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NANOSCIENCE AND NANOETHICS: DEFINING THE DISCIPLINES

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Nanoethics, or the study of nanotechnology's ethical and social implications, is an emerging but controversial field. Outside of the industry and academia, most people are first introduced to nanotechnology through fictional works that posit scenarios—which scientists largely reject—of self-replicating "nanobots" running amok like a pandemic virus (Crichton, 2002). In the mainstream media, we are beginning to hear more reports about the risks nanotechnology poses on the environment, health, and safety, with conflicting reports from within the industry.

But within the nanotechnology industry, there is a strange schizophrenia afoot. We have heard about the wonderful things that nanotechnology might enable—not just today's mundane products, such as better sports equipment or cosmetics, but the truly fantastic applications. Our imagination seems to be our only limit, as scientists and other experts predict such innovations as toxin-eating nanobots, exoskeletons that enable us to leap walls in a single bound, affordable space travel for everyone, nanofactories that can make anything we want, and even near immortality.

Yet nearly in the same breath many advocates continue to deny or to ignore that nanotechnology will cause any significant disruptions or raise any serious ethical questions that we have to worry about—dismissively labeling these as "hype" (e.g., The Nanotech Schism, 2004). But how is this possible? How can such a brave new science, one that is so full of potential that it has been called the "Next Industrial Revolution" by governments and scientists, not also impact our relationships, society, environment, economy,

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or even global politics in profound ways (e.g., National Science and Technology Council, 2000)?

Let's take a step back and consider *any* given technology we have created: gunpowder, the printing press, the camera, the automobile, nuclear power, the computer, Prozac, Viagra, the mobile phone, the Internet. Undoubtedly, these have brought us much good, but each has also changed society in important, fundamental ways and caused new problems, such as increased pollution, urban sprawl, cybercrimes, privacy concerns, intellectual property concerns, drug dependencies, new cases of sexually transmitted diseases, other unintended health problems, mutually assured destruction, and much more. The point here is not that we would have been better off without these inventions. Rather, we should come to terms that our creations can have unintended or unforeseen consequences.

Many of the social problems associated with the aforementioned technologies might have been anticipated and mitigated with some forethought. This is a lesson not lost on policymakers and scientists today, for instance, in having spent millions of dollars to study the ethical implications of decoding the human genome, such as privacy and genetic discrimination concerns. The same lesson, however, apparently was lost on the commercial biotechnology industry, which recently discovered that by ignoring its ethical and social issues—specifically, the possible harm from genetically modified foods on human health and the environment—they invited a public backlash that crippled progress and sent corporate stocks plummeting.

To be sure, no one expects ethicists, scientists, policymakers, and other experts to anticipate and address all possible scenarios. It is a plain fact of the human condition that we do not and cannot know everything. We do not fault Thomas Edison, for instance, for the copyright-violating devices that his phonograph would inspire, or Henry Ford for the agonizing commutes we endure daily, or Bill Gates for the email "spam" we receive.

And when we try to make predictions about technology, we are often wrong. Consider the following infamous predictions: "This 'telephone' has too many shortcomings to be seriously considered as a means of communication. The device is inherently of no value to us" (Western Union, 1876); "Who the hell wants to hear actors talk?" (H. M. Warner, Warner Brothers, 1927); "I think there is a world market for maybe five computers" (Thomas Watson, chairman of IBM, 1943); "With over 50 foreign cars already on sale here, the Japanese auto industry isn't likely to carve out a big slice of the U.S. market" (*BusinessWeek*, August 2, 1968); and "There is no reason anyone would want a computer in their home" (Ken Olson, founder of Digital Equipment Corp., 1977).

Clearly, it is easy to be too conservative or short-sighted in estimating the future impact of technology. The dangers associated with technology can likewise be underestimated, for instance, as was the case with asbestos, lead paint, and the pesticide DDT. But this is not just a failing of our distant past. In 2006 alone, a study has suggested that mobile phones, after all our years of using them, can cause brain tumors and infertility (Hardell et al., 2006). Another study showed that computer manufacturing workers, after decades on the job, are at a much greater risk of death from cancer and other illnesses (Clapp, 2006). In the same year, the U.S. Environmental Protection Agency (EPA) concluded that a key chemical (PFOA) used to make Teflon—the ubiquitous material used for the last 50 years in nonstick cookware, carpeting, clothing, food packaging, and thousands of other products and traces of which can be found in the blood of nearly everyone in the United States and other developed nations—is a carcinogen (EPA, 2006).

At the other end of the spectrum, some predictions also overestimate the role of technology, as was the case with robotic maids, flying cars, meal-in-a-pill, and the death of privacy, for instance. So it is no surprise that the impact of nanotechnology should be both understated and overhyped, and in either case, we can trust that it will have consequences that we have not even considered or imagined. However, not being certain about the future does not relieve us of any moral obligation to investigate the issues we can anticipate as being reasonable possibilities or relevant. From the rapid pace of new technologies entering our lives, we can now appreciate that such technologies will have societal implications, for better or worse. Learning from history, we also now understand that we have a responsibility to consider these scenarios in advance to mitigate any harms, if not also to maximize benefits.

Discourse into the ethical and social dimensions of nanotechnology—so-called nanoethics—is therefore critical to guide the development of nanotechnology. This anthology provides a broad introduction to nanoethics, with contributions by some of the most respected names in the field.

1. WHAT IS NANOTECHNOLOGY?*

First, we need to be clear on what nanotechnology is before we can appreciate the ethical and social questions that arise therein. Nanotechnology is a new category of technology that involves the precise manipulation of materials at the molecular level or a scale of roughly 1 to 100 nanometers—with a nanometer equaling one-billionth of a meter—in ways that exploit novel properties that emerge at that scale. How small exactly is a billionth of a meter? As one journalist had put it, "If a nanometer were somehow magnified to appear as long as the nose on your face, then a red blood cell would appear the size of the Empire State Building, a human hair would be about two or three miles wide, one of your fingers would span the continental United States, and a normal person would be about as tall as six or seven planet Earths piled atop one another" (Keiper, 2003, p. 18).

Working at the nanoscale, it turns out that ordinary materials can have extraordinary properties about which we are still learning. At the nanoscale, quantum physics begins to play a key role in the behavior of materials, and the large surface-to-volume ratio of elements means that they are much more reactive. So, for instance, things that are brittle at the ordinary scale may possess superstrength at the nanoscale, and things that do not normally conduct electricity now might at the nanoscale, among other surprising changes to physical and chemical properties.

As a specific example of how properties change with scale, aluminum is used ubiquitously to make harmless soda cans, but in fine powder form, it can explode

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violently when in contact with air. But it is not only about the size: By precisely manipulating common elements at the nanoscale, scientists can fashion new materials. For example, carbon atoms bound together in a relatively loose configuration may create coal or graphite found in pencils; in a tighter configuration, carbon makes diamonds; and in an even more precise configuration, it creates carbon nanotubes, one of the strongest materials known, estimated to be up to 100 times stronger than steel at one-sixth the weight.

Given these new properties, nanotechnology is predicted to enable such things as smaller, faster processing chips that enable computers to be imbedded in our clothing or even in our bodies; medical advances for dramatically less invasive surgeries and more targeted drug delivery; lighter, stronger materials that make transportation safer and energy efficient (e.g., enabling us to travel farther into space); new military capabilities such as energy weapons and lighter armor; and countless other innovations. Some even predict that nanotechnology will extend our life span by hundreds of years or more by enabling cellular repair, which might slow, halt, or reverse the aging process (Freitas, 2004). And because nanotechnology may enable us to manipulate individual atoms—the very building blocks of nature—some have predicted that we will be able to create virtually anything we want in the future (Drexler, 1986, pp. 14, 58–63).

Today, however, research is still continuing on the basic science, so we are years and possibly decades away from most of the fantastic nanotechnology products that have been predicted, if they ever come to fruition at all. Nevertheless, companies are beginning to productize more of their research to create commercially viable applications based on nanomaterials. These nanotechnology products are quickly entering the marketplace today, from stain-resistant pants to scratch-resistant paint to better sports equipment to more effective cosmetics and sunblock.

In fact, Procter & Gamble, as one example of a leading consumer goods company, announced in 2006 that it is looking to incorporate nanotechnology into its products (O'Donnell, 2006). Other notable companies made similar statements recently as well, such as BASF's plan to invest US$221 million in nanotechnology research and development over just the next three years (James, 2006).

2. IS NANOTECHNOLOGY A DISTINCT DISCIPLINE?

Before we investigate the myriad issues in nanoethics as covered in this anthology, we must first address a persistent meta controversy surrounding the status of nanotechnology itself, which casts questions about the legitimacy of nanoethics as its own discipline.

Despite massive spending in nanotechnology by corporations and countries—the U.S. government alone is expected to invest over US$1.2 billion in 2007 through its National Nanotechnology Initiative (NNI)—there is still a debate over whether "nanotechnology" is an independent or new science, so unique from other fields that it should require or deserve its own category or moniker. Some have complained that nanotechnology is *not* distinct from other sciences—or at least its boundaries might be somewhat hazy—and therefore its ethics must be equally ill-defined. Others argue further that nanoethics is not an interesting or distinct field because it does not raise any

new questions that are not already considered by, say, bioethics or computer ethics. In the remaining part of this introduction, we will argue that nanoethics should be afforded legitimacy, and we will also set some context for the essays that follow in this anthology.

At first glance, this controversy seems strange, given that so much is being invested in nanotechnology worldwide. If nanotechnology were not a distinct science, then why does it command so much attention and money? Many people, however, believe nanotechnology to be merely a convergence or amalgamation of several existing disciplines, such as chemistry, biology, physics, material science, engineering, information technology, and so on; claims like this have at least some truth.

As an example of biology inspiring engineering, scientists are creating artificial noses with nanosized sensors which can accurately "sniff" out smells that are otherwise imperceptible to humans (Nanomix, 2006). Similar work has been done to create artificial compound eyes (Jeong, 2006), borrowing from nature's design of insect eyes, as well as artificial skin (Maheshwari and Saraf, 2006) using nanomaterials to mimic the sensitivity of touch. And entire research centers have been created to explore this rich field, including Georgia Institute of Technology's Center for Biologically Inspired Designs (CBID) and the University of California at Berkeley's Center for Interdisciplinary Bio-Inspiration in Education and Research (CIBER).

But does drawing from other scientific areas preclude nanotechnology from being a field in its own right? Consider the similar and ongoing debate in philosophy of science whether chemistry, biology, and other established sciences can be reduced to simply physics. One line of thought is that these other fields operate the way they do given the laws of physics that govern how atoms, molecules, and their dependent structures interact with each other and the world. But no matter which side of the debate we take here, no one on either side actually suggests that chemistry and biology, for example, do not constitute their own disciplines; so it would be inconsistent to insist that nanotechnology—even if it substantially borrows from other fields—cannot be meaningfully discussed or investigated as a field of its own. As with these other scientific fields, nanotechnology seems to bring something unique to the discussion that merits recognition as its own field; in other words, it is greater than the sum of its parts. At the least, it appears to be the first to integrate otherwise-distinct fields into this one area.

Another source of the controversy about nanotechnology's ontological status comes from various opinions on when the field was first created. Many point to Richard Feynman in 1959 as the founding father of nanotechnology, others to Norio Taniguchi in 1974, and sill others to K. Eric Drexler in 1986. But as the following statement from physicist Richard A.L. Jones (2006, p. 995) indicates, a growing sentiment in the field points to a much more recent, and unlikely, person:

> Perhaps a better candidate to be considered nanotechnology's father figure is President Clinton, whose support of the USA's National Nanotechnology Initiative converted overnight many industrious physicists, chemists and materials scientists into nanotechnologists. In this cynical (though popular) view, the idea of nanotechnology did not emerge naturally from its parent disciplines, but was imposed on the scientific community from outside.

So depending on whom one speaks to, nanotechnology might have been first established anywhere from 1959 to 2000. And if former U.S. President Bill Clinton can plausibly claim the title "father of nanotechnology," then it is no wonder that many scientists and other experts regard nanotechnology as merely a political construct or a marketing buzzword invented to resuscitate old disciplines that appear to be losing ground, particularly in the United States, where the decline of science graduates has been well documented.

3. WHAT IS THE STATUS OF NANO*ETHICS*?

Whether or not nanotechnology is a fabricated area of study and indistinct from other scientific fields, which is not a question we intend or need to answer here, we can already now understand some of the controversy surrounding the status of nanoethics: If nanotechnology is just a fancy term for a range of other fields, then ethical and social questions arising from nanotechnology would seem to be the same kind of questions already raised in these other fields.

Indeed, one critic, Sören Holm (2005), asks:

> It is difficult to specify exactly what could make an area of technology so special that it needs its own ethics, but a minimal requirement must be that it either raises ethical issues that are not raised by other kinds of technologies, or that it raises ethical issues of a different (*i.e.*, larger) magnitude than other technologies. Is this the case for nanotechnology?

Philip Ball (2003), science writer *for Nature*, elaborates on this point:

> Questions about safety, equity, military involvement and openness are ones that pertain to many other areas of science and technology [and not just nanotechnology]. It would be a grave and possibly dangerous distortion if nanotechnology were to come to be seen as a discipline that raises unprecedented ethical and moral issues. In this respect, I think it genuinely does differ from some aspects of biotechnological research, which broach entirely new moral questions.

These are fair and forgivable concerns, and current research in nanoethics might even support this position. For instance, in shrinking down devices, nanotechnology is expected to create a new class of surveillance devices that are virtually invisible and undetectable, thereby raising privacy questions; however, according to critics, these questions do not appear to be new but simply an extension of the current debate about privacy. Nanotechnology is also predicted to play a critical role in developing human-enhancing technologies, such as cybernetic body parts or an exoskeleton that gives us superhuman strength or infrared vision; however, society has already been discussing the ethics of such technologies with respect to biotechnology and cognitive sciences. In the more distant future, some people envision nanotechnology's role in extending the human life span to the point of near immortality; but the question of whether we want or should live longer or forever—as well as its political, economic, and social impacts—does not seem dependent on nanotechnology per se.

On the other hand, some issues are emerging that appear unique to nanotechnology, namely the new environmental, health, and safety (EHS) risks arising from nanomaterials. For instance, research studies suggest that some nanoparticles are directly harmful to animals, and because they can be taken up by cells, they might enter our food chain to unknown effects on human health (Clithrani et al., 2006). Other research asks whether carbon nanotubes will be the next asbestos, since both have the same whiskerlike shape that makes it so difficult to purge from our lungs if inhaled (Gogotsi, 2003). And the flip side of creating superstrong materials such as carbon nanotubes is their fate at the end of a product life-cycle: Will these materials persist indefinitely in our landfills, as is the case with Styrofoam or nuclear waste (Colvin and Wiesner, 2002)?

One new ethical issue is perhaps not enough to legitimize the independence of nanoethics. And in fact, we could perhaps reduce even this apparently unique issue to belong to another discipline, such as engineering or environmental ethics that questions the wisdom of creating products that do not decompose. But there are other good reasons for believing that nanoethics deserves our attention, especially if we believe that nanotechnology itself is a distinct field.

First, nanoethics also commands a significant amount of attention and money, though far less than the amount poured into nanotechnology. In the United States, the NNI currently sets aside approximately $43 million for the "identification and quantification of the broad implications of nanotechnology for society, including social, economic, workforce, educational, ethical, and legal implications." [1] So it would certainly be strange that there would be so much invested by various government agencies, universities, publishers, and other organizations globally if nanoethics were not important as its own field. Of course, there is a possibility that all these organizations and scholars have been fooled because nanotechnology and its ethics allegedly do not exist, but that appears more unlikely than correctly and reasonably identifying nanotechnology as a meaningful area of its own. And at any rate, the point is perhaps already moot given that nanoethics and nanotechnology have taken a life of their own.

Second, it is unclear why we should accept the litmus test that, to be counted as a new discipline in its own right, nanoethics must raise either new or larger ethical issues than already raised by previous technologies. Looking again at chemistry, for example, whether or not we can properly categorize it as a subset of physics (because chemistry arguably does not raise new questions that cannot be answered by physics), there is no existential dilemma about its status as a legitimate category; no one is proposing to do away with the name or reorganize the university chemistry laboratory under the physics department. Therefore, it is unclear why such a dilemma would exist with nanoethics, even if nanoethics can be wholly contained within another field or set of fields.

Third, to the extent that nanotechnology is a convergence of many disciplines in the first place, it should be no surprise that nanoethics is a convergence of many ethical areas as well. So even if a new area of ethics requires raising new or larger issues, that standard may no longer apply with the discovery or creation of nanotechnology. Rather, nanotechnology might uniquely draw from other disciplines like no other discipline before it.

Rather than an argument that nanotechnology is not a distinct discipline because it does not truly break new ground, nanotechnology seems to represent a new pinnacle in our understanding about the world. We are finally able to integrate our learning from a wide range of fields (e.g., physics, chemistry, biology, engineering, and others) to create profoundly useful applications which can be categorized under the moniker of nanotechnology. So just as, for example, architecture can be regarded as a convergence of aesthetic design and engineering, so too can nanotechnology and nanoethics be rightfully acknowledged even if they are a convergence of other fields. Again, the whole of nanotechnology is arguably greater than the sum of its parts because of the new synergies or interplay between the various parts.

Fourth, nanoethics *does* seem to raise new ethical issues insofar as it adds a new dimension, or "flavor," to current ethical debates. For instance, though privacy may be a relatively old debate, the possibility of creating near-invisible and undetectable devices did not meaningfully exist prior to nanotechnology, so nanotechnology brings a new urgency and reality to the issue of privacy. Further, nanotechnology may help shift the privacy debate in an entirely new direction: Whereas worries about unauthorized or unwanted surveillance have traditionally focused on a few agencies, notably governmental organizations, the possibility of cheap, ubiquitous tracking devices "decentralizes" surveillance and changes the terms of the debate.

Nanotechnology likewise is putting a new spotlight and elevating other ethical issues, such as related to human enhancement or longevity. Even something as apparently tangential as the ethics of space exploration and settlements—or space ethics—now overlaps with nanoethics because only with nanotechnology does the possibility of extended space flights and terraforming (i.e., the ability to create a hospitable atmosphere and environment on another planet or moon) become plausible.

Finally, it is not even clear that the question of whether nanotechnology and nanoethics are disciplines in their own right has any real consequence to our discussion here. That is, even if we agree that both are not distinct disciplines, it does not follow that nanoscientists and nanoethicists should stop conducting their work, nor does it follow that the massive levels of funding for both nanotechnology and its social impact should be diminished. Rather, it seems that, even if nanotechnology and nanoethics were each comprised of overlapping, established areas in science and philosophy, they nonetheless are comprised of *something*. Furthermore, it is this constitution that legitimizes the disciplines, not their entitlement to necessarily proprietary issues which continue to exist even if the associative terms of nanotechnology and nanoethics are successfully challenged.

In other words, the debate seems to be more semantic than substantive; this debate is not an obstacle to intelligently discussing either nanotechnology or nanoethics. Even if we agree that both borrow substantially from other areas and therefore should not be considered as distinct disciplines in their own right, we can nevertheless stipulate that we mean nanotechnology to be simply short-hand or abbreviations of some longer and unwieldy (yet technically accurate) descriptors such as, for instance, the development, characterization, and functionalization of materials based on nanoscale research in chemistry, physics, biology, engineering, materials science, and so on. And perhaps nanoethics means something like the ethical, social, environmental, medical, political, economic, legal issues, and so on, arising from nanotechnology (as defined by the preceding) or however we want to precisely define these terms. Regardless, the point is that these terms can be stipulated as is linguistically useful to capture actual investigation in the world; the conceptual independence of those investigations does not deprecate the enterprise.

4. ISSUES IN NANOETHICS

If nanoethics is a distinct discipline—or even if it is not, but we still understand what the term describes—then what are its issues? Again, controversy surrounds even this question. If we are conservative and only acknowledge those issues that will likely or possibly arise from current lines of research in nanotechnology—which is primarily focused on the discovery and applications of new nanomaterials—then nanoethics certainly covers some of the issues mentioned above: EHS impacts, privacy, human enhancement, as well as global security (since the military is a major driver of nanotechnology research to such a degree that some fear a new arms race) (Lawlor, 2005). Other relevant issues may include research ethics (if some research seems to dangerous to publish or pursue), intellectual property (if today's patent-grab and processes stifle innovation), and humanitarianism (why we are not doing more to solve poverty, hunger, energy, clean water, and other problems through nanotechnology).

But more imaginative people, such as Drexler, postulate a more advanced form of nanotechnology in our future—sometimes called "molecular manufacturing" —by which we can position individual molecules with exact precision. The difference between how we create nanomaterials today (e.g., carbon nanotubes) with precisely positioned molecules and molecular manufacturing is the difference between engineering and chemistry. Carbon nanotubes rely on bulk chemical processes and reactions at high temperatures to create the desired configuration of carbon atoms, which is similar in principle to the usual chemistry experiments in which various elements and compounds are thrown together in bulk and shaken up to predictably create a batch of new compounds.[2] In contrast, molecular manufacturing is envisioned to be more like a construction job, grabbing single atoms and deliberately attaching them to others to form the desired structure. This high degree of precision, without messy chemical reactions, would in theory enable us to create practically any possible object.

This line of thought is instantiated by a detailed speculative design for a "nanofactory" that might be a portable or desktop device—a black box of sorts—that can create virtually any object we want, from cakes to computers. To oversimplify things, raw materials, say dirt and water, might go in one end, and a raw steak or perhaps an unmanned fighter jet might come out the other. While this may sound like science fiction, the theory behind it seems sound: If we can precisely manipulate molecules and physical objects are only made up of molecules, then why wouldn't we be able create any physical object we want?

If this still sounds far-fetched, consider the similarities with today's 3-D printers that can print out plastic or ceramic objects one thin layer at a time. No longer limited to producing only manufacturing prototypes and machine parts, 3-D printers recently broke new ground in printing out fully functional and fashionable footwear, among an expanding and impressive array of print-on-demand products (Engineering & Management Services, 2006). The nanofactory operates by the same concept, except with much more precision and a mix of different materials.

So if advance nanotechnology is in our possible future, then it raises truly unique and serious questions; following the litmus test considered earlier, it may strongly support nanoethics as a legitimate discipline. Molecular manufacturing appears to have the potential to wreak havoc on our economic system where millions might lose their jobs overnight in the manufacturing and other industries and perhaps eliminating the need for global trade. If people and terrorists can easily create weapons with personal nanofactories, that may threaten global security and the lives of millions or billions of others. Some of the more fantastic issues are also related to advanced forms of nanotechnology, if not directly to molecular manufacturing, such as longevity or immortality, space settlements, and artificial intelligence.

However, because these issues are tied to advanced forms of nanotechnology—the plausibility or likelihood of which is contentious among mainstream scientists—critics may believe that it is inappropriate or premature to consider such issues now. But we do not need to resolve that question here in order to take seriously the ethical and social issues advanced nanotechnology might raise. Even if advanced nanotechnology is a remote possibility, its scenarios appear so disruptive that they merit consideration. A simple cost–benefit analysis might justify spending $5 million over the next decade to study and perhaps mitigate a scenario that has a 1 percent possibility of causing $1 billion of economic disruption, which has an expected negative utility or value of $10 million. (These figures are purely hypothetical but appear to be in a plausible range.)

As an analogy, if decoding the human genome had just a small likelihood of, say, leading to employment or insurance discrimination based on a person's genetic predisposition, we would then still expect that scenario to be important enough to warrant an investigation; in fact, such ethics research has been ongoing in the last decade. Or more abstractly, if a political course had even a bare possibility to leading to a devastating war, costing the lives of millions, it seems that we are morally obligated to seriously consider that possibility, no matter how remote.

With nanotechnology, so much is still unknown that scientists are really not in a position to accurately forecast what is likely or not and by when. Some believe molecular manufacturing is inevitable; others disagree. But again, if history is any guide, most of our mid- and long-term predictions about technology will be overly optimistic or pessimistic. Many things we have today were once believed to be impossible or impractical—such as gas streetlights, residential electricity, telephones, highways, radio, airplanes, rockets, and even today's ubiquitous personal computer—so perhaps the prudent course is to treat most of these possibilities as reasonable until proven otherwise.

Even near-term challenges in technology—such as how to shrink the smallest computer processor even further—seem difficult if not intractable to us *right now*, but somehow we find a way to sustain Moore's law, which posits a doubling of processing power every 18 months and which some predict will soon fail to hold (Zhirnov et al., 2003). Technology is moving rapidly indeed and may be limited now only by our imagination, so it is not implausible to think any technical challenges associated with molecular manufacturing might be eventually solved.

Indeed, scientists have recently announced creating a blueprint, and then a working prototype, of an "invisibility cloak" —essentially a heavy blanket created with nanomaterials that can bend, instead of reflect or diffuse, light and other electromagnetic waves around the object cloaked, just as water might flow around a rock in the middle of a stream (Pendry et al., 2006). (This, too, seems to give rise to ethical issues associated only with nanotechnology, namely privacy and security, if we are still interested in identifying unique issues.) But as late as 2006, such innovations would have been thought as merely science fiction, consigned to fantasy worlds such as Harry Potter's. Again, throughout history and even now, ideas that have been dismissed as unworkable somehow become reality, despite their technical challenges, so it is not irrational to treat molecular manufacturing, space settlements, and so on as a real possibility absent compelling evidence to the contrary.

Furthermore, no matter how speculative some of these scenarios seem to be, they provide a useful platform to test our moral principles as at least "thought experiments," which is a commonly accepted practice in ethics. For instance, no one thinks that anyone would plausibly be kidnapped and surgically connected to a famous violinist—the premature detachment of whom would lead to the violinist's death—but this hypothetical example isolates and tests out intuitions in Judith Jarvis Thomson's discussion about the moral permissibility of abortion (Thomson, 1971).

Also, few actually question the wisdom of sending spiders into outer space on the grounds that spiders do not exist and may never exist in space (unless we introduce them into space); yet this sort of experiment is useful to study the relationship between gravity and a spider's ability to orient itself and spin webs by isolating gravity as a variable. As it applies to nanotechnology, even if cybernetic people never exist, the possibility of human enhancement provides a platform, or thought experiment, to explore intuitions related to human dignity, personal identity, and other concepts.

Given all this controversy, it should also be no surprise that the questions in nanoethics seem ill-defined as compared to, say, ethical questions in decoding the human genome, as some critics have pointed out (Harris, 2006). Nanotechnology itself is fractured into different approaches or visions, each of which raises it own questions, so, until there is a consensus on what nanotechnology is and will be, it will be difficult to gain a consensus on a plausible set of issues for nanoethics. Moreover, the overlap of nanotechnology with other disciplines—and the overlap of nanoethics with bioethics and other areas—contributes to this challenge.

5. NANOTECHNOLOGY: A MAELSTROM OF ETHICAL AND SOCIAL ISSUES

That said, it is still important to look at both near-term and speculative issues in nanoethics for reasons previously stated. This anthology will present some of the most exciting ethical debates emerging from developments in nanotechnology and by some of the most prominent names in the field.

In Part I, in addition to this introduction, we start the debate in nanoethics with an infamous article by Bill Joy, co-founder of Sun Microsystems, which takes a dystopian view about our future in a technology-dominated world. A counterpoint to this worry is provided by the U.S. Congressional testimony of acclaimed technology inventor Ray Kurzweil, who has been called the "rightful heir to Thomas Edison" by the media, about the implications of nanotechnology on ethics and society.

In Part II, we set some context for the issues with background about where nanotechnology is predicted to help society and individuals the most; how nanotechnology recently exploded onto the national and global scene with the U.S. NNI; and what the controversy or debate is surrounding nanotechnology itself in more detail.

Part III addresses one of the most immediate or near-term issue in nanotechnology: ethical considerations in research and preparing for the new era of nanotechnology. On the frontlines of nanotechnology, scientists play a pivotal role—even if reluctant or unintentional—in how their creations impact the world. We start here with a look at the history of technological revolutions in order to glean any lessons, and we also take a closer look at the role of government and science in driving the nanotechnology revolution. We continue with discussions about the role of complexity, uncertainty, and the so-called precautionary principle (the prudential guideline in science) in nanotechnology research.

In Part IV, we look at the next area of concern as nanotechnology research is applied to the real world: its impact on the environment and health. Nanotechnology is predicted to have broad benefits in the field of medicine; this part examines how our concept of medicine might then change as well as the ethical issues surrounding the use of nanotechnology for purposes other than therapy, such as for human enhancement. We also examine the impact of nanotechnology on the environment and nature.

In Part V, because there is much concern today about regulating nanotechnology's apparent risks to the EHS, our discussion naturally transitions to issues in regulation and public policy. Returning to Chapter 2, we look at alternatives to relinquishment as ways to deal with apocalyptic technological threats. This leads into a broader discussion about guiding nanotechnology in the framework of a democracy. And we take a critical look at current initiatives worldwide to engage the public and other stakeholders in the development of nanotechnology.

Part VI investigates specific policy issues in nanotechnology and society. As a top concern, we can anticipate privacy issues in nanotechnology by looking at a related debate with radio frequency identification (RFID) devices. Nanotechnology is also expected to profoundly increase military capabilities, thereby raising associated ethical issues. Of course, for countries such as the United States, much of the innovation in nanotechnology—including military superiority—may occur in other global regions, given the well-covered decline in science education in the United States, so we also explore educational reform specific to nanotechnology. With an eye still on global affairs, we consider the impact and potential of nanotechnology for developing countries.

Finally, in Part VII, we consider more temporally distant and theoretically speculative issues. Again, molecular manufacturing would seem to lead to massive disruption if it becomes a reality. We also consider the ethics of space exploration, artificial intelligence, and life extension—in which nanotechnology is expected to play an essential role.

This collection certainly does not address every relevant issue in nanoethics, but it gives a sense of the depth and diversity of ethical and social issues in nanotechnology and provides a starting point for further discussions and investigations. The chapters also do not necessarily reflect the viewpoints of the editors or publisher, but only of their authors, whom we thank for their generous contributions. As nanoethics gains momentum, we hope to see more industry experts, academics, and the broader public engaged in this critical field—helping to guide science and humanity to a better future.

NOTES

1. See the U.S. National Nanotechnology Initiative website. http://www. nano.gov/html/society/home_society.html, accessed November 13, 2006.
2. Other methods also exist to create carbon nanotubes, e.g., using high-pressure gas or electricity or lasers, but they do not change the point here that existing methods are radically different and less precise than molecular manufacturing.

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