AC 2012-4784: NANOTECHNOLOGY: TEACHING ETHICAL AND SOCIAL ISSUES IN A STS COURSE

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Nanotechnology: Teaching Ethical and Social Implications in a STS Course

Abstract

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 new systems are designed at Nano scale, the scientific community develops 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 design power of products represents tremendous social and ethical questions. In order to enable the future leadership to make decisions for sustainable ethical, economic nanotechnological development, it is imperative that all nanotechnology stakeholders are educated 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 describes the teaching approaches used to teach the ethical and social implications of nanotechnology in a "Science, Technology and Society (STS)" capstone course at DeVry University, Addison, Illinois. There are essentially four objectives to this course: (1) developing a strong understanding of local and global forces and issues which affect people and societies, (2) guiding local/global societies to appropriate use of technology, (3) alerting societies to technological risks and failures, and (4) developing informed and encompassing personal decision-making and leadership and providing ways to solve problems in a technological world. It is anticipated that that by teaching about the ethical and social implications of nanotechnology, educators can further promote in students everywhere, the future reality and urgency of technological social leadership to appropriately and responsibly help to develop our global community. The paper also presents the results of a survey, conducted at the Addison and Chicago campuses, to gauge the students' perceptions about nanotechnology and its impact on society.

I. Introduction

The accomplishments of the 20th century are revolutionizing science and technology in the 21st century. Researchers have gained ability to measure, manipulate and organize matter on nanoscale --- 1 to 100 billionths of a meter. At the nanoscale, physics, chemistry, material science, biology and engineering converge towards common principles, mechanisms and tools. This convergence of multiple-disciplines will lead to a significant impact on science, technology and society.[1]

In 1960, prominent physicist, Richard Feynman, presented a visionary and prophetic lecture at the meeting of the American Physical Society entitled "There is plenty of room at the bottom," in which he speculated the possibility and potential of nanosized materials. In 1974, the term nanotechnology was used for the first time by Nori Taniguchi in Tokyo, Japan at the International Conference on Production Engineering. [2] However, it was not until 1980s with the development of appropriate methods of fabrication of nanostructures that a notable increase in research activity occurred and a number of significant developments materialized. [3] Table 1 presents a summary of the modern era discoveries and developments that led to the evolution of nanotechnology.[4]

Table 1: Timeline of evolution of nanotechnology

Year	Milestone
1857	Michael Faraday discovers colloidal "ruby" gold, demonstrating that nanostructured gold under certain illumination conditions produces different-colored solutions.
1936	Erwin Muller, at Siemens research Laboratory, invents the field emission microscope, making it possible to achieve near-atomic-resolution of imaged materials.
1947	John Bardeen, William Shockley, and Walter Brattain, at Bell labs, create the first semiconductor transistor, ending the era of vacuum tubes and laying the foundation for solid state electronics devices and the information era.
1950	Victor La Mer and Robert Dinegar develop the theory and a process for growing monodisperse colloidal materials. This controlled ability to fabricate colloids led to numerous industrial applications such as papers, paints, thin films, and dialysis treatment.
1951	Erwin Muller develops the filed ion microscope, a way to image the arrangement of atom at the surface of a sharp metal tip.
1956	Arther von Hippel at MIT pioneered many concepts, and coins the term "molecular engineering" as applied to dielectrics, ferroelectrics, and piezoelectric.
1958	Jack Kilby, at Texas Instruments, originates the concept of, designs and develops first integrated circuit (IC).
1965	Gordon Moore, Intel co-founder, forecasts trends in electronics; one trend known as "Moore's law" describes the density of transistors on an IC doubling every 12 months (later amended to every 2 years). Moore's law is still valid fifty years later, as nanotechnology replaces microtechnology in IC manufacturing.
1959	American Physical Society meeting on nanotechnology concepts is held. Richard Feymann describes foundational concepts in nanotechnology.
1974	Norio Taniguchi gives a name to the new field in a scientific paper "On the basic Concept of "Nano-Technology."
1981	Gerd Binning and Heinrich Rohrer invent the scanning tunneling microscope at IBM's Zurich lab.
1981	Alexei Ekimov, in Russia, discovers nanocrystalline, semiconducting quantum dots in a glass matrix and conducts pioneering studies of their

	electronic and optical characteristics.
1985	Harold Kato, Sean O'Brien, Robert Curl, and Richard Smalley, at Rice University discovers the Buckminsterfullerene (C60), commonly known as buckyball, which can be used to make carbon nanotubes (CNT).
1986	Invention of the atomic force microscope (AFM) makes it possible to view, manipulate and measure matter at the nano-scale.
1989	IBM scientists spell IBM logo with 35 Xenon atoms, demonstrating how nanoparticles can be manipulated.
1991	Carbon nanotube (CNT) is created by Sumio Iijima of NEC.
1992	C.T. Kresge and colleagues at Mobil Oil discover the nanostructured catalytic materials MCM-41 amdMCM-48, presently used for refining crude oil, drug delivery, water treatment, etc.
1993	Moungi Bewendi, at MIT, invents a technique for controlled synthesis of nanocrystals (quantum dots).
1998	White house forms the Interagency Working Group of Nanotechnology (IWGN) to investigate the state of the art in nanoscale and technology and to forecast possible future developments. The IWGN's study and report "Nanotechnology Research Directions: Vision for the Next Decade (1999) defines the vision for and leads to formation of the U.S. national Nanotechnology Initiative (NNI) in 2000.
1999	Use of nanotechnology appears in the global marketplace.
2000	National Nanotechnology Initiative (NNI) launched to coordinate federal research and development efforts and promote U.S. competiveness in nanotechnology
2002	European Union launches gatherings called Nanoforum to educate the public about nanotechnology.
2003	Congress enacts the 21st Century Nanotechnology Research and Development Act (P.L. 108-153).
2003	Naomi Halas, Jennifer West, Rebekah Drezek, and Renata Pasqualin at Rice University creates gold nanoshells, which when "tuned' in size to absorb near infrared light, serve as a launching platform for integrated discovery, non-invasive diagnosis, and treatment of breast cancer.
2004	The European Commission adopts the communication "Toward a European Strategy for Nanotechnology," which proposes institutionalizing European nanoscience and nanotechnology R & D efforts with an integrated and responsible strategy.
2007	Angela Belcher and colleagues at MIT develop a lithium-ion battery with a common type of virus.
2008	The first NNI strategy for Nanotechnology-Related Environmental, health and Safety (EHS) Research is published.
2009-2010	Nadrian Seeman and colleagues at New York University creates several DNA-like robotic nanoscale assembly devices.
2010	Toxic Substances Control Act requests regulation of commercial nanomaterial use. United Kingdom issues a lengthy report on nanotechnology and food, warning the country's food industry not to hide the use of nanotechnology

2011	The Senate Environment and Public Works Committee continues gathering evidence on revisions to the 30-year-old Toxic Substances Control Act to regulate the commercial use of nanomaterials. The NEST Subcommittee updates both the NNI Strategic Plan and NNI EHS Research strategy based on inputs from stakeholders: government, academia, NGOs, public etc.

II. Social Implications of Nanotechnology

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 . 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 ethical, 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. [5,6]

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 life span of humans increases, it will create a large portion of elderly persons requiring medical attention, resulting in increased health expenditures. [7]

It is essential for the Nanotechnology stakeholders to strive to achieve four social objectives (1) developing a strong understanding of local and global forces and issues which 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 implement 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 the future possibilities)
(3) The Challenge of Credibility and Understanding (clearer understanding of what these technological possibilities)
(4) The Challenge of Formulating Public Policy (formulating polices based on understanding)

As the global economy continues to be transformed by new technology, an intense competition will grow for intellectual capital and intellectual property. Technology will continue to drive the global and domestic GDP. Advances in nanoscience will enable researchers to manipulate the behavior of a "single cell," reverse disease, repair and grow human tissues. Nanotechnology could supply improved services for a small fraction of current energy in lightening, computing, printing, water filtration. Nanotechnology innovations such as quantum dots, semi-conductor nanoparticles, carbon nanotubes, and nanoshells will enable the fabrication of electronics hardware devices using the "bottom-up," approach in contrast to present "top-down," approach. [7]

III. Society, Ethics and Technology Course: Objectives and Methodologies

Students at DeVry University are given the challenge and opportunity to guide and direct their technological knowledge into responsible awareness and choices for local/global solutions of problems and 21st Century urgent issues. All DeVry students must pass a senior-level inter-disciplinary capstone Humanities course entitled "Society, Ethics and Technology (HUMN-432)." This course challenges students to realistically assess technological implications within the world stage and to bridge the gap between the developed world and the developing worlds. The course falls into the inter-disciplinary STS classification (a field known as Science, Technology and Society whose main focus is to explore the influences of technologies on society and the relationships between societies and technologies). The course emphasizes an integration of all their previous studies at DeVry in addition to professional group work, research, research presentations and technical reports, communication, critical thinking and analysis, solutions and applications of the moral and ethical dilemmas the use of technology sometimes presents. The course also identifies conditions that have promoted technological development and assesses the social, political, historic, environmental, ethical, cultural and economic effects of current technology and what technology might hold for the future on the local, national and international fronts. The challenges of this course include the interdisciplinary dimensions as well as the multi-cultural perspectives that are needed along with the dynamic of constantly changing current and relevant issues associated in the news which revolve around the ethical and responsible use of technology.

This course is very relevant in not only the interdisciplinary knowledge it encourages, but especially for our students who as future engineers cannot be blind to social issues and the implications of the technologies that they promote and use. Our future engineers must guide society to the appropriate uses of technology, alert society to technological failures, and provide a vision to society in helping to solve societal problems that are related to technology. Using Nanotechnology as an urgent example for responsible decision making, a number of teaching and learning tools are used including: online threaded discussion, case studies, modeling, and logical flow charts. Such approaches promote not only concept and practical awareness but also lead to constructivist understanding of macro and micro problems of present and future technologies and issues. [4, 6 & 7]

In HUMN-432 course students are first given an introduction to the nanotechnology through lectures with the help of scenarios, case studies and web exercises, and then they are required to work in teams to explore the ramifications of by writing a research paper and presenting their findings in form of an oral presentation on one of the following topics:

- Nanotechnology Ethical Implications
- Nanotechnology Social Implications
- Nanotechnology and Healthcare and Medicine
- Nanotechnology and Consumer Electronics
- Nanotechnology and Biotechnology
- Nanotechnology and Ecology
- Nanotechnology and Military Applications
- Nanotechnology: International Perspective
- Future implications of Nanotechnology

Students learning and performance outcomes are evaluated with the help of an assessment tool that gauges student competencies with respect to the following General Education program goals:

1. Communicate clearly with particular audiences for particular purposes.
2. Work collaboratively to help achieve individual and group goals.
3. Apply critical thinking skills in learning, conducting applied research, and defining and solving problems.
4. Develop tolerance of ambiguity and mature judgment in exploring intellectual issues.
5. Build on intellectual curiosity with fundamental concepts and methods of inquiry from the sciences, social sciences, and humanities to support life-long learning.
6. Apply mathematical principles and concepts to problem solving and logical reasoning.
7. Use study and direct experience of the humanities and social sciences to develop a clear perspective on the breadth and diversity, as well as the commonality, of human experience.
8. Connect general education to the ethical dimensions of issues and to responsible, thoughtful citizenship in a democratic society.

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 concept and practical awareness but also lead to constructivist understanding of macro and micro problems of present and future technologies and issues. In typical exercises students are encouraged to find questions to the following questions:

- How should we manage exposure to nanowaste by humans and environment?
- How can we develop effective risk management strategies dealing with the uncertainties of nanotechnologies?
- How should people be educated about the potential benefits and risks of nanotechnology?
- What will be the impact of nanotechnology on the privacy of the individual?
- How can prevent the proliferation of nanotechnology based weapons be prevented?
- Is humankind playing the role of God when it comes to applying nanotechnology in the areas of biotechnology and genetics?
- Will nanotechnology be the catalyst for future military interventions and hegemony by the ruling world powers?
- What will be the impact of human-machine union? How it will affect the ideology of existentialism relative to the “being” in general?
- What will be the impact of nanotechnology on the developing countries?
- What will be the governing moral principles for advancement of life by artificial means through nanotechnology?
- What would the social impact of implementing nanotechnology-based systems at workplace, homes, industries, government, etc.?
- Will Nanotechnology intensify the divide between the haves and the have nots?

Using case studies and scenarios, the students are exposed to the following areas of science- or technology-based ethical issues and conflicts categorized by Robert McMinn [9]:

- Violations of Established World Orders
- Violation of Supposedly Exceptionless Moral principles
- Distribution of Science- or Technology Related Benefits
- Infliction of Harm or Exposure to Significant Risk of Harm Without Prior Consent
- Science- or Technology-Precipitated Value Conflicts
- Science or Technology-Endangered “Positive“ Rights
- Pubic Harms of Aggregation
- Practitioner Problems (Problems of Execution: Distributive Justice, Whistle-blowing, consideration of long term-effects. Problems of Communication: Fraud, and Misrepresentation]
- Challenges of Contemporary Science and Technology to traditional ethical theories.

To gauge the students’ understanding of nanotechnology and their perceptions about its impact on society, a survey is also conducted at the end of the course using a questionnaire (see Appendix A). The results of the survey are exhibited in Appendix B.

IV. Conclusion

Nanotechnology has the potential to change society, positively or adversely. It will affect everyone. Therefore all members of society – all stakeholders -- should have a voice in its development and commercialization phases. Presently, unfortunately, nanotechnology is in its infancy and there is a lack of knowledge-base about its effect on humans and environment viz a viz its application in the areas of food, agriculture, and medicine. As humankind marches forward, the key question is: How should we manage the risks and uncertainties?[4] The paper presented an overview of the evolution of nanotechnology. It also discussed the social and ethical implications of nanotechnology. Furthermore it presented the description of the STS course and teaching approaches used at DeVry University, Addison, Illinois, and students' perceptions of their understanding of the impact of nanotechnology on society.

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Appendix A

Nanotechnology Survey

1. Do you have a clear understanding of what nanotechnology refers to?
   Yes __________ No _______________

2. How will nanotechnologies impact society? Select the level of impact of the following nanotechnology on society.

	Level of Impact on Society	
Nanotechnology	High	Low
Nano carbon tubes		
Nanomaterials		
Nanoelectronics		
Nanophotonics		
Nanomanipulations		
Nano medicine		
Nano robots		

3. Do you think that the advantages offered by the nanotechnology will outweigh their drawback/s?
   Yes ___________ No ______________

4. Do you think that nanotechnology will enable humans t*o live longer and healthier?*
   *Yes*___________ *No* _______________

5. What will be the impact of nanotechnology on the stress level of humans?
a. Cause more stress
b. Cause less stress
c. No effect

6. What will be the impact of nanotechnology on privacy?
a. Privacy would increase
b. Privacy would decrease

7. How do you think higher education will change with nanotechnology developing in our society? What kind of courses will be even more urgent?

8. If you were to predict a nanotechnology future for human in 15 years, how would you describe it?

Appendix B

Survey Results (Addison Campus)

To gauge the students' understanding of nanotechnology and their perceptions about its impact on society, a survey is also conducted at the end of the course using a questionnaire (see Appendix A). The results of the most recent (Summer & Fall 2011) student survey (N= 46) are as follows:

Question 1. Do you have a clear understanding of what nanotechnology refers to?

Ninety-seven percent of respondents agreed that they have a clear understanding of nanotechnology.

Question 2. How will nanotechnology impact society? Select the level of following nanotechnology on society?

There was a high level of agreement (98%) among respondents that nanotubes, nanomaterials, nanoelectronics, nanomanipulations, nanomedicine and nanorobots will have a high level of impact on society.

Question 3.Do you think that the advantages offered by the nanotechnologies will outweigh their drawbacks?

Eighty-six percent of respondents agreed that the advantages offered by nanotechnology will outweigh their drawbacks.

Question 4. Do you think that nanotechnology will enable humans to live longer and healthier?

Seventy-one percent of respondents agreed.

Question 5. How will nanotechnology increase or decrease the stress level of humans?

Forty-two percent of respondents believed that nanotechnology will increase stress level of humans; 36% believed that nanotechnology will cause less stress and 22% believed it will have no effect on stress levels of humans.

Question 6.What will be the impact of nanotechnology on privacy?

Seventy-four percent of the respondents think that nanotechnology will increase privacy, and 26% believed it would reduce privacy.

Question 7. How do you think higher education will change with nanotechnology developing in our society? What kind of courses will be even more urgent?

Most of the students said that there will be an increase in nanotechnology courses and that there will be more international competition and demand for such courses at a high knowledge level.

Some of the selected responses are:

- *Higher education needs to offer more courses in ethics.*

- *Higher education will change in the technical fields. Students will need to know how to work with nanotechnology right away so like we learn new software they will need to know nanotechnology skills.*
- *Higher education will change with nanotechnology developing in our society. Courses related to electronics and medicine.*
- *We need to understand how the technology can benefit as well as harm environment and humans.*
- *All technical and non-technical course must address nanotechnology issues and challenges.*
- *I think that higher education will enable future generations to expand its impact exponentially. Nanotechnology course will be in great demand.*
- *I think higher education will have to be modified to be more complement as humans retain more info and get smarter.*
- *There will inevitably be need to educated ourselves on what it is . people who want to go into the filed.*
- *More course related to nanotechnology.*
- *There will be more requirements for nanotechnology course.*

Question 8. If you were to predict a nanotechnology future for humans in 15 years, how would you describe it?

Some of the selected responses are:

- *Nanotechnology is just emerging, but is happening rapidly so I would say humans will be very involved with nano technology 15 years from now.*
- *I think it will take over just as technology has these last few years. The need for faster efficient and cheaper products is already being sensed.*
- *Medicine and health fields will see the largest applications of nanotechnology.*
- *Yes, I think higher education will change in the nanotechnology.*
- *I think nanotechnology will enable people to live longer.*
- *Nanotechnology will practically be in everything around our lives.*
- *Nanotechnology will offer humans a way of living longer if nanotechnology is correctly developed to deliver medicine to the infected cells. In addition with the use of nanotechnology we can make more durable materials at much lower cost.*
- *Corporations are investing more money in research. We hope to see a lot more discoveries and more answers to many puzzling questions. I personally would like to see rejuvenation of organs and limbs come to reality.*
- *I would describe it as ominous.*
- *I think technology will be pretty much ruling the world, we already rely so much on it, and the advancements will only make us more reliant.*

Survey Results (Chicago Campus)

The results of the most recent (Spring 2012) student survey (N= 42) are as follows:

Question 1. Do you have a clear understanding of what nanotechnology refers to?

Forty percent of respondents agreed that they have a clear understanding of nanotechnology.

Question 2. How will nanotechnology impact society? Select the level of following nanotechnology on society?

There was a high level of agreement (65%) among respondents that nanotubes, nanomaterials, nanoelectronics, nanomanipulations, nanomedicine and nanorobots will have a high level of impact on society.

Question 3.Do you think that the advantages offered by the nanotechnologies will outweigh their drawbacks?

Fifty-eight percent of respondents agreed that the advantages offered by nanotechnology will outweigh their drawbacks.

Question 4. Do you think that nanotechnology will enable humans to live longer and healthier?

Seventy-six percent of respondents agreed.

Question 5. How will nanotechnology increase or decrease the stress level of humans?

Thirty-one percent of respondents believed that nanotechnology will increase stress level of humans; 52% believed that nanotechnology will cause less stress and 17% believed it will have no effect on stress levels of humans.

Question 6.What will be the impact of nanotechnology on privacy?

Twenty-two percent of the respondents think that nanotechnology will increase privacy, and 78% believed it would reduce privacy.

Question 7. How do you think higher education will change with nanotechnology developing in our society? What kind of courses will be even more urgent?

Some of the selected responses are:

- *The more nanotechnology that is developed, the more people will be needed to utilize it and develop it further. People will need to know how to use it.*
- *Medical applications will have the most educational impact on higher education.*
- *I think that with nanotechnology, our society will change our education by the way it will be taught.*
- *Courses on ethical implications will be needed.*
- *I think that higher education will get better with the change of nanotechnology in our society because we will have a better understanding of how thing are affected.*
  .
- *High education will make nanotechnology more advanced.*

Question 8. If you were to predict a nanotechnology future for humans in 15 years, how would you describe it?

Some of the selected responses are:

- *People would be more reliant on it.*
- *It's already here. More research is needed.*
- *I would describe it as the future.*
- *Humans live longer and live healthier lives. People are stronger and more resilient to disease. Products are more durable and pollution is taken care of by nano machines.*
- *I can describe it as high tech industrialization, and the evolution of super humans. Life will be one big sphere run by computers and technology.*
- *Nano robots would be injected in our bodies to fight off viruses and other hard to kill diseases. With carbon nano tubes, we can use them to create a line to space for a space elevator to transport materials in an easy and inexpensive manner.*
- *It will improve how things are made and its level of existence.*
- *No idea. Maybe things will keep getting smaller and more compact/efficient.*
- *Not sure. Possible cures for various illnesses.*
- *It sounds like science fiction but it's possible. People would be able to communicate with each other with nanotechnology implanted in their bodies. Nano robots will be used in the medical field to diagnose and operate or aid the human body.*
- *I couldn't predict how it will be!*
- *I can picture a fast paced world that we don't really know what we're getting ourselves into.*
- *It will leave people to depend more on technology and increase the possibility of invisibility.*