AC 2010-1336: FIRST-YEAR STUDENTS PERCEPTIONS OF THE SOCIETAL AND ETHICAL IMPLICATIONS OF NANOTECHNOLOGY

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First-year Students' Perceptions of the Societal and Ethical Implications of Nanotechnology

Abstract

Nanotechnology has established itself as an important new scientific discipline with an extraordinary number of potential applications. Consequently, researchers and policy makers have identified a need for well-trained scientists, engineers, and technicians in nanotechnology and its ethical, legal and societal implications. This project builds on this consensus that workforce training and education must include, in addition to technical training, *education on the ethical, legal, and societal implications of nanotechnology* in the core courses so that future professionals and scientists will be able to shape the direction of nanotechnology policy. As an initial step, this pilot project sought to characterize the current level of awareness of the societal and ethical implications of nanotechnology among first-year engineering students. This project also proposes an educational approach for including the education of the societal and ethical implications of nanotechnology in engineering courses. Engineering students that encounter nanotechnology education across science, technology, social sciences and humanities may be better equipped to participate in debates about how societies ought to be transformed.

Introduction

Nanotechnology has established itself as an important new scientific discipline with an extraordinary number of potential applications. Consequently, researchers and policy makers have identified a need for well-trained scientists, engineers, and technicians in nanotechnology. However, there is an equally urgent need for expert training and research in the ethical, legal, and societal implications of nanotechnology (Roco and Bainbridge 2001)[1]. The National Science and Technology Council (2000)[2] proposed two components for promoting a new generation of skilled workers for the rapid progress in nanotechnology: a) awareness of ethical, legal, societal implications and b) workforce education and training efforts. Similarly, Roco (2003)[3] argued that nanotechnology success is determined by an interaction of different factors such as training of students in nanoscale science and engineering, legal aspects, and state and federal policies among others (Roco, 2003, p.181)[3]. This project builds on this consensus that workforce training and education must include, in addition to technical training, *education on the ethical, legal, and societal implications of nanotechnology* in the core courses so that future professionals and scientists will be able to shape the direction of nanotechnology policy.

What are the Societal and Ethical Implications of Nanotechnology?

According to Roco (2004)[4], societal implications were addressed from the start of the National Nanotechnology Initiative (NNI). It began with the first research and education program on environmental and societal implications, issued by NSF in July 2000. In 2004 The United States Congress refined the details of a nanotechnology Research and Development Act and called for a focus on the societal and ethical implications of nanotechnology (Gorman, Groves, and Catalano

2004)[5]. This allocation of funds demonstrated the importance of the inclusion of social scientist and humanistic scholars in the social process of setting visions for nanotechnology. However, according to Gorman and his colleagues (2004)[5] what is unusual about this emphasis on societal dimensions is that it must occur while the new discoveries and inventions are being made.

Classifications and definitions of ethical and societal implications of nanotechnology have been attempted. For example, Mnyusiwalla, Daar and Singer (2003)[6] alleged that ethical and societal issues of nanotechnology fall into the areas of equity, privacy, security, environment, and metaphysical questions concerning human machine interactions. In contrast, Roco and Bainbridge (2001)[1], reported ten areas of research, education and infrastructure development that would be most valuable for society. From those ten, four were related to societal and ethical implications of nanotechnology:

Ethics, governance, risk, and uncertainty. Roco and Bainbridge (2001)[1] addressed the need of a two-way conversation between the public technical experts and the media. They pointed out the need for balanced and inclusive public participation in decision making between nano-engineers or scientists and their publics.

Public policy, legal and international aspects. Relevant themes related to societal and ethical implications of nanotechnology addressed by Roco and Bainbridge (2001)[1] are related to safety and legal aspects. They argued that legal or policy issues need to be addressed on a global scale. They also addressed the issue of public trust; the public should be confident that the government is taking appropriate steps to safeguard the environment and human health.

Interaction with the public. Roco and Bainbridge (2001)[1] discussed the role of the NNI as a broker in coordinating research and development in nanotechnology together with public hopes and fears. They also commented that the NNI should embrace the goal of building capacity for public dialogue. Roco and Bainbridge also addressed the need for honesty when genuine risks are identified.

Education and human development. Nanotechnology and its social, cultural scientific and technological consequences create an opportunity to integrate education across science, technology, social sciences and humanities (Roco and Bainbridge 2005)[7]. The end-result may be informed, educated publics emerging from our high schools and colleges, able to shape the direction of nanotechnology in beneficial ways (Roco and Bainbridge)[7].

Societal implications of nanotechnology apply in a variety of areas, including technological, economic, environmental, health, and educational, ethical, moral, and philosophical. Similarly, Sheremeta and Darr (2004)[8] proposed taxonomy of major issues likely to face nanotechnology research, development and commercialization in Canada. These are: public perception and public engagement, regulatory issues, economic and commercialization issues, equity and global governance issues, philosophical and ethical issues and application-specific issues.

From these descriptions we can identify that nanotechnology and its societal and ethical implications are complex systems (Roco and Bainbridge, (2005)[7] , and therefore rational management must involve stakeholders, experts, and the general public to develop well-informed and agile policy. The ultimate goal is to accomplish a robust balance between benefits and limiting factors of nanotechnology.

As a way to start addressing some of these issues, this pilot project sought to characterize the current level of awareness of the societal and ethical implications of nanotechnology among first-year engineering students. This characterization included aspects related to students' understanding of the societal and ethical implications of nanotechnology, their perceptions of positive and negative impacts of nanotechnology, and their level of consistency between nanotechnology and their values, past experiences, and needs. Once student beliefs and attitudes about nanotechnology are characterized, one can use this information to design appropriate educational interventions to address knowledge and skill gaps.

Methods

As a way to have a sense of first-year engineering students' current understanding of the societal and ethical implications of nanotechnology, 80 first-year engineering students from an introductory course in engineering problem-solving and computer tools were invited to participate in a voluntary and anonymous open-ended questionnaire. These students were not exposed to any instruction related to the societal and ethical implications of nanotechnology as part of this course. The questionnaire was applied once the semester was over and from the 80 invited students, 66 started responding the questionnaire and from those, 2/3 responded explicitly all the questions including statements such as "I don't know".

This questionnaire elicited a) how students define the societal and ethical implications of nanotechnology, b) how students perceive the positive and negative impacts of nanotechnology and how those may affect them personally, and c) how nanotechnology is consistent or inconsistent with their past experiences and needs. Data were analyzed using Grounded Theory approaches (Strauss and Corbin, 1994)[9] by identifying themes emerging inductively from students' responses. Once identified the themes, frequencies of responses were counted. Below, results are reported providing both the response frequencies as percentages of the total number of respondents for that question, with one or two supporting and illustrative quotes for each identified theme.

Results

Students' definitions of the societal and ethical implications of nanotechnology

Of the 66 participants 41 of them responded to this particular question. In general, students defined the societal and ethical implications of nanotechnology as situations when technology is misused (24%) and to measures against that misuse (2%), including situations affecting privacy rights (2%), situations in which a level of risk is involved (22%).

> "Nanotechnology could bring many advantages, but it also has potential to be abused or misused. The how and who of use of nanotechnology have potential for ethical or social implications."

> "Because little is known about its dangers (or lack thereof), there may be ethical concerns for the distribution of such technologies without further testing. On the other side, if one does further testing, there could be further ethical implications (i.e. the dangers of the testing)."

Some students have referred to the societal and ethical implications of nanotechnology as moral or even religious issues (12%).

> "Nanotechnology has the same basic implications as any emerging technology except that nanotechnology involves the fundamental altering of matter witch some could take for 'playing God'."

> "Some people may feel that it isn't right to be able to change things using nanotechnology."

Others have emphasized the socio-economic benefits and disadvantages. For example, two students mentioned issues related to improving cost effectiveness of goods (5%) while another emphasized the existence of a "nano-divide" arguing that some countries will not have the access to the technology (2%).

> "It has the potential to greatly improve society through commercial, industrial, and medical applications. I specifically see nanotechnology as a field in which America could specialize. The incredibly high amount of infrastructure and expertise required to develop and utilize nanotechnology gives us an advantage over most countries. It could be what we need to spark job creation here at home."

> "Some countries will not have access to this technology"

Some students were not able to identify the fact that nanotechnology is related to ethical and societal issues (10%) and some others, even though they were aware of societal and ethical issues related to nanotechnology, could not explain how they are related (12%).

> "I'm not really sure how nanotechnology by itself can have a negative ethical or societal impact; only the misuse thereof can have any effect."

> "I don't really know, I guess I'll have to look more into it now that I know someone thinks there are ethical implications."

Students' perceptions of the positive and negative impacts of nanotechnology.

Of the 66 students 39 of them responded to the question aimed to identify the positive impacts/consequences of nanotechnology. Many of the students identified medical and health

benefits as the biggest positive impact (36%). Along similar lines, some students also reported that in general nanotechnology could bring better quality of life (26%).

> "Better drug delivery systems."

> "Ability to extend and improve quality of life."

Some students identified as positive impacts the creation of efficient and smaller technology (23%), specifically better computer technology (15%), and more scientific discoveries (13%).

> "It may lead to further scientific discoveries, and many technologies may be useful in everyday life. It has obvious benefits in electronics and materials, and there may be future uses in treating diseases."

About 23% of the students identified specific benefits such as less waste (5%), cleaner environment and better energy usage (5%), and creation of new and better materials (10%).

> "Nanotechnology offers very efficient materials and energy usage."

Considering now the negative impacts/aspects of nanotechnology, 44 students out of the 66 responded to this question. Students reported that a potential negative impact could be the intentional or unintentional cause of harm to humans, such as the self-replication of machines and the grey-goo scenario (in which out-of-control nano-machines can potentially cause the end of the world) (27%). In the same lines, some students reported that nanotechnology could result in more advanced weapons that could create human harm (16%) and approximately 10% of the students identified environmental or economic negative impacts.

> "The negative impacts that are often thought about are that if nanoscale machines are allowed to replicate themselves then they may continue replicating destroying everything in their path to create more nanites."

> "The possibility of new biochemical weapons, the intrinsic altering of God's creation."

In contrast, some students reported that they did not know of any negative potential consequences of nanotechnology (23%).

Students' perceptions of personal positive and negative impacts of nanotechnology.

Students were asked to identify how nanotechnology may impact them in a positive and in a negative way. Of the 66 participants, 43 responded to the question related to the positive impacts and 43 responded to the question related to negative impacts. When we asked for specific ways in which students believed nanotechnology could impact them positively, most of them mentioned improvements in medical treatment and healthcare (54%). Some others mentioned that the positive impacts could be in having access to better effective and cheaper products in particular better electronic and computing tools (40%). Also, some students reported that they

may have benefits related to good employment opportunities for them or better ways to conduct their future jobs (14%).

> "It might impact me in everything from daily routines to prescriptions. It might also increase my life expectancy due to the precise nature of drug delivery."

> "Electric devices keep getting smaller and more convenient to use, and depending on what happens in the future, it could save my life some day."

When asked about potential negative impacts of nanotechnology in their personal lives, many of the students reported they were not sure how nanotechnology may impact them negatively (37%). On the other hand, some students identified examples such as the creation of weapons that could harm them (9%), the possibility of resulting in harmful health effects (9%), and the fact that the technology could get out of control and cause some harm (9%).

> "Unless the nanotechnology doesn't work, I don't know how it would impact me negatively."

Students' perceptions of how nanotechnology is consistent or inconsistent with their values, past experiences, and needs.

When students were asked to describe how nanotechnology is consistent or inconsistent with their values 44 of them responded to this question. The most common response was that they are not able to identify how it may be consistent or inconsistent with their values, or they believe that it is not related to their values at all (39%). Some other students responded that it is consistent with their values as they would like to improve human lives for example by solving human problems (43%).

> "I am unfamiliar with the moral and ethical problems with nanotechnology and cannot judge it based on my values for this reason."

> "Nanotechnology is consistent with my values because it can provide many positive things for our economy and our lives. It can be used for harmful things, but the positive values of the application of this technology outweigh the bad."

Students were also prompted to describe how nanotechnology is consistent or inconsistent with their past experiences and 43 students responded to this question. While most of the responses described not having enough evidence or knowledge to respond to this question (67%), some students related their experiences to their use of technology and products (12%) and their goal to expand human knowledge (5%).

> "I don't know much about nanotechnology to feel comfortable answering this question."

> "It is consistent with how people have continued to discover and explore every avenue of knowledge available, and find ways to study and research those values that are not available."

Finally, we also asked students to describe how nanotechnology is consistent or inconsistent with their needs; 43 students completed this item. While approximately 25% of students responded that they don't know or they don't have a specific need that nanotechnology may fulfill, others reported that it will fulfill the need of better technology (23%) and better quality of life (18%).

> "It's like any other technological advancement. It can be useful to me as a consumer because it can lead to more useful products, and it can be useful to me as an engineer because it can lead to important and practical applications that can better serve the needs of the public."

Discussion

From the descriptions provided above we could identify that whereas some students showed a low level of awareness of the societal and ethical implications of nanotechnology, some others, who knew about them, showed fragmented ideas. Furthermore, one third of the students who started responding the questionnaire did not finish it. Potential reasons for not completing the entire questionnaire could have been that students did not know the answers, they lacked of interest in the topic, or any other reason.

While most of the students were concerned with aspects related to risk and in particular to technological, economic, environmental, and health aspects, few of them actually identified educational, ethical, moral, and philosophical aspects. Moreover, some of these students identified as potential risks visions of science fiction writers, such as self-replicating robots. To the extent that students articulated ethical arguments, they tended to express a single perspective grounded in one approach to ethical thought, most commonly utilitarianism. These assumptions were implicit, suggesting many students may not even be aware they are taking a particular ethical approach, or that there are alternatives.

Identifying the current level of awareness of societal and ethical implications of nanotechnology is important for two main reasons. First, the perceived attributes of an innovation are one important explanation of the rate of adoption of an innovation (Rogers 2003)[10]. Therefore, it is important to identify public concerns, perceptions of risks, fears, conceptions and misconceptions surrounding nanotechnology and its potential applications. Second, there is a need to develop effective training methods to prepare scientists and engineers not only in the technical and scientific aspects related to nanotechnology, but also in issues related to the societal and ethical implications of nanotechnology (Roco and Bainbridge 2005)[7]. Students may have low awareness of certain ethical issues in other areas of engineering; our specific focus on nanotechnology hopefully provides an example of how one might undertake similar research on improving ethics education in other specialized areas.

Implications for Instructional Interventions

It is clear that there is a need for well-trained scientists, engineers, and technicians in nanotechnology in order to take advantage of its benefits (Roco and Bainbridge 2005)[7]. The National Science and Technology Council (2000)[2], proposed two components for promoting a new generation of skilled workers for the rapid progress in nanotechnology: a) ethical, legal, societal implications and b) workforce education and training efforts. Similarly, Roco (2003)[3] argued that nanotechnology success is determined by an interaction of different factors such as training of students in nanoscale science and engineering, legal aspects, and state and federal policies among others (Roco, 2003, p.181)[3]. Based on these needs, we propose a synergistic approach for workforce training and education consisting of the addition of the ethical, legal, and societal implications of nanotechnology to the technical training. Furthermore, we also propose that this training should take place earlier in the engineering curriculum. That is, we propose that not only postdoctoral and other advanced students in areas of technology that will be in demand will be trained in the societal dimensions of nanotechnology (Roco and Bainbridge 2005)[7]; but also undergraduate engineering students, perhaps starting from first-year engineering students, be trained in the societal and ethical implications of nanotechnology.

Complexity thinking is then suggested as an appropriate approach to teach the technical aspects of nanotechnology together with the ethical and societal aspects. For this, we have adopted Davis and Sumara's (2008)[11] description complexity thinking in educational research and have adapted it as an educational approach. Therefore, informed by Davis and Sumara's description of complexity thinking, we have considered it as a way of thinking and acting acknowledging individual complicity with grander systems and considering multiple levels of specific phenomena. That is, we propose the focus of nanotechnology education should be on "the transition from a disconnected to a connected structure around a matter of shared concern (Davis and Sumara, 2008, p. 76)[11]." Davis and Sumara (2008)[11] pointed out that under a post-structuralist perspective a main pedagogical strategy to be employed is "to turn the language onto itself (p.123)," where learners are invited to participate in "critical examinations of the conventions that frame their own complicity in those conventions."

To foster conversations and critical examinations among students, we propose the use of case studies as a way to convey the societal and ethical implications of nanotechnology. Our vision is to create a learning module that could be implemented in the first year engineering program. The proposed learning module will consist of case studies informed by the work reported by Berne (2006)[12] based on conversations with scientists and engineers about ethics, meaning, and belief in the development of nanotechnology. The rationale is that by crafting case studies into a 'pedagogy of awareness' theoretically grounded in variation theory (Pang, Linder, and Fraser, 2006)[13], we will describe different ways of how the societal and ethical implications of nanotechnology have been experienced by scientists and engineers. According to variation theory, learning is seen as a change in the learners' capability of experiencing a phenomenon through discerning certain aspects (including their own) of the phenomenon (Pang and Marton, 2003)[14]. The aspects of the phenomenon will be informed by the experiences of scientist and engineers described by Berne (2006)[12] and the perceptions described by students as part of this study.

We believe that by raising the level of awareness of the societal and ethical implications of nanotechnology by prompting students to consider these aspects such as technological, economic, environmental, health, educational, ethical, moral, and/or philosophical aspects, may eventually result in educated publics emerging from our high schools and colleges, able to shape the direction of nanotechnology in beneficial ways (Roco and Bainbridge 2005)[7].

This pilot study suggests that education needs to be multi-disciplinary, as students may lack a basic grounding in philosophical and ethical concepts, fundamentals of policy and politics, and essential understandings of the complexities of socio-technical systems including the co-construction of technology and society. While incorporating all of these ideas presents a challenge, even incremental changes that introduce some of the foundational concepts will provide students better preparation than they have now to enter a world in which nanotechnology is rapidly emerging.

Conclusion

This study identifies a starting point for students' understanding societal and ethical implications of nanotechnology and it also proposes an educational approach for including the education of the societal and ethical implications of nanotechnology in engineering courses. We believe that this is just an initial step to address the need to develop and assess training methods that effectively incorporate the technical and the social aspects of nanotechnology. Future work will include the development of instruction as proposed above and assessments will be conducted before and after the intervention. The ultimate goal is to prepare engineering students to encounter nanotechnology education across science, technology, social sciences and humanities to be better equipped to participate in debates about how societies ought to be transformed.

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