Teaching Societal and Ethical Implications of Nanotechnology to Engineering Students Through Science Fiction

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Societal and ethical implications of nanotechnology have become a hot topic of public debates in many countries because both revolutionary changes and strong public concerns are expected from its development. Because nanotechnology is, at this point, mostly articulated in visionary and futuristic terms, it is difficult to apply standard methods of technology assessment and even more difficult to consider it in engineering ethics courses. In this article, the authors suggest using selected science fiction stories in the engineering ethics classroom to provide students with ethical skills and cultural knowledge required for engaging in public debates and for responsible decision making. Against the background of general debates on teaching engineering ethics, they do so by discussing the advantages and possible drawbacks of this approach and by presenting two examples of nano–science fiction classics.

Keywords: *nanotechnology; ethics; engineering education; science fiction*

1. Introduction

Nanoscale science and engineering, generally referred to together as *nanotechnology*, cover the investigation and manipulation of matter at the nanometer length scale, from which revolutionary technical applications are being expected. Under the umbrella of nanotechnology, an intriguing diversity of formerly distinctive fields of science and engineering research flourishes, including physicists, chemists, materials scientists, and biomedical scientists as well as electrical, chemical, and mechanical engineers, such that great hopes exist of the synergistic effects of interdisciplinarity.[1] Many national initiatives have been launched around the world including Japan, the United States, European countries, Singapore, Korea, Brazil, and South Africa. In the United States, a report by the National Science and Technology Council claims, "The emerging fields of nanoscience and nanoengineering are leading to unprecedented understanding and control over the fundamental building blocks of all physical things. This is likely to change the way that almost everything—from vaccines to computers to automobiles to tires and objects not yet imagined—is designed and made" (Committee on Technology, 2002). The National Science Foundation has touted nanoscience as leading to "dramatic changes in the ways materials, devices, and systems are understood and created" and lists among the envisioned breakthroughs "orders-of-magnitude increases in computer efficiency, human organ restoration using engineered tissue, designer materials created from

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direct assembly of atoms and molecules, and the emergence of entirely new phenomena in chemistry and physics" (Committee on Technology, 2003).

How nanotechnology research and development and the marketing of products might reshape and otherwise affect human living conditions as well as beliefs, values, and social relationships is an unanswered question. The unknown and potentially substantial harms and benefits and the risks and opportunities it represents to social, cultural, and material life warrant immediate and careful ethical reflection. The effort to engage and develop an ethics for nanotechnology complements other efforts to explore the moral dimensions of the scientific and technological transformations of society, such as environmental ethics (dealing with the effect of human civilization on the natural environment), biomedical ethics (focusing on the growing technological capacities to heal diseases, to enhance human performance, and to control reproduction), and computer ethics (researching the effect on society of the increasing digitalization of information and the computer control of all kinds of processes). And yet, there is at least one factor that may at this point distinguish nanotechnology ethics from other areas of engineering ethics. Most nanotechnology pursuits are still in the research, if not visionary, stage and have not emerged as actual development. No one really knows where the initiatives will lead or what the course of nanotechnology research and development will be. It is touted as having a potentially profound effect on virtually every facet of human life, but that effect is still futuristic and cannot be predicted with any accuracy. Formulating an ethics of a technology that has yet to develop is a daunting quest, to say the least. There are many uncertainties about the moral obligations that may come as a result of nanotechnology development and that confound the nano-ethics inquiry. To identify moral rules and principles for the future development of nanotechnology, other than traditional rules and principles, requires the impossible task of seeing into the future. However, the importance of doing so is enormous, especially in the engineering classroom where future designers and researchers of nanotechnology are being educated.

In this article, we suggest including selected nano–science fiction stories in the teaching of nano–engineering ethics. We start with a survey of current debates on how to teach general engineering ethics (section 2) and then point out the general and particular advantages as well as possible drawbacks of using science fiction in the classroom (section 3). In section 4, we present two examples of classical nano–science fiction texts that we find useful for engaging engineering students in the discussion and reflection of moral issues of nanotechnology, from which we draw conclusions in section 5.

2. Educational Approaches in Engineering Ethics

At this point, the teaching of nano–engineering ethics is still in a rudimentary and explorative state, because societal and ethical implications of nanotechnology are still a matter of theoretical reflection. Governmental agencies in the United States and Europe have recently organized several workshops[2] that began stocktaking moral and societal issues and that have encouraged further scholarly reflection.[3] However, it is almost certain that nano–engineering ethics will soon become part of the engineering education, so that it is worth starting to reflect on its implementation now against the background of existing educational approaches in engineering ethics.

Since 2001, all the engineering programs in the United States are to be accredited using the Engineering Criteria 2000 by the U.S. Accreditation Board for Engineering and Technology (ABET), which requires, among others, that students should be educated in "professional and ethical responsibility" and "the impact of engineering solutions in a global and societal context" (Herkert, 2000). Although courses in engineering ethics have been offered long before and in many countries, mostly on a nonmandatory basis, the new requirement has started a debate on educational approaches in engineering ethics.[4] In the United States as well as elsewhere, controversies focus on four different issues.[5]

1. *Curriculum integration*. Besides the question of whether engineering ethics should be mandatory or not, there are different models for integrating it into the general engineering curriculum.[6] The two main issues are whether engineering ethics should be a freestanding course or pervading the engineering curriculum and whether engineers, philosophers/ethicists, or a team of engineers and philosophers should teach it.
2. *Goals and topics*. Typical goals and topics of engineering ethics include the awareness of moral issues and societal implications of technology, of professional and general moral responsibili-

ties; the learning of moral arguments, judgments, and problem-solving skills; and the understanding of ethical frameworks and the general place of science and technology in society. Different approaches put different emphases on these topics, however. For instance, philosophers tend to emphasize the learning of ethical theories and skills, whereas engineers tend to focus on particular problem awareness and moral education. American approaches frequently include professional responsibilities to engineering societies, colleagues, and customers, whereas European approaches mostly focus on moral responsibilities to the general society. Another issue, which usually depends on resources, is whether the topics or courses should be specified for different engineering disciplines or be general enough so as to cover all the engineering (and science) disciplines.

3. *Ethics approach*. The old debate in ethical theory (and law)—whether moral judgments can and should be based on general principles or particular cases—has, via debates in applied ethics, also pervaded engineering ethics and its education.[7] The "top-down approach" starts teaching ethical theories or professional codes of conduct and deals with particular cases only later as illustrations or derived instances. The "bottom-up approach" first introduces particular cases and problems (taken either from history, forecasting, or fiction) from which other cases are to be developed either by analogy or via general ethical perspectives that first need to be introduced by logical induction. Although the bottom-up approach has become prevailing, at least in the United States, because many students understand particular cases better than general principles, it is a matter of debate if students thus achieve general ethical skills to deal also with new problems. For both case studies and professional codes, rich teaching resources are available online now.[8]
4. *Student engagement*. Depending on the goals of engineering ethics education (see above), there is debate, and room for further innovations, on how students should become engaged, either intellectually or emotionally or both (Newberry, 2004). Besides traditional forms of education, new pedagogic approaches exercise collaborative learning and role-playing or include visits to practicing engineers in companies and institutions.[9]

Much of what is taught in the engineering ethics classroom is a matter of practical, personal decision making and responsibility—the avoidance of harm and the doing of good in various professional settings. However, in the consideration of newly developing, futuristic technologies such as nanotechnology (and its proposed convergence with bio-technology and artificial intelligence), there are critical questions to be addressed but also great difficulties in formulating a system of ethical reasoning and guidance from which to pursue those technological developments. How might students consider, for example, the ambition of nanotechnology to "revolutionize" human living through the technological ability to control and manipulate matter with precision? How do we teach the ethics of such a daunting, futuristic claim? How might classroom instruction provide for probing, insightful thinking about this ambition? This article suggests a bottom-up approach, which uses science fiction as a tool with which students might navigate the ethical and societal dimensions of such unknown and unfamiliar technological terrain.[10]

3. The Use of Science Fiction in Teaching Engineering Ethics

The use of literature for moral education is actually as old as higher education and was implemented in various modern educational models, from the humanistic Bildung ideal to the Liberal Arts Education and the Classic Text approach. In fact, the idea that reading their poems, novels, stories, or plays can contribute to the formation of a moral person has been prevailing among writers themselves since early antiquity. Nowadays, literature teachers also use various pieces of classic literature to make students aware of potential moral issues of modern science and engineering, which is one of the existing models of engineering ethics that is frequently ignored in the debates mentioned above. It is questionable, however, whether such 19th-century "mad scientist" stories as Mary Shelley's (1818/1831) *Frankenstein, or the Modern Prometheus* or Nathaniel Hawthorne's (1844) *Rappaccini's Daughter* are helpful, because they rather induce antiscientific clichés based on early modern, if not premodern, views of science and thereby reinforce the split of the "two cultures" (Schummer, in press).

Opposed to that, we suggest including selected nanoscience fiction stories in engineering ethics courses. To that end, the stories need to raise moral issues that are considered both important and realistic, in the sense that they are sufficiently complex and that similar scientific and technological capacities are likely to come in the near future.

Within the mentioned debates on educational approaches in engineering ethics, our approach is open to all kinds of curriculum integration (1). The goals and topics (2) essentially depend on the selected stories, for which we present two examples in section 4. The approach is, of course, bottom-up, as we start with cases and problems that are not taken from history but from fiction writing. Student engagement (4), both emotionally and intellectually, is actually one of the strengths as we replace conventional ethics texts with intellectually provocative, entertaining science fiction stories to be discussed in the classroom.

Today, nanotechnology is mostly articulated in visionary terms about industrial revolutions, transformations of society, and radical changes of the human condition. Apart from science fiction authors, many software engineers, scientists, policy makers, business people, and transhumanists are heavily engaged in drafting such grand visions (Schummer, 2004c). That is also what the public mainly associates with nanotechnology and what people are mainly fascinated with and afraid of (Schummer, 2005). It has even been argued that nanotechnology is about to blur the boundary between science fiction and nonfiction (Milburn, 2002). Whether all these visions will turn out to be correct or not, scientists and engineers working in nanotechnology research are faced in public discourses with that visionary climate and with great hopes and fears. Whether they like the role or not, nanotechnologists are considered the essential actors of making the greatest dreams and the greatest fears come true. Therefore, more than in any other field, students of nanotechnology must be prepared to respond to such expectations, in public discourse as well as in daily research decisions. They need to understand what these visions are about, what their cultural backgrounds and driving societal forces are. Because science fiction authors are arguably the most professional and influential vision writers, their texts are an ideal source for making engineering students aware of the public expectations they will increasingly face in their professional lives.

Furthermore, engineering students, when confronted with novel phenomena and with unfamiliar, perhaps uncomfortable, curious, and intriguing ideas, must have some way of negotiating and responding. Through science fiction, the imaginative process takes the mind beyond recognized material awareness and cognitive boundaries into domains of unexplainable sensory experience and psychological unknowing. It can be used to reach beyond what is known and understood to make meaning of those elements of human awareness and perception that otherwise elude one's grasp. It can also help break down conceptual barriers to awareness and, in turn, inspire imaginative consideration of what is right and good in futuristic technological development. In the engineering classroom in particular, science fiction can provide a way for students to cross the barriers of rational limits to knowing, through provocative images that reach past intellectual domains into the collective unconscious of myth, belief, and archetypes toward otherwise inaccessible realities. When notions such as personal transformation emerge in the imagined possibilities and promises of nanoscale manipulations of matter, students need to understand what that may mean in moral terms and how that might change the notion of being persons that underlies all ethical theories.

Science fiction can help students to approach an understanding otherwise inaccessible, except through the realm of intuition, emotion, and imagination. Traditional deontology cannot easily be applied to futuristic technologies if life then may in no way resemble what we now know life to be. To approach ethics of futuristic technologies in the engineering classroom, rationalistic methodologies must be supplemented with awareness of feelings and even fears, excitements, and dreams about what students may one day play as either consumers or designers of that future. Only then can they learn to articulate and define moral judgments and standards about the development of technologies that promise such profound changes to the characteristics of human life. Through science fiction, moral imagination can be elicited as a primary analytical tool, so that engineering students can engage and deliberate over moral judgments in light of emotion, attitudes, and preferences, through the creative and illuminative power of the human intuition.

Of course, there are also drawbacks of teaching engineering ethics through science fiction, and we do not recommend basing engineering ethics courses entirely on science fiction. Instead, science fiction provides, for the reasons mentioned above, a useful additional approach in such visionary fields as nanotechnology to be complemented by traditional approaches and careful guidance by teachers. First, students need to be aware of the difference between science fiction and nonfiction, that science fiction is not a prediction of future scenarios but about stimulating the thinking about possible futures, which includes imagining quite different scenarios. Second, as with all bottom-up approaches, classroom discussion should move from the particularities of the stories to the morally relevant aspects and to the underlying general moral issues, such that students learn general analytical skills of ethics that they can apply to other cases. Supplementary reading of top-down approaches might be advisable.[11] Third, whereas the emotional access to moral issues is an advantage of the science fiction stories, students should also learn to reflect on their own emotions, on what part of the stories induced them, and on how they influence their moral judgments. Finally, the selection of science fiction stories should be made carefully and balanced to include not only different moral issues but also different perspectives.[12] Students should be provided with critical thinking skills and learn that science fiction authors have their own moral positions and that writing novels can sometimes be a powerful tool to impose moral positions on readers.

4. Two Examples of Nano-Science Fiction for Teaching Engineering Ethics

Some nano–science fiction stories are plainly horrifying, reflecting fears of the unknown and of the power of misguided science to potentially destroy the foundations of life as we know it. Greg Bear's (1985) classic, *Blood Music*, and Michael Crichton's (2002) recent novel, *Prey*, which is currently being made into a movie, are examples. Although there is an argument to be made for the importance of the inclusion of such literature in public discourse about developing nanotechnology, its place in the engineering ethics classroom is less clear. We would recommend, instead, writings that more subtly bring to light the ambiguities and complexities of future social and moral life, which are hauntingly plausible under the influence of nanotechnology. Supplementary to the technical education, engineering ethics should make students aware of the complexity of human society, the sensitivity of the environment, and the complex relationship that exists between technology, humans, and the environment.

In this section, we present two examples of nano–science fiction stories that can be useful in that pedagogical ambition. Both stories are classical texts of nano–science fiction, written between 1989 and 1995.[13] They differ in the kinds of moral and societal questions they pose and in the extent of their visionary horizon. The first story focuses on researchers and their research motives, visions, interactions with other researchers, and sense of moral responsibility. In the engineering ethics classroom, this text provides a fictional case-based introduction to research ethics by spinning a web of moral conflicts rather than by presenting simple moral answers. The second story develops visions of a technologically radically changed society, most poignantly expressed from a child's perspective. This text is useful to make students reflect on the role of technology in society and its far-reaching effects on values and beliefs.

Moral Conflicts in Michael Flynn's *The Nanotech Chronicles*

In his novel *The Nanotech Chronicles*, Michael Flynn (1991a) presents his view on the gradual development of future nanotechnology and its social implications in six nano-science fiction stories. The second story, "The Washer at the Ford" (Flynn, 1991b), is an ideal reading for introducing engineering students to a large variety of moral issues that might arise along with the research and development of new technologies. By masterfully arranging six characters with different moral positions, for each of which we find almost convincing arguments, Flynn prompts his readers to reflect on moral issues and to solve moral conflicts.

The main character, Dr. Charles Singer, is described as the inventor of molecular nanotechnology (pp. 19-20) and president of the small American research company, Singer Lab. His three collaborators (and associates) are his wife, Dr. Jessica Burton-Peeler, the "second best geneticist in North America" (p. 31) and vice president of Singer Lab; Dr. Kalpit Patel, a second-generation Indian American microbiologist and, at 52, the oldest of the group (p. 31); and Eamonn Murchadha, a young Irish microbiologist and "nanomachinist" (p. 33). The group is joined by Dr. Masao Koyanagi, a citizen of the nonallied "codominium of Brazil and Japan," whose "grandparents were killed in Nagasaki . . . from radiation induced cancer" (p. 140), such that the story cannot play in the far future. Based on his former research on radiation-resistant bacteria, Koyanagi convinces the group to work on "nanomachines" that should considerably increase the radioactive radiation resistance of humans by genetic modification of corporal cells. Compared to many other nano–science fiction stories, that project does not sound too far-fetched such that there is no barrier for readers to understand the following conflicts. The sixth character in the plot is John Royce, a representative of the American government from the "Office of Technology Assessment" (p. 60), who offers to Singer Lab almost unlimited financial support of the project in return for full governmental rights on all results.

As the story develops, all six characters form different positions and interact with each other in a variety of conflicts. Koyanagi has strong idealistic motives to increase the radiation resistance of all humans, across all nationalities and social classes, as this will reduce the human suffering from cancer and other health consequences of radioactivity. Singer is not only a competent scientist but also an individualistic entrepreneur with strong ambitions to make profits for him and the company, so that he only reluctantly agrees to the governmental contract because his company is having financial problems. Between Koyanagi's responsibility for humanity and Singer's focus on his company and himself, Royce engages in moral arguments for the researchers' responsibility to the country and for the national interest. Patel represents the morally disinterested researcher who wants to focus only on technical problems and solutions ("All I ever wanted to do was design better molecules. . . . I do not wish to be the decision-maker" [p. 120]).

The different moral positions let the first three characters act against each other: Royce wants the foreigner Koyanagi out of the project for which he promises Singer additional money. Singer, to secure the governmental funding and because he suspects that Koyanagi's altruism might undermine his profits, is at first willing to fire him. Koyanagi mistrusts both Singer's profit-orientation and the governmental interest and pirates the research results for worldwide dissemination. In the end, Singer and Koyanagi form an alliance against Royce when it turns out that the government is planning to use their research for a secret weapon.

The remaining two characters, Murchadha and Burton-Peeler, raise moral concerns about the potential misuse of the prospective technology and agree that the risks outweigh the benefits. They argue that human radiation resistance would make people careless in dealing with radiation around nuclear power plants, to the detriment of animals and plants as well as of fetus and unprotected humans in case of malfunction. They are particularly concerned that governments might more likely run the risk of a nuclear war because of the illusion of total radiation protection, which in fact would only be limited. Whereas Murchadha is only worried about the dangers, Burton-Peeler is very anxious and sabotages the common project to the dismay of all others, including Murchadha.

Murchadha's and Burton-Peeler's criticism put them in opposition to the other characters. Of course, they mistrust Royce and the government. They reproach Singer not only for being blind to the broader societal effects of the prospective technology, which Burton-Peeler explains to her husband in a longer ethical discourse (pp. 128-132), but also for being selfish and mercenary. Because they are equally concerned about humanity as Koyanagi is, although with contrary positions, the relation between both parties is particularly interesting. Burton-Peeler, the activist who has little trust in the responsibility of humans, sees danger and naiveté in Koyanagi and tries to get him out of the project by guiding suspects about her sabotage toward him. Koyanagi, the Buddhist and "bleeding-heart idealist" (p. 104), has "greater faith in human nature" (p. 119) and strongly condemns Burton-Peeler's sabotage.

Without being boring or artificially constructed, Flynn's nano–science fiction story is full of moral issues without undue simplification, each worth discussing at length in an introductory class in engineering ethics. The main issues include the following:

1. *The dimensions of intended and unintended social consequences of technological innovation*, including attempts to fix unintended consequences by technological implementation (145ff), and cultural conservatism (p. 151): Engineering students see their future activity embedded in a wider social context, broaden their imagination, and learn that good intentions can sometimes result in bad consequences. At the same time, they understand the limits of social foresight and of planning technology-induced social changes.
2. *The intricacy of issues in engineering ethics*, such that even contradictory positions can, each of their own, convincingly appeal to "reason" (pp. 122-129, 133). Students are prompted to solve such contradictions by analyzing for each moral position the different hidden assumptions

about the scope of responsibility, fundamental values, and the human nature.

3. *The different kinds of interests and values* that engineers are confronted with in real-case research and development and for which they need to make balanced and responsible decisions (pp. 117-124): Students learn that, beyond mere technological performance standards, economical, political, and moral values as well as competition, friendship, and social group dynamics actually play important roles in engineering decision making.
4. *Risk analysis* (pp. 128-132, 144) and the social relativity of risk perception (pp. 81, 129, 135): Students learn risk calculation and its limits in extreme cases (small probabilities of infinite harm) as well as the difference between objective and subjective risks assessment. They understand that risk perception is not only essentially subjective and dependent on personal hopes and fears but also embedded in social contexts.
5. *Standard excuses from moral responsibility*, such as technological determinism ("If I don't do it, somebody else will do it" [pp. 136, 145]); higher necessity ("If we don't do it, we are lost"); technological naivety ("My only job is to solve technical problems" [p. 120]); and the appeal to good intentions ("I always had only good intentions" [p. 141]). By reading such excuses and their responses in moral debates throughout the story, students learn the weakness and narrow-mindedness of such phrases and how to replace them with better arguments.

Societal Quagmires in Neal Stephenson's *The Diamond Age*

While telling the story of a little girl named Nell, Stephenson's (1995) novel, *The Diamond Age*, weaves the reader through a world that is at once familiar and strange. Much as with today, in that world, human beings have divided themselves into rather isolated societies, living in self-ruling territories and being determined primarily by racial identity and common ideas and rituals. Wars are fought over material resources, land, and power. Criminals are judged according to the severity of their deeds, and entertainment is accorded significant value. However, unlike today's world, in Stephenson's fictional world, nanotechnology is able to provide for all of the basic human needs and many other material desires. "Matter Compilers" use "feed" to build from molecules any object that is programmed into the system, from food to clothing to entire buildings (p. 57). Scarcity of resources is a political maneuver by powerful territories to both limit and control the use and possible abuse of technological power. This is one reason war persists, such as in the "Chinese Civil War," where people in the North have no access to nanotechnology (p. 253).

Stephenson's world combines highly developed technology with traditional, sometimes archaic, social conditions. In some territories, social justice is suppressed under the pursuit of information acquisition. There are world governances, but the independence of each territory leaves social conditions up to the individual governments, so that in the "Chinese Coastal Republic," the old ("Confucian") laws prevail and criminals are sometimes punished with physical torture or death. In one such occurrence, a judge from "New China" orders a magistrate to "revert to the time-honored methods of his venerable predecessors." The prisoner is strapped to a heavy metal rack that was normally used for canings, stripped from the waist down, and situated over a bucket for elimination. Earlier, the court physician "thrusts in a spinal tap," introducing a set of "nanotechnological parasites." These parasites had "migrated up and down the prisoner's spinal column" through the cerebrospinal fluid and "situated themselves on whatever afferent nerves they happened to bump up against." These nerves, used by the body to transmit information such as (to name only one example) excruciating pain to the brain, had a distinctive texture and appearance that the "sites were clever enough to recognize" and the ability to "transmit bogus information along those nerves" (p. 125). Despite their extraordinary technological abilities, the inhabitants of this future world are troubled, competing, and perpetually in struggle.

The story's main character, a young girl named Nell, is abused, neglected, and impoverished. As Stephenson's narration gives the reader glimpses of many different characters, their world, and their struggles, it is Nell's personal journey out of the hell of her own life and into a state of enlightened freedom that consumes the reader's moral hopefulness in an otherwise dark novel. And that hope is embedded behind a "book" called the Primer. Books are not only obsolete, they are forbidden. Information is transmitted only through "nano-electronics." An illegally developed device, because it would threaten the established social structure, the Primer is read, like a book, but responds in real time to the fantasies and desires, fears, and imaginings of its reader. The Primer generates the story as the reader proceeds to read it by responding to the queries the reader poses to it. Nell is particularly vulnerable to the book's responsive writing, as it senses her physical poverty and her emotional needs. In due time, the book begins to "know" her better than she knows herself and becomes her companion, confidant, and ultimately her savior in the face of real threats to her life.

More than just an inexhaustible source of information, the Primer is a super-intelligent computing device that interacts with its user in a quasi-personal manner. It is omniscient and perfectly empathizing, prudent, foresighted, and benevolent—a device that meets various human desires through advanced information technology. Retrospectively, the psychological and social conditions have drastically changed with each innovation in information technology, from the inventions of speaking, writing, and printing to digital computers. In *The Diamond Age*, Stephenson offers a fantastical but eerily plausible glimpse at what it may mean to be alive in human society when nanotechnology reshapes information technology once more.

There are many significant strands of social-ethical inquiry in *The Diamond Age* that might be considered in an engineering ethics classroom, including the following:

1. *The social reality of technological visions*. Various proponents of the nanotechnology "revolution" have suggested that by manipulating atoms with precision, humans will have more control and, through that, fewer material needs and eventually less struggle. Stephenson's story reconsiders the premise that material wants and needs are the basis for human struggle. In *The Diamond Age*, social and personal struggle persist, as does material need, despite the highly developed capacities of nanotechnology. Human struggle is depicted in this story not simply as an outgrowth of material want, but from more complex elements of the human psyche and social structure.
2. *The concept of privacy*. In Stephenson's story, the concept has lost any meaning because new technologies have radically changed expectations and behaviors concerning the information humans extrude from one another. In one scene, the narrator explains that the foyer of a home has come to be used in new ways, because all visitors were carefully examined before entering into a home's "inner sanctum" ("So elaborate waiting room etiquette had flourished, and sophisticated people all over the world understood that when they called upon someone, even a close friend, they could expect to spend some time sipping tea and pursuing magazines in front of a room infested with unobtrusive surveillance equipment" [p. 154]). One of the stated interests of today's governments in nanotechnology is the development of undetectable surveillance systems to be placed in a variety of locations and materials. In *The Diamond Age*, that technological ability is moved beyond military or national security use into daily use by individuals, organizations, and businesses. Engineering students might consider the values embedded in the information-gathering devices being designed today, considering that in the future, "when everything can be surveyed, all we have left is politeness" (p. 174).
3. *Nature and technology.* In Stephenson's futuristic world, nature, in the sense of both the natural environment and the human body, is reduced to mere instrumental objects. Birth control, for example, is pursued through a technology called "the Freedom Machine," where "mites" are placed inside the body of the female to eat fertile eggs as they are formed. Excessive sexual promiscuity is the norm, due to the "freedom" from conceptualization and the ability to intercept sexually transmitted diseases. Trees have no other use than for the production of oxygen, which could also be done by nanotechnology, so that they are removed for unlimited land development. An interesting discussion subject for the engineering ethics classroom is the relationship between nature and technology, which in Stephenson's science fiction is used to master and control otherwise natural processes. What values are driving the instrumentalization and "mastery" of nature, and what social and moral consequences might this process have?

Conclusion

Through science fiction, engineering students are given opportunities to move beyond ideas of present material reality into the domains of the imagined future, where they can work with moral questions of our future with nanotechnology in creative and active ways. From their engagement with science fiction, they can move back to real time and the actual state of nanotechnology research and development, to ask where we may possibly move with these technologies, and how they may affect social, moral, and environmental conditions of human life. Most important, the imaginative process can better equip them to engage reflection over such issues as what we take to be our most cherished values and beliefs, and how those values and beliefs might drive the technology development and in turn be affected by the technologies we are creating. By bringing this imaginative process of reflection into the engineering classroom, engineering students are freed from the constraints of technical problem-solving efforts to reflect more deeply on the ethical dimensions of the emerging nanotechnology age.

If accompanied by guided classroom discussion, selected science fiction stories can be used to introduce students to pertinent ethical concepts, to train awareness of moral issues, to educate skills for solving moral conflicts, and to prepare them for their future role as responsible engineers. In addition, students of nano-engineering can learn from classical nano–science fiction novels something about the visionary roots of their field, the public image of nanotechnology, and the great hopes and fears that they as professionals will be faced with.

Notes

1. Thus far, the degree of interdisciplinarity is rather poor, however (see Schummer, 2004a, 2004b).

2. Published proceedings include Roco and Bainbridge (2001) and Roco and Tomellini (2002).

3. For example, see Weckert (2001), Sweeney, Seal, and Vaidyanathan (2003), and Wolfson (2003). See also the works on ethics in Baird, Nordmann, and Schummer (2004) and Schummer and Baird (2004-2005).

4. See, for instance, the Essays on Ethics Education in Engineering and Science at the Online Ethics Center for Engineering and Science (http://onlineethics.org/essays/education/) and the recent special issue, "Integrating Ethics Into Engineering Education and Practice" (2004).

5. For a survey of the U.S. debates, see Herkert (2002).

6. For a discussion, see, for instance, Davis (1999) and Lincourt and Johnson (2004).

7. See Jonsen and Toulmin (1988) and Whitbeck (1996).

8. For case studies, see Pritchard (1992) and Online Ethics Center for Engineering and Science (http://onlineethics.org/eng/cases.html). For professional codes, see Resources at the Center for the Study of Ethics in the Professions at the Illinois Institute of Technology (http://www.iit.edu/departments/csep/PublicWWW/codes/index.html) and Online Ethics Center for Engineering and Science (http://onlineethics.org/codes/index.html).

9. See Herkert (1997), Loui (2000), and Whitbeck (1995).

10. For an earlier suggestion, see Pritchard and Goldfarb (1995).

11. For instance, see Schummer (2001).

12. For an introduction to American science fiction, see Landon (1997). For nano–science fiction, see Landon (2004).

13. For a bibliography of English nano–science fiction, see Napier (2004).

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