CONVERGENCE
Final Technical Report
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Section 1. Process

We undertook this research in order to further the development of an existing project that proposes to examine the ethical, social, legal, and environmental (ESLE) issues surrounding the emerging and diverse field of nanoscale science and technology. We began by constructing a short survey instrument to assess the views of scientists working in the field. We then developed a list of possible survey respondents from members of the scientific community. The list included a total of 87 scientists, approximately two-thirds of whom were senior and one-third of whom were junior. Out of the 87, 32 agreed to respond to the survey. Ultimately we interviewed or received responses from 22 of these scientists.

We discovered that the majority of scientists who agreed to respond were from the academic community. There were two notable exceptions, both coming from major computer companies and both well known for their views. Not surprisingly, the majority of respondents had not considered or had only a limited concern for ESLE issues derived from their science. The one exception to this was general agreement that some members of the scientific community had oversold nanotechnology.

Using the results of the survey instrument, we designed a second survey to query individuals with particular expertise and/or training in ESLE issues or who were involved in some aspect of formal or informal education. We contacted over 30 individuals who met this criterion, with 20 responding to our request.

By meshing the information gathered from this process we have been able to define and divide the ESLE issues into three distinct areas described in section 3.

Section 2. Findings

We discovered that most respondents view nanoscale science and technology as a part of the continuum of scientific discovery rather than as a discontinuity, a viewpoint with which we agree. Therefore, scientists practicing at the nanoscale will face the same questions with which science and society have historically struggled. However, there are two aspects of nanoscale science that differentiates it from all others. The first is the degree to which nanoscale science crosses all established scientific boundaries, bringing together a set of disciplines and scientists who have rarely collaborated in the past. This will mean that the scope of discovery and application will be extremely broad. The second is the speed with which scientific discovery is proceeding, with applications that seemed quite futuristic materializing far more rapidly than anticipated by most.

The attached table summarizes the most pertinent of the responses.

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Section 3. ESLE Issues and Potential Framework

We have concluded that the best way to approach this challenging topic is through the development of a series of Socratic dialogs in partnership with Fred Friendly Seminars. The objective of Fred Friendly Seminars is to open minds to the complexity and ambiguity of issues facing contemporary society. The potentially polarizing and controversial questions likely to be raised by nanotechnology lend themselves to the type of Socratic dialogue that has distinguished the Fred Friendly Seminars for over 20 years.

Seminars begin by painting "little pictures" – dilemmas or conflicts such as almost anyone would confront in their lives – and end with an informed and emotionally compelling exploration of the large ethical, legal and public policy questions at the heart of a well-functioning democratic society. We propose to build a series of four "little pictures," reality-constrained hypotheticals that will allow a skilled moderator to lead scientists, social, ethical, and legal scholars, policy and decision makers, business leaders, and members of the general public into thoughtful discussions about the decisions ahead as nanoscale science moves increasingly from theory to application.

Thus far, most of the commercial products of nanotechnology are fairly mundane. They include such things as fabrics that are "nanostructured" to prevent staining, keep water out, and retain their color, a tennis ball covering that prevents loss of pressure, tennis rackets that are stronger and more resilient, and suntan lotion filled with nanoparticles that don't reflect the sun and are thus transparent. But most scientists and many business leaders think that this will change and change rapidly.

Despite all the recent hyperbole surrounding the potential benefits and dangers associated with nanotechnology, there really is no significant discontinuity in the path of scientific discovery. In other words, nanotechnology has grown as an extension of our progress in understanding how things work at increasingly small scales. This means, in part, that the issues surrounding nanotechnology are also extensions of the same social, ethical, and legal issues with which society has already been wrestling. The two factors that make societal consideration more urgent are the speed with which the science and its applications are moving and nanotechnology's cross-cutting nature. These are powerful enabling technologies and as such they will speed many of the things that science has promised into existence much sooner than believed possible a decade ago. We will try to emphasize these points as we build each Seminar's hypothetical structure.

Content Focus

The Socratic Seminars will be designed to focus on a specific set of core ethical, social, environmental and/or legal issues raised by nanotechnology. We will create hypothetical frameworks that allow us to consider the following three sets of issues:

(1) The first hypothetical framework will explore environmental and related regulatory concerns along with the ethical conduct of science and business, and intellectual property rights. Nanomaterials have properties that differ significantly from related macromaterials. Carbon nanotubes, for example, behave in ways that traditional forms of carbon do not.

Scientists and business leaders argue that their responsibility is to research, create, apply, and sell these materials; they believe that nanotechnology can significantly reduce our effect on our environment by making materials stronger and more efficient. They have traditionally relied on government to measure risks and set environmental rules. Some environmentalists fear a cataclysmic environmental impact if nanomaterials are released before we understand their properties. They would argue that we should keep nanomaterials in the lab until government and university scientists know considerably more about them.

Wei-Xian Zhang, a researcher at Lehigh University, for example, has developed iron-palladium nanoparticles that convert carcinogenic cleaning solvents into harmless substances. The particles have been pumped into the ground water at a contaminated test site in Trenton, NJ in a field test of the technology. The benefits hold great promise for efficient and less costly cleanup...but what happens to the particles after the cleanup? Do they enter the water table or accumulate in biologic organisms? Multiple other examples of new nanomaterials abound.

Should nanomaterials be regulated separately/differently from macromaterials or are our current regulations sufficiently robust to cover special qualities that nanomaterials may have? Who determines what the risks of nanomaterials are? Who decides what risk levels are acceptable given the potential benefits? Who provides 'insurance' – financial, cleanup, remediation, etc – in case a mishap does occur? What implications are there for the contemporary conduct of research and collegial disclosure of laboratory advances when the potential for profit is extremely high? What is the ethical role for business and academic labs? What special characteristics of nanoscale science and technology challenge our current legal framework for intellectual property rights and do we need to revise what can and cannot be protected through patents? Can we train a workforce prepared to support a highly technical and rapidly changing business landscape or will nanotechnology be another example of jobs exported out of the United States? Nanomaterials are unlikely to respect state and national borders. Should the UN be involved? Do we need a Kyoto treaty creating international rules for nanomaterials?

(2) A second hypothetical framework will explore issues of security and privacy. In 2000, President Bill Clinton announced the $500 million National Nanotechnology Initiative, an inter-agency effort to fund research and education in an area that many see as the science that will be the foundation for the next industrial revolution. That was just the beginning. President George Bush has continued Clinton's support for nanoscale science and technology, signing the bill into law in December of last year and committing $3.7 billion over the next four years to advancing the research. Private industry is expected to at least double the government's investment in research and development. One of the major application areas is defense.

Nanotechnology offers us an array of new materials and sensing devices to help capture, analyze, and respond to information from all around us. One approach has been developed at a company called Dust, Inc. Dust was created out of a research effort begun on the UC, Berkeley campus by Kris Pister, the company's founder and CEO. Their current applications, called smart dust, or "motes" as Pister refers to them, are comprised of a sensor, a tiny computer, a radio transmitter, an antenna and a power supply. At present the motes are relatively large - about 1 mm or roughly 100 times too large to be considered a nanoscale device. One of the goals of the research is to shrink the devices even further, however, bringing them into the nanoscale range. The company's literature advises that "Dust puts reliable, comprehensive information gathering within reach. By reducing the cost and complexity of collecting information from the physical world, Dust will help make your physical processes more reliable and more efficient."

The motes can be designed to collect all sorts of information from the world around them. They work in large groups, are self-organizing into communicating wireless networks, are self-healing, and can gather and send information to a central receiving unit. The receiving unit, in turn, sends information back to them. Dust says, "In hostile environments where it is too dangerous for humans to operate, Dust wireless sensor networks obtain information needed to assess critical situations. Dropping a robust, self-configuring, self-organizing wireless sensor network into a battlefield to obtain information presents an invaluable, strategic advantage. Collecting information from enemy movements, hazardous chemicals and infrastructure stability are just a few of the military applications."

It's clear that the military applications of nanotechnology are an important aspect of our future security. It's also clear that civilian applications of the same technology could pose significant issues in terms of privacy. How will the American public be informed about military applications and how might they be able to influence those applications? When sensor technology becomes imbedded in everything from clothing to wall paint, how much information do we want shared about our personal habits and preferences? We are fearful today of the dangers posed if scientific advances in microbiology and genetics, or nuclear and materials science fall into the hands of terrorists or hostile states. Nanotechnology adds another layer of complexity to this concern. Will we inevitably see the fruits of military nanotechnology hurled back at us? Or is there some way to limit the spread of this technology?

If we realize the promises of ubiquitous computing, who preserves our privacy? What are the implications for our security if some other country takes the lead in quantum computing, making our encryption coding far less able to protect sensitive information and systems? How do we reconcile the need to have sophisticated identification methods for individuals with our personal privacy?

(3) A third hypothetical framework will explore issues of biologic enhancement; equity and access; evolution and aging; and creation of devices with life like characteristics. This is the most futuristic content area and we will work carefully to insure that the examples of technology used are credible; we will require a consensus from our scientific advisors that the examples are realistic.

At the beginning of 2004, a company called U.S. Genomics based in Waltham, Massachusetts, announced that Craig Venter, the scientist who helped push the research community to complete the sequencing of the human genome far earlier than expected, would be chairing their scientific advisory board. The company has a new technology that utilizes nanosized channels to direct single strands of DNA through an analytical device. Their goal is to sequence a single person's entire genome within minutes and Venter is betting that they can do just that. Such a break-through would bring all of the issues related to human genetics much closer to reality.

Other researchers are actively seeking ways to couple computer chips to human neurons; Eric Kool, a professor of chemistry at Stanford, has designed DNA nanocircles that can reverse a cell's natural aging mechanism; many researchers, including James Baker and his group at the University of Michigan's Center for Biologic Nanotechnology, are developing nanostructures that can deliver drugs, genes, or diagnostic imaging devices to target cells; the ultimate goal of some is to create functional nanostructures – nanobots – that can monitor our well-being, signal when something is amiss, and repair the damage.

Much of this technology offers tremendous advances in our ability to detect and treat disease. But, if we can build nanoscale devices that repair damaged tissue and defective genes, or root out cancerous cells, who will have access? Most agree that the technology will be expensive, at least initially. Should we use those devices to enhance human characteristics? Enhancements lead us well beyond the traditional path of treatment and prevention of diseases and may challenge our notions of equal opportunity and justice even further. Will we allow this ability to shift the boundary that society has drawn between misfortune and injustice?

If we can delay or even subvert the aging process, what are the implications to society? Should there be a limit on how long we live? What are the ramifications of creating human/machine/nature interfaces? Ultimately, if we can build things with all the characteristics of living creatures, at what point do we actually create life? Will we finally take evolution directly into our hands? What controls will be necessary, or even possible, and who should establish them?