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Ethical and social implications of nanotechnology

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ABSTRACT

The projected impact of nanotechnology has been touted as a second industrial revolution—not the third, fourth, or fifth, because despite similar predictions for technologies such as computers and robotics, nothing has yet eclipsed the first. In the United States and in many other countries, numerous partnerships among industry, university, and government have been created to facilitate the research, development, and commercialization of nanotechnology advances. Such a collaboration is expected to bring about next generation of nanotechnology based products and new markets with a promise of job creation and economic development. According to the National Science Foundation (NSF), products incorporating nanotechnology will contribute approximately $1 trillion to the global economy by the year 2015. About two million workers will be employed in nanotechnology industries, and three times that many will have supporting jobs. Despite many benefits of nanotechnology there are potential risks and ethical issues involved in its implementation. There's a concern that some nanoparticles could be toxic because elements at the nanoscale behave differently than they do in their bulk form and these particles could easily cross the blood-brain barrier.

Society is at the threshold of a revolution that will transform the ways in which materials and products are created. How will this revolution develop? The opportunities that will develop in the future will depend significantly upon the ways in which a number of challenges are met. As we design systems on a nanoscale, we develop the capability to redesign the structure of all materials—natural and synthetic—along with rethinking the new possibilities of the reconstruction of any and all materials. Such a change in our design power represents tremendous social and ethical questions. In order to enable our future leadership to make decisions for sustainable economic nanotechnological development, it is imperative that we educate all nanotechnology stakeholders about the short-term and long-term benefits, limitations and risks of nanotechnology. The social implications of nanotechnology encompass so many fundamental areas such as ethics, privacy, environment, and security. This paper presents an overview of new and emerging nanotechnologies and their societal and ethical implications to address 21st Century challenges and issues. The discussion includes a range of different types of nanotechnologies and their potential social and ethical implications on society. The paper also highlights the approaches used to teach Science, Technology and Society (STS) courses at DeVry University, Addison, IL, USA.

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I. INTRODUCTION

A number of definitions of nanotechnology exist in the literature. According to the National Nanotechnology Initiative (NNI), nanotechnology is an area that encompasses the following traits/characteristics:

1. Research and technology development at the atomic, molecular, or macromolecular levels, in the length scale of approximately 1 to 100 nm range.
2. Creating and using structures, devices, and systems that have novel properties and functions because of their small and/or intermediate size.
3. Ability to control or manipulate matter on the atomic scale.[1]

According to Professor Stephen Fonash, nanotechnology is a process involving manipulation of matter at the atomic and molecular scale; seeing matter at the atomic and molecular scale, and exploitation of the unique capabilities and properties of structures fabricated at the atomic and molecular scale.[2] In short, nanotechnology refers to the convergence of multiple disciplines and applied technologies dealing with particles and structures having dimensions in the range of a nanometer, or one billionth of a meter.

II. APPLICATIONS OF NANOTECHNOLOGY

At the nanoscale, materials exhibit novel electronic, optical, and magnetic properties, which have led to new applications of nanotechnology. Advances in nanoscience have enabled researchers to manipulate the behavior of a "single cell," reverse disease, and repair and grow human tissues. Nanotechnology is supplying improved services in the areas of energy, lighting, computing, printing, and water filtration. Nanotechnology innovations such as quantum dots, semi-conductor nanoparticles, carbon nanotubes, and nanoshells (see Table 1) have led to the fabrication of electronic hardware devices using the "bottom-up" approach in contrast to the current "top-down" method. Nanotechnology has numerous other applications. In concrete manufacturing, the introduction of nanotubes increases the strength of cement. In plastics and polymers manufacturing, the use of nanoparticles allows precise control over color change and increases the strength of the materials. Nanocomposite materials are being used to manufacture various auto parts, including body panels, instrument panels, bumper fascia, and front end module bolsters, etc. In the medical field,

Table 1. Potential applications of nanotechnology innovations.

Nanotechnology example	Potential applications
Buckyball: A soccer-ball shaped molecule made of sixty carbon atoms 	– Composite reinforcement – Drug delivery
Carbon nanotube: A sheet of graphite rolled into a tube 	– Fuel cells – High resolution displays – Composite reinforcement
Quantum dot: A semiconductor nanocrystal whose electrons show discrete energy levels like an atom	– Energy-efficient light bulbs – Medical imaging
Nanoshell: A nanoparticle composed of silica surrounded by a gold coating	– Medical imaging – Cancer therapy

nanotechnology has been used to study cancer cell structure, and nanoparticles have been used for fluorescent imaging of tumors. Fluorescent nanoparticles have also been employed for the diagnosis and treatment of cancer. Nanoparticles of gold and palladium have been used to remove toxic chemicals from water. Nanoparticles have been used as catalysts, cancer therapies, sunscreens, antibacterial composites, solar cells, and, more recently, advances in microfluidics; biosensors have made it possible to fabricate lab-on-a-chip devices.[3]

The application of nanotechnology in food production offers various ways to produce high quality foods in a much more sustainable way. Experts believe the food supply is much safer today compared to 50-100 years ago. Moreover, the food processing industry continues to devise innovative solutions to key issues: how to achieve efficient fractionation of crops; how to do efficient product structuring; and how to optimize products' nutritional value. The main categories of known and potential applications of nanomaterial for the food and health food can be described as areas where:[4]

1. Food ingredients have been processed or formulated to form nanostructures.
2. Nano-sized or nano-encapsulated additives have been used in food.
3. Engineered nano materials (ENMs) have been added into coatings and packaging materials to develop innovative food contact surfaces and materials, and nano-bio-sensors for "smart"packaging.
4. Nanomaterials have been used in nanofiltration for the removal of undesirable components from food.
5. ENMs have been suggested for pesticides, veterinary medicines, and other agrochemicals for improved production systems.

Examples of nano additives include minerals, antimicrobials, vitamins, and antioxidants. Virtually all such additives and supplements claim improved absorption and bioavailability in the body compared to their larger equivalents. Technological processes involved in nano-sized materials involve fabrication of nano-sized particles or nano-encapsulating them in the form of micelles, liposomes, or biopolymer-based carrier systems.[5] Nanotechnology can also be used to supply high-quality food for an increasing global population. Table 2 presents a summary of nanotechnology research and applications in food science.[3]

Table 2. Nanotechnology research and applications in food science.

Food science area	Nanotechnology research/application
Food safety and quality	– Development of sensors to detect a single molecule – Research to improve the detection capability of bimolecular by exploiting nanomaterials such as carbon nanotubes, silicon wires, and zinc oxide nanorods – Biosensors that detect changes in environmental conditions (temperature, oxygen, chemical contaminants, and microbial contaminants) – Biosensors for detection of microorganisms and toxins
Ingredient technology & systems	Nanoparticle utilization for flavor, antioxidants, antimicrobials, bioactives, etc.
Food processing	Development of new membrane separation systems and catalysts
Food Packaging	Development of low permeability, high-strength plastics and high-performance edible packaging

III. ETHICAL AND SOCIAL IMPLICATIONS OF NANOTECHNOLOGY

As we design systems on a nanoscale, we develop the capability to redesign the structure of all materials– natural and synthetic–along with rethinking the new possibilities of the reconstruction of any and all materials. Such increases in design power present significant social and ethical questions. To support sustainable, ethical, and economic nanotechnological development, it is imperative that we educate all nanotechnology stakeholders about the short-term and long-term benefits, limitations, and risks of nanotechnology. Nanotechnology, like its predecessor technologies, will have an impact on all areas. For example, in healthcare it is very likely that nanotechnology in the area of medicine will include automated diagnosis. This in turn will translate into fewer patients requiring physical evaluation, less time needed to make a diagnosis, less human error, and wider access to health care facilities. And, with nanomedicines, if the average human life span increases, the larger number of elderly persons requiring medical attention will likely result in increased health expenditures.[6] It is essential for nanotechnology stakeholders to strive to achieve four social objectives: (1) developing a strong understanding of local and global forces and issues that affect people and societies, (2) guiding local/global societies to appropriate uses of technology, (3) alerting societies to technological risks and failures, and (4) developing informed and ethical personal decision-making and leadership to solve problems in a technological world.[7] Advances in nanotechnology also present numerous challenges and risks in health and environmental areas. Nanotechnology risk assessment methods and protocols need to be developed and implemented by the regulatory bodies. Eric Drexler, author of *Engines of Creation,* has identified four challenges in dealing with the development, impact, and effects of nanotechnology on society.[8]

(1) The Challenge of Technological Development (control over the structure of matter)
(2) The Challenge of Technological Foresight (sense of the lower bounds of future possibilities)
(3) The Challenge of Credibility and Understanding (clearer understanding of what these technological possibilities are)
(4) The Challenge of Formulating Public Policy (formulating polices based on understanding)

IV. NANOTECHNOLOGY RISKS

Nanotechnology is remaking the world at an alarmingly rapid pace. Presently nanoproducts are being developed in a regulatory vacuum at national and international levels. As new understanding in chemistry, physics, and genetics is being reached and nano products developed and marketed, it has become imperative that future policy makers and lawyers understand the complexities and implications of nanotechnology in order to provide society with adequate insight into the issues of intellectual property, patents, and commercialization.[3] The biggest question is how to deal with uncertainty and risk assessment in this developing discipline. In 2007, Mike Honda, a Congressional Representative from California, summed up nanotechnology uncertainty in a press statement: “Uncertainty is one of the major obstacles to the commercialization of nanotechnology—uncertainty about what the risks might be and uncertainty about how the federal government might regulate nanotechnology in the future.” Risk assessment is defined as a process intended to calculate or estimate the risk to a given target organism, system, or [sub]population, including the identification of attendant uncertainties following exposure to a particular agent, taking into account the inherent characteristics of the agent of concern as well as the characteristics of the specific target system.[9] All new and emerging technologies pose challenges and uncertainties; in the domains of science and technology these can be addressed through additional research, but in the realm of law and regulation, immediate answers are sought. Because uncertainty must be dealt with in regulation, and in the absence of straightforward regulations, various methodologies are used to address uncertainty. One such methodology used for dealing with uncertainty in regulation is risk assessment.[10] To illustrate some of the concerns discussed regarding nanotechnology development, as well as address the challenges of educating the next generation of scientists, engineers, and technologists about the broader issues posed by nanotechnology, a concrete example of an STS course at DeVry University will be examined.

V. TEACHING THE SOCIETY, ETHICS, AND TECHNOLOGY COURSE AT DEVRY UNIVERSITY: OBJECTIVES, INSTRUCTIONAL METHODOLOGIES, AND APPROACHES

DeVry University’s baccalaureate students are given the challenge and opportunity to direct their technological knowledge into responsible awareness and choices for local/global solutions of problems and urgent 21st century issues through a senior-level interdisciplinary capstone humanities course entitled Society, Ethics, and Technology (LAS-432). This course challenges students to realistically assess technological implications within the world stage and to bridge the gap between the developed and developing worlds. The course falls into the interdisciplinary STS classification (a field known as Science, Technology, and Society, whose main focus is to explore the influence of technologies on society and the relationships between society and emerging technologies). This course is valuable not only in the interdisciplinary knowledge it encourages, but as an experience for our students who as future engineers cannot be blind to social issues and the implications of the technologies that they will promote and use. In the LAS-432 course students are first given an introduction to the nanotechnology through lectures, scenarios, case studies, and web exercises; they are then required to work in teams to explore the ramifications of nanotechnology by writing a research paper and presenting their findings in an oral presentation on one of the following topics: nanotechnology and ethical implications, social implications, healthcare and medicine, consumer electronics, biotechnology, ecology, military applications, international perspectives and future implications.

Student learning and performance outcomes are evaluated with the help of an assessment tool that gauges student competencies with respect to the general education program goals. Using nanotechnology as an urgent example for responsible decision making, a number of teaching and learning tools are used including cultural field studies, case studies, modeling, and flow charts. Such approaches promote not only concepts and practical awareness but also lead to constructivist understanding of macro and micro problems of present and future technologies and issues.

VI. CONCLUSION

This paper presented an overview of nanotechnology and its applications and discussed its social and ethical implications. Through the description of an STS course focused on nanotechnology, the paper has suggested approaches to the challenges of educating the next generation of engineers and technologists about the promises and perils of this exciting technology. Nanotechnology has the potential to change society, positively or adversely. Because it will affect everyone, all members of society – all stakeholders – should have a voice in its development and commercialization phases. Presently, nanotechnology is in its infancy, and there is a lack of knowledge about its effects on humans and the environment in its applications in the areas of food, agriculture, and medicine. As humankind marches forward, the key question is: How should we manage the risks and uncertainties of this emerging technology?

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