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Nano-Ethics

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Abstract: Nanotechnology will bring surprises, both beneficial and harmful, and so will create ethical issues for its practitioners and for society. If we are to have some understanding of what lies in store, we need to distinguish between ethical issues internal to a practice and thus of particular concern to its practitioners, and ethical issues external to a practice. We also need to understand how artifacts can produce harms and how rapidly developing technologies produce harms by provoking errors, wholly unintentionally, among those who use its artifacts.

Introduction

Any developing technology brings surprises. We are not now in any position to know the details of how nanotechnology will develop, what it will produce, or how it will affect our lives. We can only draw inferences from what we can argue, hope, or fear are analogous technological developments – with no way to gauge the extent and limits of any analogy. One certainty, however, is that ethical problems will arise within and because of nanotechnology, exacerbated by particular features of nanostructures.

Suchman (2002) lists three features of nanostructures that, according to Glimell, "will generate novel issues of responsibility and control":

> (1) *Invisibility*: nano-machines would be among the first complex constructions intentionally engineered to accomplish human purposes at a microscopic level, and their introduction into the technological armory would dramatically increase the potential for orchestrated covert activities;
> (2) *Micro-locomotion*: (the ability to move through and within macroscopically solid matter): free ranging nano-machines will radically challenge our traditional understandings of macro-boundaries and barriers; fences, walls and even human skin are largely open space, at the nano-scale;
> (3) *Self-replication*: as difficult as it may be to realize as of yet, self-replication will be a common attribute for any nanotech production passing market conditions, thus becoming socially significant; it poses profound challenges to human foresight and control, since without a carefully designed ready 'off switch', a population of self-replicating nano-machines could grow exponentially. (Glimell 2004, this volume, quoting Suchman 2002, p. 97)

At least two other features are relevant to ethical issues that nanotechnology will bring:

(4) *Behavioral unpredictability*: things do not behave at the nano-level as we would expect given how they behave at the macro-level. We shall thus find ourselves surprised at the ways in which invisible, free-ranging and perhaps self-replicating nanostructures penetrate our lives.

(5) *Ontological status*: the ontological status of nanostructures is contested. Even the understanding of why nanotechnology will be so important mirrors a contest between seeing nanostructures as Lilliputian machines that are constructed atom-by-atom, and seeing them as organisms, mirroring nature's reproductive processes.

Of these five features, the third, self-replication, is most problematic. What underlies the third feature is a concern that nanostructures be inexpensive so that they become a significant part of the market. But presuming that self-replication is the only solution to expense puts limits on our imaginative capacities – never a good idea with developing technology. The potential harms of nanotechnology could be considerably greater if nanostructures turn out to be self-replicating, but in what follows, I will ignore this possible feature of nanostructures, keeping in mind only that their social impact will no doubt be affected by their cost. We shall find that the potential harms are still significant.

Two more comments about these five features are necessary. If we do not presume that nanostructures are self-replicating, then micro-locomotion does not imply that nanostructures are self-driven, only that they are capable of moving through what we have traditionally thought of as barriers to movement – our skin, for instance. In addition, to claim unpredictability is to claim no more than what we have discovered already. No one predicted that carbon nanotubes would exhibit the great strength they display. We are going to be surprised by the behavior of nanostructures, and only a Candide would not think that at least some of those surprises will be harmful to us.

Those potential harms are of two sorts, what I call external and internal. We need to begin by clarifying that distinction, at least in a rough way.

1. Internal and External Ethical Problems

Ethical problems are internal or external to a developing technology just as they are to any profession. One often finds in engineering texts such claims as that engineers are not responsible for the misuse of the artifacts they design. Why should an engineer be held responsible when someone drives a car into a crowd? The ante is then upped by adding that, for example, although an engineer could make a car that would be significantly safer to drive – a tank is the standard example – anything an engineer designs can be misused by someone in some way. After all, the range of stupidity, the capacity for inattention and carelessness, and the failure to learn are far greater than the capacity of even the best and brightest engineer to anticipate these. Besides, anticipating problems will not preclude the tradeoffs required in terms of cost, for example, that hem in engineering design. The implication of upping the ante is that engineers are not accountable for any use at all of what they design – although if that conclusion were ever drawn explicitly, its falsity would be apparent.

A clear example of what an engineer would be responsible for is an artifact that provokes a user to cause harm. An engineer who designed such an artifact would have made an engineering and a moral mistake and be ethically at fault. No tradeoffs in cost, efficiency, simplicity or any other desiderata can justify an engineering design that entices a user to do or fail to do something that will produce harm, particularly if the harm is grievous.

Engineers are not responsible for every use of what they design, but they are responsible for what they design, and it is easy to find examples of artifacts that entice users to cause harm. Such error-provocative designs, as I call them, are the responsibility of engineers. We do not need philosophical imagination here, but can draw on our own experiences.

Consider doors whose design signals they should be opened one way, when they open the other (so that wrists are wrenched as we pull when we should push, or vice versa) or double glass doors that fail to signal that they are locked. We come into a building by pushing on the right-hand door, but when we attempt to exit by pushing on the other one, we discover it locked and so wrench our shoulders or get hit by those behind us. Nothing about the door indicates that it is locked, and, indeed, the situation implies it is unlocked. Why make those who are coming in and going out use the same door so they block each other's way?

An engineer who purposefully designed artifacts to entice users to cause harm would be thought ethically perverse. I am not at all suggesting that engineers are perverse – no matter how many examples of apparently perverse designs we run into daily. But let us suppose an evil genius of an engineer. Understanding how such an engineer could cause harm will show us how deeply ethical engineering is.

Consider what happens when an accident occurs – a train wreck, for instance. Three variables matter: the operator, the artifact, and the situation in which the accident occurred. Of the situation, we ask if there was fog, something amiss about the signals, or something else that would cause problems for even the best and brightest of operators. Of the artifact, we ask if something about it led to the accident. Did the throttle stick? Of the operator, we ask about what can go wrong – inattention or lack of intelligence or training.

'Inattention' covers a variety of problems, all having to do with the mental state of the operator – sleeping, inebriated, dead, high on drugs, distracted, and so on. When police investigate an accident, they try to see if the driver was inattentive for some reason. "Do you have a cell phone?" "Please step out and take this test (to determine if you are drunk)." Any one of these and similar failures in the driver could be the culprit, that is, the decisive factor that led to the accident.

Such questions presume that the operator is intelligent enough to use the equipment in question and well enough trained so as not to make simple mistakes. But not all operators are well enough trained, and some are not the brightest and best. So a thorough inquiry into an accident would investigate the training the operator received and the general level of intelligence the operator displays.

Yet a real evil genius of an engineer would presume intelligence and training. Failures of intelligence and training take care of themselves, as it were, causing enough harm without any help from an evil genius. A really evil genius would ensure that the more attention we paid to using an artifact, the more likely harm would occur. A really perverse design would entice even the most cautious of the best and the brightest to cause harm. To assure that such operators do not always approach artifacts with caution honed by failure, a real evil genius of an engineer will randomly introduce artifacts that mislead, such a genius would hone through practice and research what best misleads. A real evil genius of an engineer would take most pride in artifacts so designed that even the most intelligent and well-trained operator, alert to all the difficulties that might occur, will be misled by the design into producing exactly the opposite of what was intended.

My Subaru SVX has a shoulder harness that automatically closes on passengers as the door is shut, giving the illusion of safety but ensuring that if the seat belt is not fastened, "severe head trauma" will result, as the car manual puts it, when the harness belt slices through one's neck in an accident as one's forward momentum is checked so one slides down in the seat. I cannot count the passengers who were surprised when I asked them to fasten the seat belt, which meant that they thought the harness protected them automatically.

That we would think an engineer evil who intentionally designed such artifacts, tells us that good engineering is not ethically neutral. We should expect tradeoffs between safety and other criteria. But a good engineer minimizes the risks to those who are to use the product and does not design an artifact that signals a way to use it which guarantees that the end for which it appeared to be designed will be defeated. We should look ethically amiss at an engineer who designed an artifact that consistently misled the normal user, the user who is not the best and the brightest, sometimes distracted or inattentive, and often not well trained.

"But surely," any engineer would say, "we can't be held responsible for every mistake that's made!" Right. A line needs to be drawn between what an engineer is responsible for and what not. An automobile can be a lethal weapon, but an engineer cannot be held ethically liable for someone using it to run down pedestrians. Such use is possible, no matter how a vehicle is designed, and so no engineer can be held ethically liable for having produced a design that did not preclude this possibility. The ethical problems which arise because of that sort of misuse are what I call external to the profession of engineering.

An automobile could be made into a lethal weapon by design features not essential to it. A cowcatcher on a hood with spikes for impaling pedestrians would be such an example. Or, for those with a perverse sense of humor, the 'Spring Surprise' of the chocolate manufacturer in the Monty Python sketch serves even better: the chocolate covers a spring-loaded set of hooks and, as one sucks, the tension in the spring finally overcomes the thinning coat of chocolate to release the hooks so you are, well, surprised. A design triumph of perversity.

What is required for an engineer to maintain ethical innocence regarding the use of the design is that nothing about the design itself causes harm or tempts anyone to cause harm. Put another way, what is ethically internal to the profession is what we could attribute to an evil genius of an engineer. Ethically internal is also when we call an engineer good who produces engineering design solutions which minimize as best as possible the harms that could result from an artifact.

Such a distinction is rough, of course. The examples I have used are all relatively benign artifacts – automobiles, doors. A different set of concerns arise if an engineer is designing, for instance, an artifact whose purpose is to cause harm – a bomb, a land mine. But the distinction will serve our purposes here.

If we map this rough distinction between internal and external ethical problems onto nanotechnology, we ask the following:

a) Are there ethical issues that arise, or will arise, internal to nanotechnology?
b) Are there ethical issues that arise, or will arise, external to nanotechnology, but resulting from it?

We will first consider examples of ethical issues external to nanotechnology. These are perhaps the easiest to understand and the most likely to capture one's imagination.

2. Lilliputian Artifacts

An essential feature that sets nanostructures apart from other artifacts is size. They are from 1 to 100 nanometers, from one- to 100-billionths of a meter, significantly less than the 50,000 nanometers of a human hair. Obviously, they cannot be perceived by the naked eye (Ratner 2003, p. 6), and can thus be produced and deployed without ever being observed by any human being – except indirectly through highly sophisticated instrumentation. A consequence of their unobservability is that their deployment would be virtually undetectable.

I taught with an engineering colleague who started his career in electrical engineering and switched to industrial engineering when he realized the danger of working with something of which you cannot see that it can kill you. His insight should not be lost when we consider nanostructures. We can be harmed by them without even realizing they are in the vicinity. The kinds of ethical issues this unobservability creates can be illustrated by noting three problems. These problems are external to nanotechnology. They arise through what are predictably the ordinary uses made of nanostructures or as a consequence of there being nanostructures at all.

Privacy: One problem is readily predictable – and has been predicted. Sensing devices so tiny they are invisible to the naked eye and to any readily available instrument will be and, no doubt, are being developed. With such devices, we open the prospect of spying on individuals in ways that would make 007 and his handlers salivate with anticipation. There would be no need to open a phone to install a listening device or hide one in the electrical circuitry. We could simply add nano-sensing devices to the paint or a composition floor to turn a 'safe' room into a recording and transmitting studio. Alternatively, such devices could be put into our bodies without our being the wiser. The average citizen would be at the complete mercy of anyone familiar with nano-sensing. Those interested in someone's conversations could readily listen in by putting nano-sensing structures into jacket pockets or into a Trojan horse of a gift. Even someone with reason to suspect eavesdropping would be ill-prepared to track down the nanostructures that could be anywhere nearby. Their detection would require what we can presume to be special highly sophisticated equipment.

When nanostructures are free-ranging, the level of concern rises. Put on us or in us, they may migrate where they wish, penetrating our skin and embedding themselves wherever they end up in our bodies, perhaps in our fatty tissues – along with any HIV virus, PPB (Robison 1994, pp. 1-2), and other contaminants that find a semi-permanent home there. If they were self-replicating as well, we would need to multiply the problems astronomically.

We thus have with nanostructures a new reason to be concerned about invasions of privacy, and especially in the current political climate new reasons to be concerned about governmental surveillance. We can better understand how our privacy is likely to be invaded, and the various harms those invasions entail, by examining three of the four different privacy torts in American law – intrusion, disclosure, and appropriation (Prosser 1960). The tort of false light seems of little relevance here (Robison 1997), but the other three torts are crucial to understanding the different ways in which we will be harmed and the differing magnitudes of harm those invasions will produce. Consider intrusion first.

The standard sort of example for intrusion as an invasion of privacy is having someone come into one's bedroom while one is making love or into some other space where one has every reasonable expectation of being left alone. Sticking your hand into someone else's pocket, without permission, is a nice example of intrusive behavior, and letting loose nanosensors into that pocket or otherwise putting them onto or in a person to gather information is another instance. We have an expectation that our bodies are ours, not to be trespassed upon, as it were, without our permission. When someone sprinkles nanosensors on us, or in us, we will have no idea that intrusion has occurred. A pickpocket may be skillful at putting a hand in a pocket without the owner being any the wiser, but it is still intrusive and the owner will be the wiser once the wallet or other valuables are missed. What is added by the Lilliputian size of nanosensors is that no one could reasonably expect us to know that our privacy has been invaded. When someone bursts into our bedroom while we are making love, we generally know it or, at least, could know it. When nanosensors are in us, sending out information about our temperature, movements, and so on, thus telling someone outside our bedroom what we are doing, we are helpless to help ourselves from such intrusion.

We are also helpless to preclude disclosure, the second privacy tort. The standard sort of example is someone's passing on a secret. The secret is disclosed. We all keep some information to ourselves. This is, among other things, one way of distinguishing between friends, acquaintances and strangers. We tell friends things about ourselves that would be inappropriate to tell our acquaintances (although that would be one way of beginning to turn an acquaintance into a friend). Telling such things to strangers would mark us as addled, if not crazy. Control over information about our personal lives allows us to keep, among other things, control over who we are publicly and privately. Nanosensors would allow a stranger to know everything about us that we would want to control, from private conversations with one's spouse or lover to intimate details about one's body temperature and state of health. A stranger could well know far more about us than we can know about ourselves.

That someone knows as much or more about us as we do, permits the last relevant privacy tort, namely appropriation. That occurs when someone takes another's identity. Identity theft is the most recent variation of an old problem of someone pretending to be someone else and thus appropriate identity. Such theft will become that much easier as information about us is relayed to a stranger who will pick up all those conversations we think are private (about finances, sex, our mother's maiden name, whatever) and use that information to appropriate our identity.

In each case – intrusion, disclosure and appropriation – our privacy is invaded. While this is a harm in and of itself, the effects of such an invasion can obviously also be harmful. We encourage privacy because we value, among other things, keeping some things to ourselves and keeping control over what others know and do not know about us. With nanosensing devices easily spread wherever one might wish to spread them, and with their being undetectable without special devices, and perhaps not even then, we may find ourselves liable to far greater harm than we now experience through present devices such as video cameras.

We have had a marked increase in the ways in which our lives are being recorded since the concept of privacy was first introduced into the law by Warren and Brandeis in 1890 (Warren & Brandeis 1890). We have surveillance cameras observing us as we transact business at the bank, or watching us as we walk the aisles of a store. We have cards that allow stores to record our purchases so files can be compiled about us that are much more complete than anything we would ever have thought to compile for ourselves about our buying and spending habits. There are files on us in the computers in our physician's office, at our place of employment, in the various agencies of our government (regarding our driving, taxes, voting), at the schools and universities we attended, at the bookstores and websites we frequent, and so on. It does not take much skill to put much of this together to form a rather complete dossier, and if, as Leibniz argued, we are individuated and identified by that set of predicates that are true of each of us, someone with such information can know far more about us than even we might have occasion to pay attention to, recall or know ourselves.

We are not now aware of all the ways in which our privacy is invaded. We cannot keep track of how data about us is transmitted from one place to another – as happens, for instance, when security checks are run, or when we are stopped for speeding and our place of employment is checked as well as our driving history and record of convictions, or when a physician's office informs our insurance companies of a claim, which then informs our employers. We are so used to surveillance cameras that we rarely notice them, and they can be so readily concealed, in any event, that they become like nanostructures – unobservable to the naked eye although all-observing of what we are doing.

The introduction of yet another device for gathering information about us should come as no surprise. Knowledge is power, after all. But the minute character of nanostructures and the subsequent ease with which they can be sown in any soil at all, whether barren or fertile with possibilities for those doing surveillance, means that the stock of information about us available to those with the technology will increase exponentially. The likelihood is high that such devices will be relatively inexpensive, eventually making it to the open market, black or otherwise. The consequence is that we shall not only have governmental bodies using such devices to gather information about us, but the general public – our acquaintances, employers, spouses, voyeurs.

I have provided invasion of privacy as an illustration of how nanostructures may profoundly affect our lives and increase the risk of harms to all of us. I could have chosen other illustrations, but I suspect none is as unnerving as the second sort of illustration we need to consider about how our lives may be profoundly affected by nanotechnology.

Bionanotechnology: The worry is that bionanostructures will be created that would do for worries about anthrax and other deadly biological agents what AIDS did for herpes. One researcher in nanotechnology argues for a moratorium on all work in bionanotechnology and even defines 'nanotechnology' in a draft of the second edition of his book in such a way as to exclude bionanotechnology from the field (Lyshevski 2000). He says that he can give no details about why a moratorium is necessary, but the clear implication of his suggestion is that he is aware of potential developments that would put "all mankind at risk".

Two possibilities seem likely – new kinds of biological agents or a new means of delivery. It does not take much imagination to have concerns. We would be dealing with free-ranging Lilliputian structures. One mistake on the part of a researcher who fails to scrub thoroughly could mean a new infectious agent or a new mode of delivery out in the world, capable of moving without hindrance throughout our bodies and its organs. That healthcare practitioners are still puncturing themselves with needles used on AIDS patients is some evidence of how even the most careful and informed of practitioners can make mistakes.

The worries are multiplied when we presume that there are not just well-intentioned researchers trying to avoid mistakes, but others who purposely want to introduce new biological agents or new ways of delivering them. How could any border guard who is checking those coming into a country know who is carrying bionanostructures and who is not? The question is not rhetorical: technological means for detection of nanostructures will advance as nanotechnology advances, but the lag time in development, necessary in order to have some idea of what it is that we are trying to detect, will ensure windows of opportunity. As we have discovered in trying to intercept drugs, the cleverest will always figure out some new way to bypass the standard practices for detection. Defensive measures always lag behind offensive innovations.

How a bionanostructure might pose grave danger is unclear: presumably there would be serious consequences for us only if it were either self-replicating in some way or if it were so inexpensive to produce, that billions upon billions could be made and somehow spread for consumption. But there is no more use speculating here on what might come about regarding nano-biological agents or nano-delivery systems, than there is in proposing a moratorium on research in bionanotechnology. As the world discovered with Dolly, the clone whose creation startled those working in the field, we have little control over what those with the talent and technique can do and, rather obviously, we have few ways of knowing what they are doing. The same holds for nanobiotechnology. In a commercial world of secret development, made necessary to ensure patents, knowledge is gold, and there is no likelihood of anyone or any government ever being in a position to ascertain what the state of the field is in nanobiotechnology. Perhaps that is just what concerns the researcher who wishes for a moratorium.

Environmental health: Nanostructures are already being used in many products, from rearview mirror housings to skin cream. Their introduction into our environment and, indeed, into us, has proceeded without any thorough testing of, for instance, the consequences to our health. To state the obvious again: we have had no testing of the long-term consequences of exposure to nanostructures and, in particular, to the long-term consequences of exposure to the billions upon billions of nanostructures we shall soon have in our environment, given the pace of commercial exploitation. That means that we will all be part of a large-scale experiment on the health effects of the introduction of nanostructures into our environment and into us. We cannot now know how that experiment will turn out.

We ought to be concerned – just one analogy from what we know about other small particles. We know that particulate matter smaller than 10 microns will "infiltrate the tiniest compartments in the lungs and pass readily into the bloodstream and have been most strongly tied to illness and early death, particularly in people who are already susceptible to respiratory problems" (Revkin 2001). The relationship between such particles and death and ill-health is well substantiated and obvious. When we breathe, the smallest particulate matter is most likely to be taken into the deepest parts of the lungs and stay there, eventually clogging the lungs and, as they make their way into the bloodstream, causing whatever problems foreign particulate matter can cause (Environmental Protection Agency 2001).

The most recent reports on what experiments have been done on the health effects of nanoparticles are anything but reassuring. When researchers at DuPont "injected nanotubes into the lungs of rats", fifteen percent "died quickly". The research leader, David Warheit, said that it "was the highest death rate we had ever seen" – this from a researcher who "began his career studying asbestos and has been testing the pulmonary effects of various chemicals for DuPont since 1984". The problem appears twofold: the material is drawn deeply into the lungs because it is so small, and "the cells that break down foreign particles...have more trouble detecting and handling nanoparticles than larger particles" that have been the object of concern for toxicologists (Feder 2003; see Service 2003, p. 243.).

Research has not been limited to inhalation into the lungs. A recent study also indicates that minuscule particles in air pollution put the heart at greater risk than the lungs. The danger comes from "particulate matter less than 2.5 microns", and what was discovered through an examination of "pollution data from more than 150 cities over 16 years" and about a half million people was that for each increase of 10 micrograms per cubic meter of air, "the risk of death from ischemic heart disease went up 18 percent" (Nagourney 2003). Preliminary research also shows that nanoparticles in nostrils make their way "directly into the brain", with as yet unknown consequences. They also change their "shape as they move from liquid solutions to the air" in apparently unpredictable ways so that forming general conclusions from experiments about particular substances is complicated (compare European Commission Consumer Protection 2004). What is not complicated is the claim that we ought to be concerned about the health effects of nanoparticles.

One ethical concern we thus ought to have is that nanoparticles in and of themselves will cause harm to us. It is not just that some evil genius of a bionanotechnician may produce a new kind of nano-agent or nano-delivery system that will somehow inaugurate a new millennium plague, as it were, but that the very introduction of nanoparticles into our environment will itself produce the equivalent of a plague.

These three illustrations of ethical problems – regarding privacy, bionanotechnology, and the environment – fasten on features peculiar to nanostructures, namely, that they are free-ranging Lilliputian entities. Indeed, even if we concentrate only upon their Lilliputian size, nanostructures will create ethical problems.

These problems are external to the practice of nanotechnology. Nanosensors and nanobiological artifacts, like delivery systems, can serve good ends, and so they will be developed, and nanoparticles will enter into the environment. No nanotechnician can alter the characteristics of those nanoparticles or of the nanostructures that will cause ethical problems when those developed for good ends are misused. As for the development of new toxic biological agents, for instance, we will be dependent upon the judgment of individual practitioners, and, clearly, we live in a world where real evil geniuses thrive.

3. Harmful Surprises

An additional feature of nanostructures is that they can behave in surprising ways:

> For example, a nanoscale wire or circuit component does not necessarily obey Ohm's law, the venerable equation that is the foundation of modern electronics. Ohm's law

> relates current, voltage, and resistance, but it depends on the concept of electrons flowing down a wire like water down a river, which they cannot do if a wire is just one atom wide and the electrons need to traverse it one by one. This coupling of size with the most fundamental chemical, electrical, and physical properties of materials is key to all nanoscience. (Ratner 2003, p. 7)

The failure to obey Ohm's law is predictable – although we might not have thought through the requirements of Ohm's law before discovering its limits at the nanoscale.

Other features of nanostructures seem unpredictable. Nano-gold, if we may call it that, does not look yellow, for instance. "Nanoscale gold particles can be orange, purple, red, or greenish, depending on their size" (Ratner 2003, p. 13). It is only when they are allowed to congregate, or "combine" (Ratner 2003, p. 15), that the yellow reappears. And trying to achieve new computer chips means working with the unknown "since properties change with size at the nanoscale" so that there is "no particular reason to believe...chips will act as expected" (Ratner 2003, p. 18).

That Lilliputian structures may not behave like larger objects will no doubt mean huge benefits for us. A single recent example will suffice. It is helpful to be able to distinguish, and distinguish quickly, different kinds of gases. Think of a terrorist bringing a deadly gas into a country masquerading as something benign. Because gases ionize at different temperatures, we can distinguish them by how they react to different voltages. Yet current machines for detection are expensive and bulky, on the order of four to five feet square to generate and accommodate the high voltages necessary to distinguish gases. But "the tips of many nanotubes 'amplify the local electric field by many orders of magnitude'" with the high voltage being nano-localized, as it were (Ramirez 2003). So nano-detectors can sniff out differences in gases – at very low cost per unit, with no danger from high voltage, and, obviously, without bulk. The sniffers are not yet perfected, but we will soon have tiny sniffers available to monitor gases without intrusive and time-consuming procedures. Police officers will not need to test drivers to see if they are drunk and, if so, on what.

If we are to have some idea of what properties will be uncovered by particular investigations, we need a way of understanding, and of predicting, how nanostructures will behave. The problem is not new. John Locke says of gold that

> he that, to the yellow shining Colour of *Gold* got by sight, shall, from my enumerating them, have the *Ideas* of great Ductility, Fusibility, Fixedness, and Solubility, in *Aqua Regia*, will have a perfecter *Idea* of *Gold*, than he can have by seeing a piece of *Gold*, and thereby imprinting in his Mind only its obvious Qualities. But if the formal Constitution of this shining, heavy, ductil Thing (from whence all these Properties flow) lay open to our Senses, as the formal Constitution, or Essence of a Triangle does, the signification of the word *Gold*, might as easily be ascertained, as that of *Triangle*. (Locke 1975, III.XI.22.4-13)

Some of the qualities of substances, color, for instance, we perceive by seeing the substance itself; some, such as ductility, by working with the substance and perceiving what Locke calls its powers. But no matter how complete our list of qualities, it is a list, a compendium of what has been observed by us about gold.

Any such list has at least three limitations. It can vary from individual to individual, the bulk of us not having observed gold closely enough or manipulated it to note its many properties. Second, even if we had, the set of properties we perceive may be incomplete, and we would never know that. New instruments of observation may add to our list of observables. Think here of what the discovery of the microscope made possible. Manipulating a substance in new ways, or with different substances than before, may produce more observables. Locke would have been unaware of what happens when gold is irradiated.

The third limitation is that the list is a set of conjunctions, tied together only by their being observed in relation to – a weasel phrase – the substance we call gold. The list provides us with no way of understanding why all these qualities are conjoined. What is it about what we call gold that accounts for its having all those qualities?

Locke assumes that seeing the "formal Constitution" of *e.g.* gold would allow us to see the relations between what we do observe and know about gold. We would then have a single determinate understanding of gold. As he says, "the real Essence is the constitution of the insensible parts of that Body, on which those Qualities, and all the other Properties of Gold depend" (Locke 1975, III.VI.2.27-30).

With an understanding of the real essence of gold, Locke suggests, all of gold's properties would be as open to our understanding as the properties of a triangle.

Nanotechnology seems to promise the sort of knowledge Locke thought possible. Having the capacity to manipulate nanodots of gold gives us an opportunity to understand whether and how its appearing yellow to humans under normal lighting is dependent on its nano-properties. Working at the nano-level, that is, gives us the opportunity to prove the truth of, or give the lie to, what we might think of as Locke's conjecture. It allows us to position ourselves to understand how a substance's properties depend upon its nanostructure.

If gold appears yellow once its nano-particles are permitted "to combine" and its nanodots appear different colors "depending on their size" (Ratner 2003, pp. 15, 13), then different sized combinations of gold nanodots – two here, four there – give rise to our perceiving different colors. Descartes said that our perception of color depends upon the spin of the particles we see. Whatever the explanation, our concern is not with the promise of nanotechnology and nanoscience, but with its perils.

We have enough evidence, it seems, to hoist at least a tentative general truth about nano-particles: we will be surprised. The worry is one with which we are all too familiar from research in other pristine areas: we may unwittingly produce something harmful. We have considered one possibility in bionanotechnology, but the concern is broader, namely that we will produce a nanostructure – a new form of substance, as it were – that will do for the physical world what purple loose strife and kudzu have done for native North American plants. The world is filled with our mistakes, and the concern is that at a minimum we avoid doing something that will make the world irremediably worse.

Just as the unobservability of electricity has prevented 'better living through electricity,' this concern about accidentally producing something immensely harmful will and should not prevent the development of nanotechnology. Working with something of which you cannot see that it can kill you, is not a good idea – unless you take protective steps to insulate yourself and others from harm. We need to think through ways of working with nanostructures so as to minimize potential harms. In this, we face at least four problems.

(1) We have no agreed-upon standard that will serve as a guide for the rational development of nanotechnology. We have at hand a relatively well-developed understanding of what risks we as a society can accommodate and what risks are beyond the pale. We can accommodate some high fliers on our highways, however much we might prefer they not fly near us. The risk of our driving is increased by such high fliers, but the harms are localized, no matter how great. But the harms of nanotechnology will not necessarily be localized, and what is needed, at the minimum, is a decision-procedure for research and development that takes full account of the potential for great harm, even if unwittingly produced. What society cannot tolerate are high fliers who put all of society at great risk.

And yet, that statement's truth is a function of its generality. Once we proceed to cases, disagreements abound. Get to a specific case – *e.g.*, genetically modified food – and its failure as a guide for action becomes clear. Disagreements abound about whether something is risky, about how risky something must be to curtail work on it, and about what we ought to do when we have no way to measure the risk. We have no agreement on how to proceed in the face of such uncertainties (Robison 1994, pp. 148-63).

The controversy over CFC's and the ozone is an instance of how we disagree. Those who argued we should do nothing until we are absolutely clear about the causes of the known harm had a point: doing something of which we cannot be sure that it addresses the causes of the harm may just aggravate the situation or make it more intractable. Yet it is hard to disagree that a failure to act now, even without the full assurance usually necessary to preclude harm, will ensure that the harm being produced will become far too great to countenance. The disagreement about how to proceed turns on the weight one gives to these competing understandings of what is rational in the face of possibly great harm. That we have banned the production of CFC's is a sign that we can all reach agreement about some matters when we have disagreement about uncertainties, but that agreement stands alone.

(2) Even if we had an agreed-upon standard, it would be essentially contestable. We will have the most well-intentioned and brightest of individuals disagreeing about whether some form of research is or is not in accord with 'standard and acceptable practice.' There is no way to settle such disputes. By its very nature, no standard can guarantee its own application in particular cases. Each standard needs a set of interpretive rules by which it is to be applied. What counts as an 'out' in tennis is not self-evident, for instance, and those who must apply the standard must have some way to determine what counts as outside the line. Hitting the outer edge of the line is not the same as brushing it, for instance, and some will see the latter as out while others see it as in. The same holds for any standards we may come to have regarding research in nanotechnology. We may think we have clarified matters by hoisting a standard for what is acceptable and unacceptable experimentation, but no matter what the standard, we will come upon disagreement about what it means in particular cases.

(3) Even if we had a rational guide for development and it were somehow not contestable, not everyone would follow it. With no rational guide, the range for disagreement about what is acceptable and what is not will permit all sorts of experiments that some would not countenance. The experiment that produced Dolly is perhaps one such example. The problem is that any researcher into nanotechnology may be a high flier, a Jack-in-the-beanstalk of investigators, willing to bet the family livelihood on the promise of a bean.

Any rational guide would be unenforceable, and we would find that even for the most well-intentioned individuals, the temptations to experiment in areas deemed dangerous might overcome reluctance. The hubris of being the first to find a cure, the drive for funds to further additional work in the area of one's expertise, the biased evaluation of the risks and potential harms and benefits to be expected by those who stand to gain from success and lose by inaction – all these conspire to motivate even those who do not want to cause harm. How much the worse for all of us when we have someone whose motivations are less pure.

(4) In addition, the fastening upon a standard and the adoption of an enforceable one requires a politically loaded procedure, complicated beyond measure by its needing to be international in scope (Robison 1994, pp. 62-82). I will not pursue what ought to be obvious to us all or draw the skeptical conclusion about research that follows.

Nanotechnology and nanoscience will bring surprises if only because of the very nature of developing technologies. With surprises will come unintended harms. We can at best attempt to control what happens regarding research within a country and apprise those working at the nano-level of the complications they, and we, may face when we are surprised. But that means that we are dependent upon the ethical integrity of the professionals in the field. Put another way, we are looking at an ethical issue internal to nanotechnology and any attempt to minimize it will depend primarily upon its practitioners, not upon society and not upon those who will make use of the technology. That is why any evil genius working with nanotechnology is of such concern.

4. Ontological Status

During an interdisciplinary yearlong seminar in nanotechnology sponsored by the Provost at my university, an engineer and a chemist were discussing the use of nanostructures to deliver medication within the body or provide the silver (gold, actually) bullet to a cancerous cell where radiation would focus on it, killing the cell but leaving everything else intact. The engineer was frustrated. "Tell me what the parts are, and I'll make it!" The chemist replied, "But it's not a mechanism. It's a living organism." "I don't care," the engineer replied. "It has parts, and if I knew what they are and how they work together, I can build it."

The Cartesian allusions are not irrelevant. At issue is the nature of nanostructures. The chemist and the engineer each saw nanostructures from the perspective of their own disciplines and squared off, as it were, because each held to their own discipline. But saying that misses the more important issue. One essential feature of nanostructures appears to be that by their very nature their ontological status is contestable.

Nanostructures are, it is claimed, the smallest machines we will ever be able to build. True or not – and we should be skeptical of claims that we shall never be able to do this or that – that feature means that nanostructures are interdisciplinary, if we may put it that way, in the way nothing else has ever been. They are objects of interest to engineers, who can manipulate the atoms to create mechanisms; biologists, who can begin to understand how the smallest organisms function; physicists and chemists, who can investigate the properties of substances such as gold by understanding the nanostructure of gold, as it were, and so on.

Disciplines are so specialized that no one can be conversant with them all, let alone keep track of what is happening in them all. Someone not steeped deeply in chemistry simply cannot understand articles in chemistry journals. Someone not deeply steeped in physics cannot understand articles in physics journals. So seeing nanostructures from the perspective of all the different disciplines looks to be a pipe dream.

Barriers to understanding and cooperation are thus integral to nanotechnology and science. Yet that understates the problem we are noting. Practitioners of each discipline – *e.g.*, biology, engineering – not only will see nanostructures as objects within their discipline, but will have a vested interest in seeing them that way.

A discipline can obtain funding for its initiatives only if its object of concern is part of its subject matter. So an engineer interested in nanostructures will see them as mechanisms: they are then objects of professional interest and projects involving them are fundable. Just so for someone in biology. If nanostructures are mechanisms, their proper field of study is engineering, not biology. So someone in biology must see them as organisms to justify a professional interest in them and to justify funding. So the engineer and the biologist must be at odds. Three consequences are of importance for nanotechnology.

First, the status of nanostructures will remain essentially contested as long as competition remains for funding and for the field of study. If the ontological status were determined to be mechanisms, for instance, engineering would have them to itself. Just as biology took in all DNA research, so engineering would take in all research in nanostructures – much to the chagrin, no doubt, of other disciplines and to the detriment of what ought to occur if we are to understand fully what nanostructures are. We should be looking at them as they are from the perspective of every relevant discipline and communicating with each other as best we can about why they can be perceived as mechanisms and as organisms, for instance. But attempts at a common understanding may be difficult.

Second, the drive for funding will create distortions in our understanding of nanotechnology and nanoscience. Just as we have spent much more money investigating the properties of oil to the detriment of our understanding of the full range of natural substances in the world, so we may find ourselves spending far more money on, say, nanostructures as they are in biology than as mechanisms.

Third, such distortions are not ethically neutral. Funding that might go towards a general understanding, will go to that discipline which makes the best case for nanostructures being just the kind of object that discipline studies. And the best case for funding initiatives will be made by that discipline which makes the "best" and quickest use of nanotechnology.

Biology is advantaged because the concern for medical advances is a perennial winner in funding competition. Presumably, something good will result: we will have new cures and new ways of delivering medication. Yet these benefits will not be driven by an objective assessment of how best to proceed to make use of what we discover in nanoscience. Any benefits will be based on who makes the best case for funding. It might turn out that an objective consideration would produce just the result we get, but that would be a happy accident.

In following some discipline's success down whatever road it happens to take, we will be eschewing other paths that might have been equally or more beneficial. The attendant ethical harms are a result of the way emerging technologies are now developed. The harms are thus internal to nanotechnology: it is, after all, just another technology. Yet the way a technology develops is what I call a social artifact and so can be changed (Robison 1994, pp. 14-34). In that sense, the harms are external to the practices of nanotechnicians because those harms are not the fault of any particular practitioner. There is a degree of responsibility because one is a participant in an ongoing practice. But one would be no more responsible than someone who pronounces 'milk' as 'melk' and thereby encourages a curious colloquial variant.

5. Error-provocative Designs

Stories abound of computer programs that were rushed to market untested and, apparently, even untried. A reviewer of a program that gave driving directions told of the warning that appeared on his screen telling him that he had neglected to put in his state when he filled out the information about his current location. Unable to go forward or back, he had to crash the machine, only to discover, on rebooting, that the lines for one's address did not include a line for one's state. Such examples are all too common in a new technology which is market-driven. The faster a product is out the door, the more quickly the needed funds flow back in.

Similarly, a developing technology driven by grants requires success for continued funding. Success says, "We are on the right track: continue to fund us!" The temptation to shade the truth and the likelihood of touting success before thorough testing are thus high, with all the attendant problems of misleading other researchers, who may follow what is touted as a promising path when it is not, thus setting back development, and so on.

In a mature technology, the history of our successes and mistakes can guide product design. By the mid-thirties, certainly, the standard black desk phone could be dropped off a desk without disturbing a connection. The cutoff buttons were cradled between the prongs that held the receiver when the phone was not in use. Comparison with cell phones is striking – from the ease with which we can break a connection accidentally to the lack of a standard design, increasing the difficulties in figuring out how to operate them.

A rapidly developing technology, driven by external funding or the market and without a history, will produce mistakes. The worst sort are, as I have said, error-provocative designs. These need not be the intentional result of an evil genius of an engineer. They can just as easily be the unintended result of a rush to product, no history of failure to curb the imagination, no time to determine what could go wrong with an artifact so designed.

When the designs concern telephones, the harms are generally relatively minor. With some technologies, the harms could be disastrous. We are only now beginning to understand how flawed computer programs can cause major problems with our energy production and transportation systems because terrorists or hackers may use the flaws to infect and corrupt, disable, or reprogram our systems. Nanotechnology presents just such a concern:

First, the stakes are enormous. The company that patents a nanostructure to deliver medicine will reap a fortune. The company that patents the device that powers nanostructures will earn even more. The first country to utilize nanostructures as listening devices will gain a huge advantage on the battlefields, industrial and military.

Second, the technology is new. We have already been surprised by such small things not behaving as we might expect from their macro- or even micro-siblings.

Third, we have no lag time for discovery. One of the most impressive features of Darwin's development of his theory of evolution is that he took his time so that when his work was published, the evidence was massive and detailed. The vision of a nanotechnologist working slowly and methodically, or sitting in a study mulling over what needs to be done has no place in the development of nanotechnology. Neither does the vision of a cooperative scientific community reading each other's papers and sharing information that will guide future development and prevent the repetition of mistakes and errant investigations. The delay between discovery and publication in a journal is so great that by the time of publication, the technology has already passed it by, either incorporating it or ignoring it. Governmental and industrial initiatives will be secret, and so each lab, in government and in industry, will be working in a relatively isolated position, dependent on what scuttlebutt they can pick up through friends and acquaintances or through reverse engineering of products that are marketed or heard about.

Fourth, what drives nanotechnology gives little time for experimentation. As with genetically altered food, we will be running a full-scale experiment on the world without any clear conception of what harms could result. Think of asbestos here, or birth-control pills. We are still uncovering the difficulties their introduction into our lives has produced. This is not to say that benefits have not resulted, only that harms have occurred which perhaps could have been avoided with a larger time frame between discovery and application. Yet because the benefits of first discovery are so enormous, and the demand for new technological fixes so insistent, we will be introducing products that will likely cause harms – just as the introduction of nanoparticles already may well be causing harm.

So, fifth, we will predictably produce harmful 'stuff.' With the best of intentions, the best practitioners will be working quickly in an area in which they will be surprised.

The lesson is not that we should prohibit work in nanotechnology or in any area of nanotechnology, like bionanotechnology. We could not do so even if we wanted to. The implication to draw is more pessimistic than the one we drew about the harmful surprises we will uncover. We will not be able to control what happens regarding research within a country, and even if we apprise those who work at the nano-level of the complications they, and we, may face, any additional caution they might take will be based on the generality that they may be surprised. That is not a very helpful admonition. They will already know that.

What we have is a feature of an emerging technology supporting the conclusion we drew from a feature of the object of that technology. Nanostructures will conspire to surprise us with harms we will not have anticipated and against which we thus cannot readily protect ourselves.

6. Summary

Ethical problems will arise from features of nanostructures – their Lilliputian and perhaps free-ranging nature, with unpredictable powers, to use Locke's word – and they will arise because nanostructures are being developed in an emerging technology. Some of these ethical problems will be internal to the practice of nanotechnology and nanoscience. For example, we will have the inevitable failures of design and the subsequent harms that arise quite naturally, without intention, when an emerging technology is moving at such speed that it has no history of mistakes, that its practitioners lack the time to consider thoroughly whether there are design flaws, and so on. Some of the ethical problems will be external to nanotechnology and nanoscience. We will have the harms that occur when products of the new technology are used to invade privacy or create new biological agents or means of delivery. We will have the harms attendant upon the introduction of nanostructures into our world, new sorts of environmental hazards that we are ill-prepared to fend off or mitigate.

The ethical problems I have laid out were not randomly chosen. Some are readily predictable, such as the use of nanostructures to invade privacy. Some are scary, such as new nanobiological agents or delivery mechanisms. All require thoughtful decision-procedures on the part of the practitioners of nanotechnology and nanoscience and on the part of all of us, who will use the products of that technology and who will be exposed to nanostructures even if we do not use them. All tend towards a pessimistic view of our capacity to have any thoughtful decision procedures that will mitigate harmful surprises – or intentional harms. Yet I do not mean to provide a complete list of the ethical problems we will face with nanotechnology and nanoscience. Such an attempt would fly in the face of what we know about nanostructures, namely, that we are going to be surprised. It will help us get a handle on future surprises by distinguishing between those ethical problems that are internal to the practice and so of intimate concern to those who work in nanoscience and nanotechnology, and those ethical problems that are external to the practice. The distinction is rough, but is meant to provide a framework within which to place ethical difficulties and so begin to understand how best to respond to them. Whether the framework itself misleads, is itself an empirical question – its resolution depends, among other things, on how the use of this framework helps us grapple with the ethical issues produced by this new technology.

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