TINY ETHICS FOR BIG CHALLENGES

Calling for an Ethics of Nanoscale Science and Technology

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The emerging capability to observe and organize matter at the atomic level has captured the attention of government, the science and engineering communities, and the general public. Huge allocations of financial and personnel resources are now being poured into ventures of research, exploration, and development with the hope that nanoscience will provide the knowledge and skills required to achieve precise manipulation and control over matter. Applications projected for this new technology span a broad range, from the design and fabrication of new membranes, to improved fuel cells and new medical prosthesis techniques, to tiny, intelligent machines whose impact on humankind is unknowable. Any endeavor that could bring such dramatic new capabilities to our material existence also brings along ethical dimensions to be considered. An ethics of nanoscale science and technology is called for. Conventional rule-based, prescriptive engineering codes and guidelines are necessary but insufficient for the ethical development of nanotechnology. This article suggests that as we consider the social and ethical dimensions of nanotechnology development; inclusion of analyses of the role of human cognition is essential. Cognition is formed from sensory-motor experiences, beliefs, ambitions, and ideas; scientific research and technological development are expressive of these elements of cognition, ultimately in the technological goods we use and consume. By understanding the role of imagination, which is imbedded in the cognitive process, we will be better equipped to glean the meaning of the development of nanotechnology and to direct that development toward conscientious and humanitarian ends.

A NEW TECHNOLOGY

Nanoscale science and technology—the study, control, manipulation, and assembly of multifarious nanoscale components into materials, systems, and devices to serve human interests and needs—are rapidly developing, relatively new technological endeavors. Similar to the birth of the nuclear age and the space program of decades ago, nanoscale science and technology are potentially revolutionary, new frontiers in science and engineering. Claims about nanoscience and nanotechnology state that new knowledge and abilities that come from observation and replication of behaviors in nature at the nanoscale will open a whole new dimension of material possibilities. Scientists and engineers, policy makers, and government and business leaders attest to the incredible promise that through nanotechnology previously unimaginable and inaccessible material possibilities and economic potentials will become realities.

THE SOCIETAL IMPACT OF NANOSCALE SCIENCE AND TECHNOLOGY

Through the new tools at our disposal, human hands are for the first time able to touch atoms themselves, move them, rearrange them, and reconfigure them with attachments to laboratory-derived molecules. Where might such awesome abilities lead us? What will it mean when nanoscience and

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nanotechnology enable us to achieve our desired goals? Let us assume for the moment that the claims of the wonderful new capabilities to be realized through nanoscale devices and procedures are realistic. What we do then with the knowledge gained and how we pursue these newly acquired abilities may well determine the changing substance of our material, social, cultural, economic, moral, and perhaps even spiritual lives. In other words, if humans succeed in the projects of nanoscience research and nanotechnology development, then human life may be facing radical, perhaps wonderful, possibly unalterable, unpredictable changes. If we are to face those changes successfully and to fully embrace the advantages while averting the dangers of serious unanticipated consequences, then we need to proceed with perpension. As a society, it is our moral responsibility to pursue both a conscious and a conscientious relationship with the technologies we develop. It would be a mistake to passively watch the development of nanotechnology, or to engage and support it, without also actively engaging moral deliberation about its direction and purpose. That is a daunting challenge. The technical aspects of nanoscience are still being worked out and to a large degree represent vast, unpredictable results. Scientists don't really know what to expect from their studies. Engineers can't quite say what will come of their designs. Likewise, the social and ethical implications of nanoscience and nanotechnology are difficult to anticipate.

At first pass, the pursuit of nanotechnology could be likened to a trek through a previously impenetrable, vast, and wondrous forest made up of groves of unclassified trees and unfamiliar species of life living in habitats never before seen; the age-old quest for the riches that come from understanding the novel. The journey into this dense forest would be exciting but treacherous without signposts along the way. But no one has gone into this forest before in order to place those signposts. One would have to trust their ability to anticipate and recognize danger, to know when to change directions, whether to proceed and when, if ever, to turn back. But the analogy goes only so far. It represents a simple exploration of an existing material reality with curiosity, the thrill of challenge, and the search for new knowledge being its primary goals. What nanotechnology actually represents is exploration for the sake of control of that material reality. It entails observation but also includes manipulation, re-creation, experimentation and alteration of the world it is observing.

NANOSCALE SCIENCE AND TECHNOLOGY, A WHOLE DIFFERENT ENDEAVOR

It is often argued that there is really nothing distinctive about nanoscience, that any new scientific and technological innovation requires moral deliberation, and that the only real significance of nanotechnology is its scale. In addition, it is claimed that, while the exploration may be in a teeny, tiny forest, the flora and fauna are all the same. The argument proceeds to claim further that, because nanotechnology is really not a novel endeavor, there is no need to react with special concern over the possible ethical implications of its development since we already have a rich ethical heritage from which to proceed in our moral deliberation about nanotechnology.

The facts of the argument are indisputable; nanotechnology is developing from existing science, only at a greatly reduced scale. What is disputable is the significance of that scale. Nanotechnology represents an increasing ability of human beings to control and manipulate matter. Greater and more precise control of matter means greater access to many forms of power. Among them is the power to alter the human experience for better or for worse; the exponential decrease in the size of matter we can touch, move, and otherwise influence, conversely increasing our capacity to change our world, our bodies, our resources, our ecosystems, our political systems, and so on. Furthermore, with nanoscience and nanotechnology in particular, formerly distinct scientific disciplines are merging, and basic researchers are working in close collaboration with engineers with particular outcomes in mind. Government and private funding agencies, which largely support this initiative, have very clearly stated directives connected with the funding. Likewise, the principal investigators whose research is paramount to our national efforts are individuals with their own internal sources of motivation. The question of why we are pursuing this particular branch of new knowledge is an important one if we are committed to conscientious development of nanotechnology. Besides, the argument about "similarity" offers no adequate reason to proceed without examination in unbridled technological development. Instead, it offers the allure of security about the enormous potential that new technological developments have to alter human life.

NANOTECHNOLOGY AMBITIONS AND DREAMS

The ambitions and dreams of nanotechnology have been expressed in various ways, with an intriguing array of descriptions and applications ascribed to it. The National Nanotechnology Initiative describes it as "the ability to work at the molecular level, atom by atom, to create large structures with fundamentally new properties and functions" [1]. The National Science Foundation's (NSF's) *Societal Implications of Nanoscience and Nanotechnology* describes 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 direct assembly of atoms and molecules, and the emergence of entirely new phenomena in chemistry and physics" [2]. Endorsements of the National Nanotechnology Initiative refer to the possibilities of miniaturized drug delivery systems and diagnostic techniques, positive environmental impacts through drastic reductions in energy use, extending and repairing deficits in the human senses, and security systems smaller than dust. Senator Barbara Mikulski says, "We are poised to take the next major leap into the future where the possibilities are endless" [3]. In *Engines of Creation* [4] and *Unbounding the Future: The Nanotechnology Revolution* [5], Eric Drexler describes how molecular assemblers could make possible low-cost solar power, cures for cancer and the common cold, cleanup of the environment, inexpensive pocket supercomputers, accessible space flight, and restoration of extinct species. The potential list of applications is as endless as our imaginations and as exhaustive as our motivations for greater control over our material existence.

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THE “HYPE” DIVERSION

Some people dismiss such claims as “hype” and argue that as such, these claims are not representative of scientifically grounded reality. Scientists such as Smalley, Kurzweil, Drexler, Joy, and others dispute what will actually be the likely result of our abilities to build devices and enact various technological processes at such miniscule sizes. For example, Richard Smalley disputes the reality of self-replicating devices [6], while Eric Drexler presents such phenomenon as a likely outcome of nanoscience research. There is a great deal of speculation and debate over outcomes and applications, but no one seems to really know for a fact if the machines we create will be able to do such things as “scavenge molecules from their environment to reproduce themselves, creating an unlimited number of molecular robots that can perform feats of engineering that defy our imagination” [4].

In addition, some social theorists urge us to be skeptical about this future of nanotechnology, for both good and ill. Armstrong points out that “the societal impacts (almost certainly overwhelmingly benign, but possibly occasionally adverse) depend very much on which technology is involved, and *even more so on which application is involved.*” He asks:

> May it be that we have promised too much in the way of a nano-revolution, and aroused unease in the community at large? Are more and more areas of scientific research going to be funded with these precautionary measures attached? ...In view of the miserable track record in long range forecasting that has been run up by scientific and technical experts over the years, why would anyone take seriously what we have to say about societal impacts decades into the future of any of the emerging new nanotechnologies? [7].

Feller gives several examples of experts who failed to see the future, or who saw a future that didn’t occur (von Neumann’s prediction of free energy, or Sarnoff’s of atomic-powered automobiles by 1980), commenting that they “point to fundamental difficulties in predicting the what, where, when, and how of asserted major scientific and technological advances, however carefully and thoughtfully crafted the projections” [8]. Crow and Sarewitz point out that if nanotechnology is, as is claimed, going to “revolutionize manufacturing, health care, travel, energy supply, food supply, and warfare, then it is going, as well, to transform labor and the workplace, the medical system, the transportation and power infrastructure, the agricultural enterprise, and the military.” And they point out that none of these sectors, because they involve primarily humans and their interaction, will be revolutionized without significant difficulty [9].

To launch a counter argument to that claim, one need only to look at how the Internet and World Wide Web have rapidly revolutionized our access to and exchange of information, permanently and profoundly changing many elements of our personal and social lives. But the point here is not to engage that argument; rather, to suggest that while efforts to predict the future and the criticisms of these efforts may be worthy, they can also be inappropriately used to thwart efforts toward creative ethical discourse and deliberation about our future. As dismissive rationales for inaction, they become conceptual roadblocks to moral deliberation. In fact, disagreements over which future technologies are myth and which are realistic, such as the debate over whether it will truly ever be possible to develop self-assembling devices, begin with the assumption that technology is a willful, evolving reality rather than a directed, socially constructed one. It assumes that technology evolves separately from human imagination, ambitions, and dreams when in fact technology is by its nature a social construction, irrevocably intertwined with our conceptualizations of who we are in relation to our perceived material reality. As David Abram writes, “Indeed, the ostensibly ‘value free’ results of our culture’s investigations into biology, physics, and chemistry ultimately come to display themselves in the open and uncertain field of everyday life, whether embedded in social policies with which we must come to terms or embodied in new technologies with which we all must grapple” [10]. This said, let us now discuss which ethical system will allow the development of nanoscale science and technology to be directed toward conscientious—and humanitarian—ends.

CODES OF ETHICS: INSUFFICIENT NECESSITIES

The central argument of this article is that, despite the mystery and relative unpredictability of where nanoscience and nanotechnology may ultimately take us, its development should nonetheless be accompanied by discourse among all potential stakeholders about the beliefs, values, and aspirations that are fueling and directing its evolution. We should sort out now what we want of our technologies, which persons shall have access to them, and what goods and harms may arise as a result of our efforts at the nanoscale. The professional codes that guide engineers and scientists are a necessity. These codes are, however, insufficient for addressing some aspects of the development of nanotechnology. I will try to defend this argument and, by referring to the work of philosopher Mark Johnson, I will attempt to outline the limitations of any rule-based morality.

Joy has proposed that we "limit the development of technologies that are too dangerous, by limiting our pursuit of certain kinds of knowledge." He calls on scientists and engineers to adopt a strong code of ethical conduct, resembling the Hippocratic oath, and to have the courage to enforce this code upon others [11]. This is a natural reaction many of us have had to the possibilities of threat and harm that arise with notions of nanoscience going wrong. And there are good reasons to put codes in place, if doing so serves as the foundation for an agreed-upon system of expectations about behavior, in the face of particular circumstances that may arise with molecular nanotechnology. But professional codes cannot address the deeper philosophical questions of why we are pursuing molecular nanotechnology as we are, and what deep-seated beliefs are stimulating these endeavors. Codes may tell us what we are expected to do, but they will not help us to understand ourselves, especially when the codes seems to conflict with personal reasons, desires, or understandings. And they do not help us to understand where we got the notion that precise control of our material existence is a good to be pursued, over and above other possible scientific aims.

Johnson claims that human moral understanding is fundamentally imaginative, with metaphor being one of the principle mechanisms of imaginative cognition. Classical, rule-based moral reasoning, which consists primarily in discerning the appropriate universal moral principle that tells us the right thing to do, presupposes a way of reasoning that is incongruent with actual human thought processes. That is why, he says, there is so often such deep tension between the view of one's moral task, on the one hand, and the way people actually experience their moral dilemmas, on the other. For Johnson, "the quality of our moral understanding and deliberation depends crucially on the cultivation of our moral imagination" [12]. He sites the now-infamous 1978 Pinto case as a sad example of how our conventional ethics reasoning failed us by replacing metaphor-based reasoning with the illusion of an infallible source of moral reasoning—that of rule-based cost benefit calculations. Johnson argues that it is metaphor that "lies at the heart of our imaginative, moral rationality, without which we are doomed to habitual acts." And because metaphor is one of the principle mechanisms of imaginative cognition, he wants us to expect our common moral understandings to be deeply metaphorical, too.

Here are the connections, as I see them, between professional engineering codes and guidelines, the quest for an ethics of nanotechnology, and Johnson's thesis. First, the codes are distinctively morally rule based and prescriptive. They are functionally adequate for the regulation of actions along specific expectations according to agreed-upon values, systems of exchange, and acceptable behavior. However, they are not effective as a tool for ascertaining the essential qualities of personal or institutional morality. They cannot be that because, as Johnson writes, there is no such thing as a "universal, disembodied reason that generates absolute rules, decision-making procedures, and universal or categorical laws by which we can tell right from wrong in any situation we encounter" [12, p. 5]. The rich complexity of morality cannot be reduced to following rules. The codes are a management tool. They are not a moral guidepost. (For further discussion and a very different perspective on professional codes of ethics in engineering, see the writing and research of Michael Davis.) The most they can do in regard to the ethical development of nanoscience and engineering is to prescribe to an individual engineer or an engineering company what types of actions are viewed as permissible, endorsed, and expected within the profession. That is not enough.

Moral reasoning is directed towards solving problems about how we should act in given situations, and then justifying these actions to significant others. In engineering and science, these others include one's peers, as well as the government and general public. If the challenges of addressing the ethical problems of technology are oversimplified into rule-based prescriptions, then they are likely to fail in their purposes of directing ethical behavior. Real human experiences—especially in unfamiliar domains of inquiry, such as molecular nanotechnology—are complex, unpredictable, and metaphoric by nature. Johnson writes, "Since our experience is never static, and since evolution and technological change introduce new entities into our lives, we are faced with novel situations that simply were not envisioned in the historical periods that gave rise to our current understanding of certain moral concepts. Metaphor is our chief device for extensions from prototypes to novel cases" [12, p. 195]. Molecular nanotechnology counts as a novel case. Its ethical development requires recognition of the metaphoric basis of moral inquiry.

Any new scientific exploration—especially when fueled by federal and private funding agencies, and by the professional motivations of innovation and enterprise—is subject to metaphorical construction. In other words, imagination and metaphor are the stuff such explorations are made of. Consider the space program; its language is filled with event-structured metaphors of movement towards a location. Through the use of metaphor, we are deeply inspired and highly motivated by the imagined possibilities of what those remote locations might offer.

What matters most in morality is not the discovery and application of absolute moral laws (if they even exist). Human cognition doesn't function in that way. What matters most is the moral sensitivity that comes from cultivation of moral imagination. It is only through use of this imagination that broader narrative frameworks leave room for humans to more fully grasp the moral and symbolic meanings of their actions. As Johnson says, "We can almost never decide (reflectively) how to act without considering the ways in which we can continue our narrative construction of our situation." Further, as "selves in process," people exist as complex, self-transforming biological organisms in "interactions with our physical, interpersonal, and cultural environments" [12, pp. 160–161].

What the human mind actually does when faced with an ethical challenge is not to immediately decide from a selection of rules to follow; but rather, it imagines various narrative extensions to see how the story we are living might proceed, depending on which course of action we may choose. Failing to exercise that imaginative process by reliance on codes of behavior leaves us short of capturing actual human experience and causes us to overlook important elements of problematic situations when they arise.

Consider the following hypothetical example. An electrical and a biomedical engineer find a way to create a nanoscaled device that, when attached to the cerebral cortex, triggers a countering chemical–electrical response to the stimulations that cause depression. These engineers see the incredible social good that may come from the use of this highly sensitive device and are excited about the prospects for it to eliminate mental depression from the human condition. Which professional engineering ethics code would give them a clear direction on whether and how to proceed with further development? All of them, potentially. But without the exercise of moral imagination, none of the codes are capable of helping these two collaborators understand the deeper, profound social, cultural, and spiritual implications of their device.

How about if they were to use a set of guidelines, specifically developed for application to molecular nanotechnology? The Foresight Guidelines are written for this purpose. So, let's take a look at how they might be useful to our two excited engineers.

Foresight Molecular Nanotechnology Development Principles

1) Artificial replicators must not be capable of replication in a natural, uncontrolled environment.
2) Evolution within the context of a self-replicating manufacturing system is discouraged.
3) Any replicated information should be error free.
4) Molecular nanotechnology (MNT) device designs should specifically limit proliferation and provide traceability of any replicating systems.
5) Developers should attempt to consider systematically the environmental consequences of the technology and to limit these consequences to intended effects. This requires significant research on environmental models and risk management, as well as the theory, mechanisms, and experimental designs for built-in safeguard systems.
6) Industry self-regulation should be designed in whenever possible. Economic incentives could be provided through discounts on insurance policies for MNT development organizations that certify Guidelines compliance. Willingness to provide self-regulation should be one condition for access to advanced forms of the technology.
7) Distribution of molecular manufacturing development capability should be restricted, whenever possible, to responsible actors that have agreed to use the Guidelines. No such restriction need apply to end products of the development process that satisfy the Guidelines.

Specific Design Guidelines

1) Any self-replicating device that has sufficient onboard information to describe its own manufacture should encrypt it such that any replication error will randomize its blueprint.
2) Encrypted MNT device instruction sets should be utilized to discourage irresponsible proliferation and piracy.
3) Mutation (autonomous and otherwise) outside of sealed laboratory conditions should be discouraged.
4) Replication systems should generate audit trails.
5) MNT device designs should incorporate provisions for built-in safety mechanisms, such as:
   a) absolute dependence on a single artificial fuel source or artificial "vitamins" that don't exist in any natural environment
   b) making devices that are dependent on broadcast transmissions for replication or in some cases operation
   c) routing control signal paths throughout a device, so that subassemblies do not function independently
   d) programming termination dates into devices
   e) other innovations in laboratory or device safety technology developed specifically to address the potential dangers of MNT
   f) MNT developers should adopt systematic security measures to avoid unplanned distribution of their designs and technical capabilities.

Development Principles 1–4 pertain specifically to replication, and the device in question has no such characteristic. Because the device is a human body implant and contains no known toxic substances, Principle 5 is not a problem. Self-regulation is an element of the peer review process, so Principle 6 is addressed. Principle 7 does not apply, as the end product satisfies the guidelines.

In regards to the Design Guidelines, 1, 3, and 4 are irrelevant as the device is not self-replicating or mutating. It would be possible to encrypt the device, so Guideline 2 is satisfied. The fuel source of the device is the electrochemical charges of the brain itself; no broadcast transmission for replication are involved. However, there will be built-in safety mechanisms for the operational signals it uses; control signal paths are already a part of the design of the device, as are termination dates, and all known safety precautions have been taken, relative to the physical health of the persona who wears this implant. Guideline 5 is therefore taken care of, and 6 should not be a problem. Using the Foresight Guidelines, then, means that the engineers can feel secure about moving ahead, in terms of the ethical considerations the device may present. Unfortunately, our two engineers feel some internal tension over how the device may actually be used by the health care industry, but they have no mechanism for pursuing this moral concern.

The Foresight Institute has written and continues to revise these Guidelines for use by scientists and engineers who are developing nanoscale technology. The Institute's concern, it seems, is ultimately to avoid the prevention and interference of nanotechnological development, rather than to stimulate and encourage moral imagination. Foresight expresses the belief that the best safeguard for freedom in development is that together, the research and development community and industry, adopt self-imposed controls. And, they have placed trust in the ability of researchers to use good judgment in carrying out their work. They use as their model the National

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Institutes of Health (NIH) Guidelines on recombinant DNA, and they place a premium value on the maximum "safe" opportunities for development and commercialization of the molecular manufacturing industry. If our hypothetical engineers were to follow these guidelines, Foresight's intentions to preserve research freedom would be carried out, and the device may go into further development. But what about the deeper social/ethical questions of whether such a device even represents a good: Which people might have access to its applications? Who would benefit and who may be harmed? Might some clinically depressed individuals actually be required to use such an implant, or will social expectations arise that pressure any depressed individuals to do so? What happens to the structure of our society if depression is no longer a factor in the human condition? How will we adapt our emotional responses to deal with extremes of loss, powerlessness, and disappointment? What changes will come to our arts, such as music, painting, and theater, if we no longer experience the vicissitudes of depression in our lives? As for our two engineers, what creative possibilities does the imaginative process engage for them, as this device goes into development? What happens to the cognitive processes of metaphorical construction of the narrative, which gives the engineers motivation and justification to proceed?

Certainly, our two hypothetical engineers could achieve funding for the development of their device, because it appears to represents such a far-reaching social good and great potential economic gains. Depression causes tremendous suffering, let alone the great financial costs to our society. One might argue that once research and development are complete, the device would be regulated by the Food and Drug Administration (FDA) and, therefore, the engineers have no ethical responsibility for its actual applications. But the truth is that humans are narrative beings, and the engineers, as people, will have stories to tell about that device, its symbolic significance and meaning. And that narrative will be a dynamic one, reflective of their own personal development and relationships within a community of scientists and engineers, each of whom share experiences and expression about their own work, beliefs, and ambitions in that narrative process. Rule-based codes and guidelines are insufficient to address these deeper, profound elements of actual human experience. For that, our two hypothetical engineers need mechanisms to extend that quest for an ethics of molecular nanotechnology deep down into the domains of the moral imagination. Only through moral imagination might they, or any of us, really be able to grasp the wider social significance of their antidepression device.

MORAL IMAGINATION IN THE ETHICS OF DEVELOPING MOLECULAR NANOTECHNOLOGY

Johnson writes, "No person can be moral in a suitably reflective way who cannot imagine alternative viewpoints as a means of understanding and transforming the limits of his own convictions and commitments. This is the activity of moral imagination" [12, p. 203]. If we stop short of this activity, by relying on moral codes to make our decisions about when and how to proceed in our activities, then we are in essence retreating from our moral responsibilities in the development of molecular nanotechnology. Johnson continues, "People who fall back on rules and moral laws are people who are either afraid of the indeterminacy and contingency of life, or morally obtuse, or both. Rule mongering is a sign of moral failure, and it cannot do what it promises, namely, to tell us how to act in every situation" [12, p. 215].

There are very exciting understandings and findings emerging on a regular basis in the research on nanoscale science and technology. Nevertheless, there remains an awesome amount to learn. Moral questions of right and wrong, good and harm, justice and duty are highly speculative. Projections about how the development of nanotechnology will evolve are varied, and various individuals carry differing notions and ideals about how nanotechnology might and should be used. Thoughtful people in public policy arenas, scientific enclaves, the humanities and social sciences, and in the popular press stress the importance of thinking now about the ethics of nanotechnology [11], [13]. As we have seen earlier, this thinking should include a public discourse that takes heed of the imaginative processes of the mind.

All scientific research, including nanoscale science, is governed by recognized and well-established research ethics. It is built on a foundation of trust, to assure that results are valid and that the observable world is being described without bias. For example, great care is given to the use of human subjects to inform those subjects and to minimize any known harms that could come to them as a result of the research. Likewise, authenticity of authorship, honest documentation, respect for intellectual property, accurate reporting of findings, proper detailing of protocol, and allocation of credit are standards of ethics in the professions of scientific research and development; this is no different in nanoscience.

Engineers who work as researchers, taking the results of science into the development of new devices, machines, and techniques for human use, are also guided by detailed, well-developed professional codes. These codes govern issues such as integrity and safety of design, with the intention of anticipating and then minimizing potential harm to humans and their environment. As a group, engineers are entrusted by the public to design, build, and assemble products and materials that will serve and benefit the best interests of the common good while rigorously testing against known harms and communicating all known risks.

We tend to think of the practice of engineering ethics in the context of applications of existing technology. The challenge, given the enormous potential for nanotechnology to radically change the way we live, is to formulate ethics that can help us see the possible outcomes and consequences of nanotechnology as the technology is still developing. As Wiel writes, “An important aim of ethical investigation is to anticipate ethical problems—preventable harms, conflicts about justice and fairness, and issues concerning respect for persons likely to arise from specific nano initiatives” [13]. The question is how to anticipate these problems.

There are a number of conventional approaches that might be taken to elaborate an ethics for the guidance of nanoscience and its development into technology. The development of guidelines, identification of foundational principles, and analysis of stakeholders, for example, are standard practices in practical ethics that could play a role in the development of an ethics for nanoscience [14]. However, as we have seen, none of these approaches will really help us to understand where we are going unless engineers, scientists, policy makers, philosophers, and social scientists work together to make explicit the values, intentions, and belief systems that are implicit in nanotechnology initiatives.

ENGAGING THE MORAL IMAGINATION

I will here suggest four approaches that can serve as a starting point in unveiling cognitive motivations for the pursuit of nanoscale science and technology. The first is that I identify and acknowledge the narrative structures that frame the nanoscience and nanotechnology initiatives. For example, the widely accepted notion that matter should be controlled, can be controlled, and will control us if we don’t control it, is worthy of deep reflection. Why we categorize such conditions as aging, depression, diseases, and any physical “impairment” or deviation from the standard as something to be annihilated through technology is likewise calling for reconsideration. We should keep in mind that there are many human beings alive today who, given early diagnosis of their conditions, may not have had a chance to live at all or to be the people they have happily become. Questions about our insatiable desire for novel consumer goods have not been explored in ways that may actually cause us to reconsider the seemingly unending quest for faster, smaller microprocessing. We continue to weave stories about how we want to live and what it even means to live in relation to our technologies. Those stories are implicit in our research and in our designs but not explicit in our discourse about ethics and technology. What happens if we make them so? Might the moral imagination become more actively engaged?

Secondly, we would benefit from looking more closely at the metaphors at work that fuel our belief systems about the development of molecular nanotechnology. The role of metaphor is central in much of our conceptualization and thinking about molecular nanotechnology. For example, the basic conception of research as the movement along a path from ignorance to knowledge is replete with metaphors of control, which if looked at as such, might free our reasoning to broaden the meaning of research in very intriguing ways. Notions of deviation from the scientific method become immoral action in that they fail to get you to where you ought to go as a morally worthy agent in the community. But what happens if we select different metaphorical constructions? Does scientific exploration become a different enterprise or reveal different types of knowledge? Even the concept of knowledge itself has metaphorical roots. Learning becomes a social imperative toward mastery of one’s material world when metaphors of increase, power, and capability are associated with it.

Efforts might also be focused on critical study of the art forms that engage imaginative expression toward envisioning the futures that could be the result of our technological pursuits. Freeman Dyson said, “Science is my territory, but science fiction is the landscape of my dreams” [15]. Science fiction is born in the imaginative process. It may not be an accurate source of prediction but it can help us understand the symbolic meanings of our engagement with nanotechnology, as well as what we fear, believe, hope for, and desire. As a source of reflection, it also provides symbolic images of alternative constructions of society and human life. Irrespective of their scientific basis in reality, or the lack thereof, science fiction books about nanoscale science and technology, such as Stephenson’s *The Diamond Age* [16], Flynn’s *The Nanotech Chronicles* [17], and Crichton’s *Prey* [18], are imaginative expressions of the cognitive process of reflection. The fact that the three novels represent vastly contrasting, conflicting visions of that future is not important. What is essential for study is that they each contain elements of the more collective consciousness about human relationships to technology—and to our selves. They each contain common metaphors, fueled by the imagination, and they reflect potential externalization of futuristic visions into expressions of concrete, technological, material changes in our lives.

When the film *Gattaca* [19] was released, it sent out a shock wave of horror about the possible intentions and directions of genetic engineering in our culture. It forced us to reconsider what we hope and dream for as a result of mapping and engineering the genetic code. Notions of physical perfection so passively accepted in popular culture, and protected by the classical domain of rule following ethics, became a source of philosophical concern when portrayed in the drama of bodily life under meticulous genetic control. Those who watched the film saw what our future might be made of. As a result, they had to wonder about all the other possible outcomes of our current genetic engineering projects. Of course, that film was not the only source of moral imagination about genetic engineering. Our society has many varied art and literary forms that engage the moral imagination. The point is that we should not be so quick to dismiss those imaginative expressions as somehow irrational, or as unworthy of use in the process of developing an ethics of molecular nanotechnology. Such forms may be our saving grace.

A fourth suggestion, and the focus of my own research, is that we take a close look at the scientists and engineers whose work takes place at the nanoscale. Research scientists and engineers serve to further society’s access to knowledge. Their quest for new knowledge is a morally neutral, but socially significant, enterprise. Their enduring role in society is, for good reason, held in high esteem. As the conceptual and technical architects of the nanotechnology initiative, research scientists and engineers are a primary source of the imaginative process that nourishes its development. Winner speaks with disdain about public discourse regarding technology, saying: "Alas, if one listens to what our leaders in the White House, Congress, business, academia and the media are saying about technology and humanity, there is no compelling, positive vision whatsoever. No one seems willing to imagine technologies that might strengthen local communities, revitalize democratic politics, eradicate chronic urban poverty and encourage environmentally sound means of production around the globe. Instead, our policy elites peddle lists of gadgets, gizmos and trends—along with trivial exhortations about how people will "have to change" [20].

Interestingly, Winner's list of leaders does not include the research scientists and engineers. What about what they imagine? What is it that they believe they are doing? What do they imagine is possible as a result of their work? What personal hopes, aspirations, beliefs, and fears do they have? What are the metaphors that comprise their wildest technological dreams? What motivates their work, and what kinds of studies might they reject from their own labs? Early indications in my studies suggest that most scientists and research engineers who are working at the nanoscale do actively imagine valuable social and cultural changes coming as a result of their work and are highly motivated by those ideas.

For we who are interested in the societal elements and the ethics of nanoscale science and technology as it is developing, penetration of the cognitive processes as they are related to the development of nanotechnology may help us to better understand where we aim to go and why and to help us more actively and conscientiously direct its course. The study of metaphor use in various related rhetorical texts, the study of imaginative elements of cognition apparent in science fiction, and the focus on tacit elements of cognition in actual nanoscience research engineers and scientists all offer fruitful foci for interesting scholarship and the wonderful possibility of coming to grasp the powerful, cognitive roots of our newest technological enterprise; nanoscale science and technology.

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