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Teaching Small and Thinking Large: Effects of Including Social and Ethical Implications in an Interdisciplinary Nanotechnology Course

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Abstract

One way to ensure that social and ethical implications (SEI) of nanotechnology research are taken into consideration early in research projects is to incorporate ethical concepts into university science education. In this paper, we describe an interdisciplinary nanotechnology university science course and the ways in which the opinions of students regarding the ethical implications of nanotechnology research were influenced by the course. From an SEI perspective, there is value in scientists being aware of the need to make explicit the uncertainties that always exist in scientific and technological research and development. By the end of the class, a majority of the students felt that risks and ethical issues are not well understood by scientists working in nanomaterials, and ethical training was recommended for these scientists. Findings from this study speak to the importance of this type of interdisciplinary class in preparing students for collaborative research and making them aware of issues important to the general public who someday will become consumers of products derived from nanotechnology research.

Keywords

Social and Ethical Implications; Multidisciplinary Course; Nanotechnology Curriculum

1. INTRODUCTION

Citing prior technological disasters such as the health effects of asbestos and taking into account the public reaction to genetically modified organisms (GMOs) in European food, researchers have successfully advocated for consideration of social and ethical implications (SEI) early on in the development of nanotechnology (Colvin 2003; Mnyusiwalla, Daar, & Singer, 2003; Einsiedel & Goldberg, 2004; Sandler, 2006). SEI researchers argue that these experiences illustrate the need to examine potential impacts in parallel with early stages of technological development in order to avoid unnecessary health consequences (as with asbestos), as well as economic backlash driven by negative public perceptions, both of

which can be driven by factors outside of the scientifically understood sense of risk (as with GMOs) (Parr, 2005).

Furthermore, most supporters of SEI argue that in order for both scientific and SEI research in nanotechnology to succeed, the focus should not merely be to educate the public, but to foster dialogue between the public and scientific communities (Sandler & Kay, 2006). However, such a dialogue cannot exist if members of the scientific community are unfamiliar with the implications that need to be addressed. One potential solution to this is to integrate discussion of SEI within university level science education (Varma, 2000). As a result, several social science researchers have begun to develop courses and programs emphasizing the ethical dimensions of nanotechnology research. This includes a proposed nationwide (rather than institution-specific), web-based program entitled The Social and Ethical Implications of Nanotechnology being developed at the University of New Mexico and piloted at five institutions across the country (Mills & Fleddermann, 2006). This course seeks to help students “develop their capacity for critical analysis and their awareness of the multiple issues they will meet as they work in nanotechnology,” as well as inculcating “the flexibility and insight necessary to take an ethically responsible position when faced with unprecedented circumstances” (National Nanotechnology Infrastructure Network/Societal and Ethical Issues-Nano Portal, 2004). As a result of an increased concern for SEI considerations in U.S. National Science Foundation (NSF) grants, several other such initiatives are under way, such as the *Public Health and Nanotechnology Perceptions* project at the University of Washington and the *Nano Practitioners' Ethics Perceptions* project being conducted at Stanford University (National Nanotechnology Infrastructure Network/Societal and Ethical Issues-Nano Portal, 2004). However, there remains a concern that if these courses fail to emphasize the continuum between ethical considerations and the practice of scientific research by addressing these issues from an interdisciplinary perspective, researchers will be likely to merely compartmentalize “ethics” as just another detail to address as quickly as possible in order to proceed with their work and will fail to give these concerns the attention that they should warrant (Berne, 2007).

1.1. NIRT at Brown University

Brown University is actively pursuing the interdisciplinary approach to nanotechnology SEI through an NSF Nanoscale Interdisciplinary Research Team (NIRT) grant with three interwoven components:

- (i) *science of nanotoxicology*, led by a subteam of materials engineers and toxicologists;
- (ii) *nanomaterials safety*, led by professional staff in the Environmental Health and Safety (EHS) department at Brown and focused on safe practices in University laboratories; and
- (iii) *social and ethical implications*, led by faculty and students in the departments of Sociology and Anthropology.

This unique research cluster arose out of earlier collaborative work in the environmental area, where the small size and collaborative culture of Brown University provides a natural setting for such teams to form and play an important role in the academic community. In addition to the research being conducted independently by each of the three cores, the NIRT group has collaborated across disciplines. For example, the leaders of the course we will describe below, a materials engineer and a toxicologic pathologist, have an ongoing collaborative research program studying the fundamental properties of nanomaterials relevant to their toxicity. This interdisciplinary collaboration has led to joint laboratory meetings involving undergraduates and graduate students in engineering, chemistry, and

biology. The course leaders also try to serve as role models for the students and have developed various strategies to enhance interdisciplinary learning and research. In the context of the NSF NIRT grant, these scientists recognized the necessity of broadening their horizons to encompass the social and ethical implications, in addition to the environmental and human health impacts, of the emerging discipline of nanotechnology (see <http://www.nanotechproject.org/inventories/ehs/browse/projects/6533/>).

The *Social and Ethical Implications* core of the NSF NIRT grant conducted a series of interviews with scientists identified through a survey created by the EHS department. In addition to their exposure to the interdisciplinary work (*via* public research forums), these scientists were made more aware of SEI and environmental issues by responding to the survey. We have since extended this project to include scientists from the University of Wisconsin in order to increase our sample size and better develop a more general measure of SEI awareness among nano scientists.

1.2. Small Wonders: A Collaborative University Class

As part of our interdisciplinary approach including a major ethics component, the *Science of Nanotoxicology* group and the *Social and Ethical Implications* group also collaborated to design a course that incorporated an ethics perspective in the overview of nanotechnology. The result was a course cross-listed in the university's Division of Engineering and Division of Biology and Medicine, respectively (i.e., EN0292/BIOS27) entitled *Small Wonders: The Science, Technology, and Human Health Impacts of Nanomaterials*. This survey course (co-taught by an engineer and a toxicologic pathologist) focused on nanomaterials as enabling components in emerging nanotechnologies. It covered scaling laws for physicochemical properties, synthesis routes, manipulation and characterization tools, and example applications in sensors, composites, advanced energy devices, and nanomedicine. The course also examined the impact of nanomaterials on the environment and human health, including the interactions between nanoscale structures and biological molecules, cells, and whole organisms.

The course was truly interdisciplinary because not only was it co-taught but the syllabus was developed collaboratively, and all classes and office hours were attended jointly by both professors. The format of the class did not simply alternate topics with rotating professors, but a multitude of perspectives were fully integrated. The goals for the class were to accustom students to working in interdisciplinary teams, to familiarize them with some of the basic science associated with nanotechnology, and to expose them to some of the ethical implications of nanotechnology research. Future iterations of the class will include ecologists in the planning and teaching. At the time the course was being developed, there were no available faculty members engaged in nanoecotoxicology, but there now are individuals who are developing this research interest in collaboration with investigators at the Marine Biological Laboratory in Woods Hole, MA.

The *Small Wonders* course incorporated interdisciplinary projects that addressed social and environmental aspects of nanotechnology. The class conducted an occupational and environmental health case study project regarding a man with granulomas in his lungs and examined a number of environmental and occupational exposures associated with these lesions. For another assignment, students had to choose one of four challenges to research. Two of the challenges had explicit SEI themes, i.e., one that examined nanomaterial-based technology that kills cancer cells and another that explored nanomaterial based technology for the capture or separation of arsenic, mercury, or lead from contaminated drinking water.

The final project for the class was the development of a nanotechnology research and development project proposal undertaken in multidisciplinary teams of three. The teams

were organized by the class instructors. The project had to include a motivation or need for the research and development, relevant background from the scientific or commercial literature, *a set of concrete goals*, a detailed plan for researching and attaining those goals, *a risk assessment and management plan* (incorporating the elements of hazard identification, toxicity assessment, exposure assessment, and risk characterization), consideration of the ethical, economic and societal impacts of the project outcomes (product/process), and *a plan to appropriately address those impacts*. One team of students proposed an affordable filtration system made from carbon nanofibers that could be used by hospitals in third world countries. This project encouraged collaborations with toxicologists and nanomaterials scientists to ensure a safe filter system and also sought to address a societal need.

As part of the class that focused explicitly on the ethical implications of nanotechnology research, the sociologist who leads the *Social and Ethical Implications* section of the NIRT team gave a guest lecture about many of the ethical issues mentioned previously. He described for the class a number of public concerns regarding nanotechnology, including military applications, exploitation by terrorists, “grey goo” fears, concerns about ubiquitous monitoring, and human enhancement. The possibility of a “nano-divide” (i.e., the concern that nanotechnology will widen the economic gap between rich and poor countries) was also discussed, as well as a need to balance research that benefits only the rich with that which will help the poor. Emerging responses to nanotechnology, including government reports in the US and UK and nongovernmental organization (NGO) mobilization from activist groups such as the ETC Group and Greenpeace, were mentioned, as well as environmental health groups interested in nanotechnology. The *precautionary principle*, i.e., the idea that “when an activity raises threats of harm to the environment or human health, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically” (Wingspread Statement, 1998) was also introduced to students. This was used as a launching point to explore the concern that even though the properties of nanomaterials differ physically, chemically, and biologically from their bulk counterparts, nanomaterials currently are not widely regulated in the US, even though they already are being used in a wide range of consumer products.

Berne (2006) delineates three dimensions of “nano-ethics” in order to differentiate between the wide-ranging areas of ethical concerns regarding the development and implementation of nanotechnology. In Berne's model, first dimension nano-ethics apply to widely held standards such as safety protocols and risk assessment (she gives *primum non nocere*, “first do no harm,” as an example of first dimension ethics) (p. 79). Second dimension nano-ethics are about contestable moral claims, such as questions of distribution, and finally, third dimension nano-ethics address meta-ethical questions regarding human life, self-hood, and beliefs about existence (p. 88). The *Small Wonders* course was a response to the general considerations of Berne and others, and sought to address ethical concerns at each of these three levels, with course content ranging from nanomaterial synthesis and dispersion to the bio/nano interface and the use of nanotechnology in cancer therapy, to broader potential societal and environmental impacts of nanotechnology research.

2. SURVEY DATA AND METHODS

A survey was administered to the students at the beginning (see Appendix 1) and at the end (see Appendix 2) of the semester to determine if their opinions on potential risks, regulation, and social and legal issues related to nanotechnology had been influenced by the course and the SEI guest lecture. We hypothesized that between administrations of the two surveys, there would be enhanced awareness and concern regarding social and ethical implication topics that would be demonstrated through positive changes in students' answers to questions, due to the sociological presentation, as well as the overall social and ethical

implications that were integrated into formal lectures and class discussions during the course. We defined “positive change” as the student moving from an answer that reflects less of a SEI stance or a “don't know” position, to an answer that places greater importance on the ethical and societal implications of nanotechnology. For example, when asked if they thought nanotechnology research had ethical implications (question #4 on the first survey and question #3 on the second survey), changes between the surveys were considered positive if students changed their opinions from “no ethical implications” or “don't know” to either “minimal ethical implications” or “important ethical implications.”

We do not provide inferential statistics since we studied the entire class rather than a sample and also had a small *N*. Any generalizations toward other class interventions are therefore not completely justified. However, our purpose here is to describe an exploratory approach to how social and ethical implications can be addressed successfully in nanotechnology courses that target advanced undergraduates and graduate students from a variety of scientific disciplines.

3. RESULTS

3.1. First Round

The first round of the survey was conducted with 30 students, i.e., 23 graduate students (Ph.D.), six undergraduates, and one postdoctoral student. The survey consisted of nine questions in which students chose among a range of multiple choice options to indicate the strength of their opinion on statements, followed by 15 questions asking them to write elaborations on these opinions. (For ease of presentation, round 1 results will be discussed here and displayed in the tables in the following section.) Almost half (14; 47%) of the students had worked with nanomaterials before. A majority of the respondents (17; 56%) felt that there was a “substantial risk” in working with nanomaterials, citing the fact that so little is known about them as the main concern. As one student described, “because the risks of nanomaterials are not fully understood, it should be assumed that the risks are substantial (003).” The nine students (30%) who felt that there was “minimal risk” involved in working with nanomaterials cited sound laboratory practices as the reason for their lack of concern. One such response indicated that “there is health and environmental risk involved when dealing with nanomaterial research that require the usage of toxic compounds. However, sound lab technique makes this a minimal risk, as it is in biology research (010).”

Seventy percent of respondents (21) felt that researchers are “somewhat aware” of the risks of nanotechnology. Most of these answers were supported by the opinion that “most researchers are pretty aware of general lab safety” (017) but “safety protocols have not been established for nanoparticles research, [so] it can therefore be concluded that researchers are only mildly aware of what the dangers are (011).”

Responses were mixed with respect to the ethical implications of nanotechnology research. One-third of the students (nine) responded that there were “no ethical implications,” based on the perception that “they are not dealing with living tissue,” unlike, for example, scientists conducting stem cell research. On the opposite end of the spectrum, eight respondents (27%) felt that there were “important ethical implications” because of potential effects of nanomaterials on the environment and workers. In response to whether scientists in general think about ethical implications, the answers were divided between “a little” (14; 47%), with students explaining that it depends on the context of the research, and “not much” (10; 33%), based on personal experience and the opinion that scientists are goal driven and focused on elucidating the properties of materials; as one student responded, “If anything, they see it as a drawback to their research (002).”

When asked what they viewed as the benefits of nanotechnology, the most frequently cited response was “medical applications” (17 students, 57%) and drug delivery in particular (7 students, 23%). Eight students (27%) highlighted the novel material properties of nanoparticles, five (17%) mentioned more advanced electronics, and four (13%) wrote about increased energy efficiency. The most frequently cited potential liability of nanotechnology indicated health implications from exposure to or unknown side effects of new products (16; 53%).

When asked if the promises of nanotechnology were exaggerated, the answers were divided between “somewhat exaggerated” (14; 47%), with respondents discussing issues such as nanobots and the fact that nanotechnology has been hailed as a panacea for everything, and “not exaggerated” (12; 40%), with responses indicating that we do not yet know what potentially can be done and hence do not know if the claims being made are exaggerations. Similarly, when asked if the problems of nanotechnology were exaggerated, nearly half the students (14; 47%) answered “not exaggerated” because so little is known about the potential dangers, while 12 (40%) answered “don’t know” and indicated that more testing is needed. According to one student “until tests are performed on every version of nanotechnological particle used, then no one can say for certain what potential problems may arise (011).”

When asked if they thought that potential risks of nanotechnology are adequately addressed by scientists, 60% (18) answered that the risks were “somewhat addressed,” as evidenced by the fact that research on risks currently is being conducted and papers are being published. Six respondents (20%) felt that the risks are “not addressed” by scientists, because while some research is being done, it is not enough, because new materials are being used before the potential hazards are determined.

Students responded similarly when asked if the potential risks of nanotechnology are adequately addressed by government regulatory agencies; however, their written responses expressed uncertainty. Almost half (14; 47%) felt that the issue was “somewhat addressed” because the government is currently funding research, but there also are products on the market containing engineered nanomaterials that have not been tested. As one student noted, “I believe the government is increasing funding for such research and discussion. But I am not aware of whether or not it is enough (015).” More students (14; 47%) chose “don’t know” in this category than in any other, expressing sentiments such as “I don’t know what the government has done to provide us with better knowledge on this matter. Maybe if I don’t know, then they haven’t done enough (012).” When asked which agencies should do this regulating and oversee nanotechnology, most students referred to pre-existing U.S. regulatory bodies: the Food and Drug Administration (9, 30%), the National Institutes of Health (5; 17%), the Environmental Protection Agency (4; 13%), and the National Science Foundation (3; 10%) were cited most frequently. Three students felt that the specific institution doing the research should monitor nanotechnology. Eight students made reference to the formation of new regulatory bodies, including a new independent council of scientists; collaboration between business, government and science; a nanotechnology council; or independent self-regulating organizations for each industry.

In response to whether there should be ethics training for people engaged in nanotechnology research, a majority answered in the affirmative. Nine respondents (30%) answered “definitely,” with three students stating specifically that such training ought to include an ethics expert and a scientist working together. Ten respondents (33%) answered “maybe,” ranging from those who felt that such training was not completely necessary, to students who answered much the same way as those who indicated a “definite” response.

When asked about the implications of a “nano-divide” between rich and poor countries, five students (17%) did not answer or answered that they did not know. The other 25 (83%) respondents expressed varying levels of understanding of the term and confidence in their definitions, but most grasped the concept that richer countries have the ability to fund nanotechnology research, and because poorer countries do not have the same available funding, they will fall behind in this area of technology.

For the final question, which asked about how nanotechnology will lead to new developments in intellectual property, one-third of the respondents did not give answers or did not seem to understand the question. Other respondents cited the small size of nanoparticles as creating difficulties regarding patenting and recognized that the patenting process could slow down the inventing process, while others felt that nanotechnologies should be patented just like any other invention.

3.2. Changes Over the Period of the Class

The first round of surveys demonstrated that students had divided opinions regarding the ethical implications of nanotechnology, whether scientists consider these ethical implications in their research, and whether ethical training should be required for scientists working in nanotechnology. Students also expressed ambivalence about whether government is properly regulating nanotechnology risks. A second round survey was administered at the end of the semester to determine if the students' opinions had changed on any of these matters. This survey consisted of 16 questions, with the first 11 providing multiple-choice responses and the last five requiring written answers. Of the 30 students who completed the first round surveys, 27 students responded to the second round surveys. We examined both individual changes (indicated in Table I) and aggregate changes for the class. We chose to look at both levels of change to obtain a broader picture of the effects of this class on student opinion regarding ethical issues in nanotechnology. If we had chosen to look only at aggregate changes, situations where two groups of students moved in opposite directions might cancel each other out, masking the importance in this shift of opinion. As we discuss below, the two areas in which individual changes were most emphatic were those concerning the ethical implications of nanotechnology and the recommendation for ethical training of those involved in nanotechnology research.

From the point of view of researchers with a strong SEI approach, there is a benefit in scientists being aware of the uncertainties surrounding nanotechnology research. From this perspective, the surveys demonstrated a number of positive changes that occurred over the duration of the course regarding concern for the societal implications of nanotechnology. (Expressed by changing their opinions from “no ethical implications” or “don't know” to either “minimal ethical implications” or “important ethical implications.”) Of the 27 students who responded to the round two surveys, 14 (52%) felt more strongly about ethical implications of nanotechnology research upon completing the course. As shown in Table II, by the second round a slight majority of the students (14) felt that there were important ethical implications for nanotechnology research.

Seven students (26%) were also less convinced that scientists know about the ethical implications associated with nanotechnology: a majority of the answers (16; 59%) rated scientists' knowledge in this area as “not much,” as shown in Table III.

Interestingly, when we divided the students by their field, the answers of 12 of the 14 (86%) materials scientists in the class fell into this category (see Table IV).

The biological scientists were more likely to answer “a little” (7 out of 13) and were the only ones to answer “considerably” (2). This is one of the only questions where students' answers

seemed to correlate with their major field (in the first round they were more evenly distributed). It is perhaps because of this shift in opinion that 19 students (70%) responded after the course that there “definitely” should be ethics training for people engaged in nanotechnology research, whereas only seven (23%) felt that this should be so prior to the course, as indicated in Table V.

In addition to highlighting the doubt that some students had about scientists' understanding of the ethical implications of nanotechnology research, this also suggests a positive view of their course experience, and a feeling that such training could be beneficial to others engaged in nanotechnology research.

In response to the question of whether the *promises* of nanotechnology were exaggerated, we noted an increase of 8 students indicating an opinion of “somewhat exaggerated.” As shown in Table VI, the majority of responses in the second round fell into the “somewhat exaggerated” category (19; 70%).

In response to the question of whether the potential *problems* of nanotechnology were exaggerated, we noted a sharp decline in “don't know” responses after the second round of the survey. As shown in Table VII, 10 respondents (37%) in the second round indicated that these problems were “somewhat exaggerated” (compared to 11% in the first round), and 15 respondents (55%) in the second round indicated that these problems were “not exaggerated” (compared to 44% in the first round).

In response to the question of whether the potential risks of nanotechnology are adequately addressed by scientists, responses of “don't know” and “adequately addressed” both decreased from first round responses of 11% (three respondents) each, to zero in the second round. As shown in Table VIII, by the second round, the class was divided between those who thought potential risks either were “somewhat addressed” or “not addressed,” although a majority of the class felt that the potential risks of nanotechnology were “somewhat addressed” by scientists (16; 59%).

We had access to 21 second round surveys in which students provided written responses that elaborated on their opinions. When asked about the benefits of this kind of interdisciplinary course for learning about nanotechnology, almost all had positive statements about the interdisciplinary nature of the course, including comments that the course broadened their perspective to areas of science outside their own. The one outlier felt that the course was not as interdisciplinary as he or she had expected, but might be helpful to biologists. Two respondents in particular wrote that nanotechnology is an interdisciplinary subject, so it was necessary to learn about it from different disciplinary perspectives. Four students (19%) mentioned that the course was helpful for learning about collaboration or working as part of an interdisciplinary team. There was no distinct change over the course of the two surveys concerning opinions regarding a projected “nano-divide,” intellectual property issues, or who should regulate nanotechnology. However, three students who did not respond to the “nano-divide” or intellectual property questions during the first round of the survey did so in the second round, and seemed to have a clear understanding of the issues.

4. DISCUSSION AND CONCLUSIONS

Overall, students indicated that this course was beneficial to them because they were able to interact with scientists and students from various fields. Considering the interdisciplinary nature of nanotechnology, such interactions will be necessary for them to form future research collaborations. While it may not appear that interdisciplinarity specifically is an SEI concept, we believe that the potential for SEI teaching and understanding is heightened when undertaken within an interdisciplinary context. The instructors of this course have

pointed out that the interdisciplinary nature of this particular class composition may be exceptional; students in the class represented a variety of majors including chemistry, cell biology, pathobiology, biomedical engineering, chemical engineering, mechanical engineering, neuroscience, materials science, and electrical engineering. In most universities where courses are offered at the departmental level, it may be more difficult to attract such a varied sample of disciplinary backgrounds. The class also may have been unusual in that 8 of the 30 students previously had worked with nanomaterials in a laboratory setting. However, we did not find the survey responses of these eight students to differ appreciably from those of their classmates with less experience in nanotechnology.

From an SEI perspective, there is value in scientists being aware of the need to explicitly articulate the uncertainties that always exist in scientific and technological research and development. By the end of the class, a majority of the students felt that risks and ethical issues were not well understood by scientists working in nanomaterials, and so ethical training was recommended for these scientists. The results of these surveys and the impact of this class speak to the importance of this type of interdisciplinary class in preparing students for professional research collaborations, as well as in issues that are important to the general public who someday will become consumers of the research being performed. The traditional models of cost-benefit analysis that scientists have used to account for ethics in the development of technology typically do not address the considerations raised by ethicists, social scientists, and the public. As a result, researchers who fail to account for these concerns may be risking both the success of their grant applications in the present, as well as the success of the technologies they hope to develop in the future (Moor, 2005). Late incorporation of ethical considerations into the development of nanotechnology research could lead to a potential backlash with harsh economic consequences, especially considering how much money already has been invested in the development and production of these technologies.

Other researchers have highlighted the importance of ethics training for scientists. Varma (2000), for example, has argued that engineering curricula in the United States should include courses that use theories and concepts from the humanities and social sciences, in part so that students can better understand the favorable and unfavorable consequences of technology based progress and the moral challenge posed by new technologies. Sweeney (2006) describes a “nanotechnology ethics” seminar series developed specifically for undergraduate students taking part in a NSF funded research program. By the end of the *Small Wonders* course at Brown University described here, students in the course also felt that nanotechnology researchers should be receiving ethics education. We recognize the difficulty of including a separate “ethics course” in already crowded science curricula, but we would encourage Varma's (2000) suggestion of incorporating ethics into pre-existing science courses. As Berne (2007) has pointed out, this would prevent the compartmentalization of ethics and help scientists to better integrate ethics concepts as a natural part of their research. Cobb and Macoubrie (2004) argue that whereas scientists worry about risks attributed directly to the technology, public fears are based more on “the social and regulatory context in which they are imbedded” (p. 235). Thus, scientists and corporate stakeholders must struggle with questions that cannot be addressed by science alone, but, rather, they must publicly incorporate social and ethical concerns into the development and regulation of nanotechnologies in order to ensure the greater public trust necessary for their success (Gaskell, Ten Eyck, Jackson, & Veltri, 2005).

Due to the issues discussed above, we suggest that it is beneficial for scientists-in-training to begin learning about the potential social and ethical implications of nanotechnology in the context of their field and *before* they enter the field as independent researchers. This particular university course was a direct outcome of an NSF NIRT grant focused on

biocompatibility of nanomaterials that arose from the assumption that not enough was being done to examine toxicity of engineered nanomaterials. Even though NSF increasingly presses nanoresearchers to include SEI components, there is no reason to assume that an SEI focus will address the undergraduate/graduate science and engineering curriculum, as in our case. Researchers might choose to focus on public education, or on internal speakers addressing SEI concerns to the researchers. Curriculum development may be beyond the interest and/or capacity of many funded nanoscientists. We urge special attention to developing exportable SEI curriculum, designed in situations like ours, which can be used elsewhere.

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References and Notes

- Berne, RW. Nanotalk: Conversations with scientists and engineers about ethics, meaning, and belief in the development of nanotechnology. Lawrence Erlbaum Associates; Mahwah, NJ: 2006.
- Berne, RW. Personal Communication. Providence, RI: Mar 5. 2007 2007
- Cobb MD, Macoubrie J. Public perceptions about nanotechnology: Risks, benefits and trust. *Journal of Nanoparticle Research*. 2004; 6:395–405.
- Colvin VL. The potential environmental impact of engineered nanomaterials. *Nature Biotechnology*. 2003; 21(10):1166–1169.
- Einsiedel EF, Goldenberg L. Dwarfing the social? Nanotechnology lessons from the biotechnology front. *Bulletin of Science, Technology & Society*. 2004; 24(1):28–33.
- Gaskell G, Ten Eyck T, Jackson J, Veltri G. Imagining nanotechnology: Cultural support for technological innovation in Europe and the United States. *Public Understanding of Science*. 2005; 14:81–90.
- Mills, K.; Fleddermann, C. National Science Foundation Award Abstract #0629278/EESE: Nationwide Nanotechnology Ethics Education Development (2007–2009). 2006. see <http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0629278>
- Mnyusiwalla A, Daar AS, Singer PA. 'Mind the gap': Science and ethics in nanotechnology. *Nanotechnology*. 2003; 14:R9–R13.
- Moor JH. Why we need better ethics for emerging technologies. *Ethics and Information Technology*. 2005; 7:111–119.
- National Nanotechnology Infrastructure Network/ Societal and Ethical Issues-Nano Portal. 2004. http://sei.nnin.org/sei_research.html
- Parr D. Will nanotechnology make the world a better place? *Trends in Biotechnology*. 2005; 23(8): 395–398. [PubMed: 15967522]
- Sandler R. The GMO-nanotech (dis)analogy? *Bulletin of Science, Technology & Society*. 2006; 26(1): 57–62.
- Sandler R, Kay WD. The National Nanotechnology Initiative and the social good. *The Journal of Law, Medicine & Ethics*. 2006; 34(4):675–681.
- Sweeney AE. Social and ethical dimensions of nanoscale science and engineering research. *Science and Engineering Ethics*. 2006; 12(3):435–464. [PubMed: 16909148]
- Varma R. Technology and ethics for engineering students. *Bulletin of Science, Technology & Society*. 2000; 20(3):217–224.
- Wingspread Statement on the Precautionary Principle. 1998. Available online: <http://www.gdrc.org/u-gov/precaution-3.html>

Table ISummary of changes between round one and round two ($N = 21$).

Table II

Do you think there are ethical implications of nanotechnology research?

	Round 1	Round 2
Important ethical implications	8	14
Minimal ethical implications	4	10
No ethical implications	9	3
Don't know	6	0
Missing response	0	0

Table III

Student opinions on whether scientists think much about ethical implications of nanotechnology research.

	Round 1	Round 2
Considerably	0	2
A little	14	9
Not much	9	16
Don't know	4	0

Table IV

Materials versus biological scientists' perceptions of how much scientists think about ethical implications.

	Materials scientists round 1	Biological scientists round 1	Materials scientists round 2	Biological scientists round 2
Considerably	0	0	0	2
A little	7	7	2	7
Not much	5	4	12	4
Don't know	2	2	0	0

Table V

Student beliefs on whether there should be ethics training for people engaged in nanotechnology research.

	Round 1	Round 2
Definitely	7	19
Maybe	8	5
Not at all	5	3
Don't know	7	0

Table VI

Student opinions on whether the promises of nanotechnology are exaggerated.

	Round 1	Round 2
Very exaggerated	2	1
Somewhat exaggerated	11	19
Not exaggerated	11	6
Don't know	2	0
Missing response	1	1

Table VII

Student opinions on whether the potential problems of nanotechnology are exaggerated.

	Round 1	Round 2
Very exaggerated	1	1
Somewhat exaggerated	3	10
Not exaggerated	12	15
Don't know	11	1

Table VIII

Student opinions on whether the potential risks of nanotechnology are adequately addressed by scientists.

	Round 1	Round 2
Adequately addressed	3	0
Somewhat addressed	15	16
Not addressed	6	11
Don't know	3	0