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Social Implications of Nanotechnology: A Review

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ABSTRACT: Nanotechnology has captured the imaginations of Scientists, Engineers and Economists not only because of the explosion of discoveries at nanoscale, but also because of the potential societal implications. Nanotechnology promises to be a dominant force in our society in coming decades in roads.
Today, nanotechnology is still in its infancy and only rudimentary nanostructures can be created with some control. The science of atoms and simple molecules, a one end, and the science of matter from microstructures to larger scale, on the other, is generally established. The remaining size related challenge is at the nanoscale roughly between 1and 100 molecules diameters where the fundamental properties of materials are determined and can be engineered. A revolution has been occurring in science and technology, based on the recently developed ability to measure, manipulate and organize matter on this scale. Recently discovered organized structures of matter (such as Carbon Nanotubes, molecular motors, DNA-based assemblies, quantum dots and molecular switches) and new phenomenous are scientific breakthrough that merely hints at possible future developments. However formidable challenges remain in fundamental understanding of the systems on this scale before the potential of nanotechnology can be realized.

Keywords: Nanotechnologists, diffusion, nanofabrication techniques and nanoscientists.

NANOTECHNOLOGY AND SOCIETAL INTERACTIONS

The Interactive Process of Innovation and Diffusion: New technologies come into being through a complex interplay of technical and social factors. The process of innovation that will produce nanotechnology and diffuse its benefits into society is complex and only partially understood. Economists, as well as scholars in other fields, have long studied the generation, diffusion, and impact of scientific and technological innovation. These studies outline the variables likely to determine the rate and direction of these impacts, and to identify relevant research questions. They provide a foundation on which to build studies of societal implications of nanotechnology[1].

Scientific discoveries do not generally change society directly; they can set the stage for the change that comes about through the confluence of old and new technologies in a context of evolving economic and social needs. The thorough diffusion of even major new developments rarely happens all at once. Nanotechnologies are so diverse that their manifold effects will likely take decades to work their way through the socio-economic system. While market factors will determine ultimately the rate at which advances in nanotechnology get commercialized, sustained support for nanoscience research is necessary in this early stage of development so as not to become a rate-limiting factor[2].

Unintended and Second-order Consequences: Perhaps the greatest difficulty in predicting the societal impacts of new technologies has to do with the fact that once the technical and commercial feasibility of an innovation is demonstrated, subsequent developments may be as much in the hands of users as in those of the innovators. The diffusion and impact of technological innovations often depends on the development of complementary technologies and of the user network. As a result, new technologies can affect society in ways that were not intended by those who initiated them. Often these unintended consequences are beneficial, such as spin-offs with valuable applications in fields remote from the original innovation. For instance, consider how the Internet has progressed from a technology supported by the Department of Defense's Advanced Research Projects Agency (DARPA) to facilitate digital communications among universities with DARPA contracts, to a means by which teenagers and college students exchange music files. In another example, intended benefits may also have unintended or "second-order consequences." Nanotechnology based medical treatments, for example, may significantly improve life span and quality of life for elderly people; a second-order consequence would be an increase in the proportion of the population that is elderly, which might require changes in pensions or health insurance, an increase in the retirement age, or a substantial increase in the secondary careers undertaken by older people. Another potential consequence that would need to be addressed is the potential increase of inequality in the distribution of wealth that we may call the "nano divide." Those who participate in the "nano revolution" stand to become very wealthy. Those who do not may find increasingly difficult to afford the technological wonders that it engenders. One near-term example will be in medical care: nanotech-based treatments may be initially expensive, hence accessible only to the very rich. Other consequences are not so desirable, such as the risk of closing old industries and environmental pollution, which sometimes becomes a problem, especially for large scale technologies[3].

To assess a nanotechnology (or any technology) in terms of its unintended consequences, researchers must examine the entire system of which the technology is a part through its entire life cycle. As the case of electric automobiles illustrates, without a careful analysis of the entire set of activities that produce, operate, and eventually dispose of a technology, people may leap to false conclusions about the extent to which the technology pollutes. For example, manufacture and disposal of an electric vehicle's battery may release more lead into the environment than if the vehicle had been fueled throughout its working life by leaded gasoline. One concern about nanotechnology's unintended consequences raises the question of the uncontrolled development of self-replicating nanoscale machines. A number of very serious technical challenges would have to be overcome before it would be possible to create nanoscale machines that could reproduce themselves in the natural environment.

Some of these challenges appear to be insurmountable with respect to chemistry and physical principles, and it may be technically impossible to create self-reproducing mechanical nanoscale robots of the sort that some visionaries have imagined. A new form of life different from that known (i.e., carbon-based) would be a dramatic change that is not foreseen in the near future. Initially, the impact of nanotechnology will likely be limited to a few specific products and services. Nanotechnology-based goods and services will probably be introduced earlier to those markets where consumers are willing to pay a premium for new or improved performance. Such primary effects would be to make things work better, cheaper, with more features, etc. This might, for example, increase food yields, generate new textiles for clothing, improve power production, or cure a certain disease. As mentioned above, by and large, the displacement of an old technology by a new one tends to be both slow and incomplete. As a result, nanotechnology will coexist for a long time with older technologies rather than suddenly displacing them. During that time it will affect the further development of those competing technologies. Other secondary effects might be shifts in demand for products and services, so that people come to expect different kinds of food, medical care, entertainment, etc. This shift in demand may also initiate a tertiary effect, the need for augmented nanotechnology infrastructure —interdisciplinary research centers, new educational program s to supply nanoscientists and nanotechnologists, etc. Other tertiary effects would move upstream in our social structures and cultural patterns, such as shifts in education and career patterns, family life, government structure, and so forth. An effective and cost-efficient way to protect the public and deal with nanotechnology's potential negative consequences is to develop a tradition of social-science-based countermeasures — and to support research in publicly recognized institutions on the processes that develop nanotechnology and apply it in diverse areas of life[4].

Ethical Issues and Public Involvement in Decision Making: An important aim of a societal impact investigation of nanotechnology is to identify harms, conflicts over justice and fairness, and issues concerning respect for persons. For example, changes in workforce needs and human resources are likely to bring benefits to some and harm to others. Other examples of potential issues include safeguards for workers engaged with hazardous production processes, equity disputes raised by intellectual property protection, and questions about relationships between government, industry, and universities. Scientists and engineers bring to their work a laudable concern for the social value of their labors. However, those working in a particular technical field may be focused on the immediate technical challenges and not see all of the potential social and ethical implications. It is important to include a wide range of interests, values, and perspectives in the overall decision process that charts the future development of nanotechnology.

Involvement of members of the public or their representatives has the added benefit of respecting their interests and enlisting their support. The inclusion of social scientists and humanistic scholars, such as philosophers of ethics, in the social process of setting visions for nanotechnology is an important step. As scientists or dedicated scholars in their own right, they can respect the professional integrity of nanoscientists and nanotechnologists, while contributing a fresh perspective. Given appropriate support, they could inform themselves deeply enough about a particular nanotechnology to have a well-grounded evaluation. At the same time, they are professionally trained representatives of the public interest and capable of functioning as communicators between nanotechnologists and the public or government officials. Their input may help maximize the societal benefits of the technology while reducing the possibility of debilitating public controversies.

In addition, attention needs to be given to the individual responsibility of engineers, scientists, and others involved in the processes of generating powerful new nanotechnologies. Professional societies have a role to play in providing opportunities for discussing and devising guidelines that incorporate relevant ethical principles into emerging issues. Perhaps most importantly, ethics must be incorporated effectively into the curriculum for training new nanoscientists, nanotechnologists, and nanofabrication technicians.

Education of Nanoscientists, Nanotechnologists, and Nanofabrication Technicians: Under present conditions, far too few good students are attracted to the fields relevant to nanotechnology. To some extent, this is a problem faced by all of the sciences, but the problem is especially acute for nanotechnology because a very large number of talented scientists, engineers, and technicians will be needed to build the nanotechnology industries of the future, and these professionals will require an interdisciplinary perspective.

Development of nanotechnology will depend upon multidisciplinary teams of highly trained people with backgrounds in biology, medicine, applied and computational mathematics, physics, chemistry, and in electrical, chemical, and mechanical engineering. Team leaders and innovators will probably need expertise in multiple subsets of these disciplines, and all members of the team will need a general appreciation of the other members' fields. Developing a broadly trained and educated workforce presents a severe challenge to our four-year degree and two-year degree educational institutions, which favor compartmentalized learning. Because current educational trends favor specialization, there must be fundamental changes in our educational systems. However, introducing new degree programs in nanotechnology that provide a shallow overview of many disciplines, none in sufficient depth to make major contributions, may not give students the training that is needed to meet the future challenges. The right balance between specialization and interdisciplinary training needs to be worked out through innovative demonstration programs and research on the education process and workforce needs.

Education in nanoscience and nanotechnology requires special laboratory facilities that can be quite expensive. Given the cost of creating and sustaining such facilities, their incorporation into nanotechnology workforce development presents a considerable challenge. Under the present education system, many engineering schools, let alone the two-year-degree colleges, cannot offer students any exposure to the practice of nanofabrication. Innovative solutions will have to be found, such as new partnerships with industry and the establishment of nanofabrication facilities that are shared by consortia of colleges, universities, and engineering schools. Web-based, remote access to those facilities may provide a powerful new approach not available previously.

Despite the tremendous educational challenges, the exciting intellectual, economic, and social opportunities of nanotechnology might become a major factor in reinvigorating our nation's youth for careers in science and technology[5].

Education of Social Scientists: A related educational challenge is the very small number of social scientists who have the technical background and research orientation that would allow them to conduct competent research on the societal implications of nanotechnology. At the university level, liberal arts education gives far too low a priority to scientific literacy. Social science professional societies, universities, and government agencies will have to make a long-term commitment to attract talented young social scientists to this area of research and to encourage them to gain the necessary professional skills and awareness of nanotechnology. This will require research on the societal implications of nanotechnology at a consistent and high enough level to establish this as a viable field of social science research[6].

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