University). NNI has an exceptional opportunity to develop these approaches further, to the benefit of not only the researchers involved but – in developing new styles of governance for NSE and other emerging technologies – for the benefit of all Americans.

Recommendations

1. NNI should make strong efforts to increase the share of its resources dedicated to societal research.
    a. NNI should develop a strategy to increase the funds spent on the societal research component of PCA 8 (including workforce but not including environment or education) to approach or exceed the 3% minimum established by the Human Genome Initiative.
    b. All NNI agencies, particularly those identifying a primary or secondary interest in PCA 8, should contribute to implementing this strategy.
    c. All NNI centers and networks should contribute to implementing this strategy.

2. NNI should actively pursue the integration of social science and humanities work with NSE research, as well as its independent pursuit.
    a. NNI should convene a "best practices in integration" summit to discuss, analyze and disseminate models for integrative research, training and outreach activities.
    b. NNI should encourage participating agencies to explore a variety of funding mechanisms to expand opportunities for integrative activities, including dedicating funds in existing integrative programs and initiating new programs to support activities identified by the summit.
    c. NNI should sponsor workshops that would demonstrate the value of integrative activities to a broad set of NSE and societal dimensions researchers as well as various publics, including but not limited to scenario development workshops and informal science education workshops.

3. NNI should implement a new public engagement strategy that gives less attention to educating the public so that it will support NSE research and the adoption of nanotechnologies and more attention to developing ongoing, substantive, two-way dialogues between NSE research and lay-publics.
    a. NNI should articulate clearly a new public engagement strategy that includes a variety of engagement techniques with clearly defined purposes and audiences, including reaching those least educated and least dependent on Internet sources for information.
    b. NNI should convene, or instruct that participating agencies convene, at least one major public engagement activity every year.
    c. NNI should play an active role in ensuring that public engagement activities – convened by NNI, participating agencies or grantees – have access to NSE experts and policy makers for input and dissemination.

4. NNI should institute policies and procedures that would improve the chances for the successful implementation of these recommendations.
    a. NNI should split PCA 8 into two PCAs, one for societal dimensions research and another for education, and provide as much retrospective budget analysis for the new PCAs as is practicable.
    b. NNI should appoint an ad hoc working group to help participating agencies identify societal dimensions research topics and integrative opportunities relevant to their own portfolios.
    c. NNI should instruct participating agencies to make a thorough review and report of societal dimensions research topics and integrative research, training and outreach activities at sponsored centers and networks.
    d. NNI should ensure that the review processes of participating agencies are sufficiently charged and expert to evaluate societal dimensions research and integrative activities in their centers and other programs.
    e. NNI should ensure that sufficient funds are available for societal dimensions research in centers, large groups and ensembles that allow such work to move ahead in conjunction with other large NSE groups.

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About CSPO

The Consortium for Science, Policy and Outcomes at Arizona State University is an interdisciplinary intellectual network aimed at enhancing the contribution of science and technology to society's pursuit of equality, justice, freedom and overall quality of life. CSPO creates knowledge and methods, educates students, cultivates public discourse and fosters policies to help decision makers and institutions grapple with the immense power and importance of science and technology as society charts a course for the future. CSPO's unique and productive synthesis of theoretical, empirical and problem-oriented research and tool development is driven by three guiding ideas: desired outcomes can drive science; the value in society of new knowledge is determined by how it is used, and by whom; and the definition of the problem helps determine the relevance of the research. CSPO believes that politics and the ideas, institutions and the people behind them – and not science alone – determine the outcomes of science and technology in society. In this view, science policy is vastly more complex – as well as more interesting and malleable – than merely setting a budget for scientific research and development.

CSPO's affiliated Center for Nanotechnology in Society is funded by the National Science Foundation. Its guiding conceptual goals are two-fold: to increase reflexivity within the nanotechnology enterprise and to increase society's capacity to engage in anticipatory governance of nanotechnology and other emerging technologies. "Reflexivity" refers to the capacity for social learning that informs about the available choices in decision making about nanotechnology. This reflexiveness can signal emerging problems, enabling what we call anticipatory governance – the ability of society and institutions to seek and understand a variety of inputs to manage emerging technologies while such management is still possible. Through this improved contextual awareness, the path of nanotechnology knowledge and innovation can be guided toward more socially desirable outcomes and away from undesirable ones.