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Nanoethics: Assessing the Nanoscale from an Ethical Point of View

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Abstract: In this paper we raise and analyze three fundamental issues related to nanotechnology. First, although nanotechnology is frequently discussed, it is a difficult field to understand and define. We suggest at least a working characterization of the nature and organization of nanotechnology. Second, we examine the nature of nanoethics and motivate why it is a proper concern and possibly an emerging new field. Third, we elaborate several specific ways in which nanotechnology is likely to raise ethical issues. Some of these ethical issues will almost certainly confront us in the not too distant future and others, though not imminent, may well become serious issues some years from now.

1. What is Nanotechnology?

Does a field of nanotechnology[1] exist? This may seem like a strange question to propose given that many people, scientists and non-scientists, understand nanotechnology as today's hot scientific area. Governments are giving out millions of dollars, euros, and yen in research funds. Institutes for nanotechnology are springing up at major universities around the world. Courses and conferences in nanotechnology abound. And as the ultimate existence proof – there are academic journals for nanotechnology. Whereas all of that is true, nanotechnology is relatively new to the scientific scene and is inchoate. One has only to ask people, even those who self-identify themselves as nanoscientists, to define the field and eyes begin to dart. Asking people to describe the best example of nanotechnology produces a scientific smorgasbord of replies. As frustrating as it may be to get clear on what nanotechnology is or might be, it is important to make the attempt. Disputes about the nature and possibility of the ethics of nanotechnology may lie in differences in the conception of nanotechnology itself.

One feature that seems definitive of nanotechnology is that it is a technology that operates on matter on a very small scale – the scale of nanometers. A nanometer – one billionth of a meter – is very close to the dimensions of individual atoms whose diameters range from 0.1 to 0.5 nanometers. Hence, it is reasonable to regard nanotechnology as technology that manipulates atoms and molecules or utilizes the properties of them that occur on the nanometer scale. There is vagueness about where to draw the line. One hundred nanometers or less is a popular choice for a boundary of the nanoworld. But, some who consider themselves nanotechnologists may construct and manipulate even larger molecular structures. So, just to be generous, let us regard anything less than a micron (a thousand nanometers) to be a possible candidate for nanotechnology although obviously there are orders of magnitude differences within that range.

Size offers us an identifying characteristic for nanotechnology, but are there other defining features? A range of approaches regarding the means of production and operation of nanotechnology vie for attention. Recall how the possibility of nanotechnology was suggested originally in a famous lecture given in 1959 by the Nobel laureate Richard Feynman.

> The principles of physics, as far as I can see, do not speak against the possibility of maneuvering things atom by atom. It is not an attempt to violate any laws it is something, in principle, that can be done; but in practice it has not been done because we are too big. (Feynman 1959)

Feynman recommended a path to accomplishing these feats – develop better electron microscopes. In 1981 his vision became a reality when the scanning tunneling microscope (STM) was invented by Gerd Binnig and Heinrich Rohrer at the IBM research facilities in Switzerland. The STM allowed humans to see atoms for the first time and earned the inventors a Nobel Prize in physics. With an appropriate selection of charge the STM can lift atoms out and deposit them elsewhere. This procedure allows the manipulation of atoms one by one. In a graphic demonstration of the power of the STM, researchers in the early 1990's created the smallest advertisement in the world by writing the letters "IBM" using xenon atoms. With the development of the STM two important missions of chemistry – the analysis of substances and the synthesis of substances – were made easier. A crucial tool for the development of nanotechnology is now available. But to what extent could an atom-by-atom assembly be practical? Clearly, manipulating atoms one by one with a STM is not an efficient method for the construction of useful amounts of any substance.

General chemical techniques can be used to produce large batches of nanoparticles. For example, sol-gel technology is sometimes regarded as nanotechnology. Sol-gels are colloids, suspensions of tiny particles, in liquids that keep their shape and can be used to encapsulate very small particles. This is particularly useful in developing products such as safe sunscreens. The active ingredients in sunscreens absorb, reflect, or scatter ultraviolet light. Unfortunately, when these active sunscreen ingredients do their job, they can produce photodegradation products and free radicals that can be absorbed through the skin. To prevent absorption these active ingredients are encapsulated in miniature sol-gel nanoparticles (Wilson *et al.* 2002, p. 71). General chemical techniques are effective and efficient, but they do not seem particularly special for a new technology.

The most elegant approach for nanotechnologists is to generate beneficial products through self-assembly. Self-assembly occurs when ingredients are added in the right sequence under the right conditions and the laws of nature construct the structure. Water turning into an icicle is a familiar, simple example of self-assembly. In this manner, rather than manufacturing a computer chip from the top down as we do now, a chip might be grown from the bottom up in a beaker. An example of this approach is the development of a biosensor in 1997 (Cornell *et al.* 1997). This biosensor has an ion-channel switch one and a half nanometers across that has a high sensitivity similar to chemical sensors in living creatures. It has a synthetic membrane that allows different ions to pass selectively. Two halves of a molecule set in the upper and lower layers of a membrane slide past each other. If nothing is detected, the molecule halves can slide into alignment and ions can flow from one side of the molecule to the other. If the target chemical is present and binds to the biosensor, alignment cannot take place and the circuit is broken. Variations of this biosensor could be used to detect blood type, bacteria, viruses, antibodies, DNA, drugs, or pesticides. Because the device is attached to a gold base, it can become an integral part of a microelectronic circuit. The biosensor is not built from the top down but grown from the bottom up by adding chemicals in the right proportions.

As we have seen, if we try to define 'nanotechnology' in terms of the means of its production, we have a choice among candidates such as atom by atom, general chemical techniques, and self-assembly. Possibly, we will be more successful in our search for defining properties of nanotechnology by seeking conditions on how the technology is expected to function. But here again we see a variety of approaches. Some nanotechnologists envision the construction of mechanical nanomachines that have parts such as wheels, axles, gears, hinges, and pumps. For example, carbon nanotubes, hollow tubes with graphite walls, come in various dimensions. These can serve as axles and can be geared to translate or reverse motion. They can serve as pumps or pistons by moving the inner tube of a multiwalled nanotube. Such a nanopump already has been constructed in the laboratory (Wilson *et al.* 2002, p. 107).

In other cases the nano-objects are standard computing chips but are constructed on the nanoscale. Stan Williams and researchers at Hewlett Packard make computer memory devices by creating eight platinum wires 40 nanometers wide on a silicon wafer, putting switch molecules on top, and then running eight more wires running perpendicularly to the original wires. Each of the 64 points where the wires cross the molecules between them becomes a bit of memory. This structure is reminiscent of the core memory of the 1960's computers but on a dramatically reduced scale. It would take more than a thousand of these 64 bit chips to be the width of a human hair (Antonelli 2002, p. 3).

Eric Drexler, the leading prophet of nanotechnology, offers another conception of the future of nanotechnology in which nanomachines, mechanical or otherwise, operate as assemblers that will allow us to construct molecular structures.

> Because assemblers will let us place atoms in almost any reasonable arrangement […], they will let us build almost anything that the laws of nature allow to exist. (Drexler 1996, p. 14)

Drexler's vision of how the central nano-objects will function is the boldest. According to him, molecular computers will control these molecular assemblers. Molecular computers will operate electronically, mechanically, chemically, optically, or otherwise and will perform their calculations thousands of times faster than today's computers because of their decreased size. Drexler imagines these nanocomputers will have memory capabilities that will allow them to locate instructions and to record information as well. Whereas assemblers synthesize, disassemblers can be built to break down and analyze. Disassemblers are nanomachines guided by nanocomputers that through the use of enzymes and other chemical agents take substances apart a few atoms at a time and possibly record what they find in their analysis. Finally, replicators are assemblers programmed to make copies of themselves. If a replicator makes a copy of itself, and both of these make more copies, and so forth, in a reasonably brief time through exponential growth, literally tons of replicators could exist assuming the raw products needed for replication are available.

Although Drexler's conception of such assemblers, disassemblers, and replicators seems fantastic, he argues that nature already has them. Cells replicate by copying their DNA and dividing into two. The DNA in a cell provides the program for the cells to build the body. The information from the DNA is transcribed into RNA that is read by the ribosomes as a set of instructions for building proteins. Thus, biology provides a kind of existence proof for the possibility that molecular machinery can construct complex organisms from the bottom up.

It is not surprising that an incipient field like nanotechnology is not well-defined. There is a choice of size for which objects should be considered nano-objects. There are multiple means of construction of nano-objects (atom by atom, standard chemistry, self assembly, etc.). There are multiple means of operation of nano-objets (mechanical, electronic, chemical, etc.) Necessary and sufficient conditions are difficult to find for many concepts and the evolving, multifaceted concept of nanotechnology is among them. 'Nanotechnology' is probably better understood as a family resemblance term. There are some paradigm examples of nanotechnology and other cases that are related more or less closely to the paradigm examples. Paradigm examples of nanotechnology have an interdisciplinary flavor to them. A good paradigm of nanotechnology is a self-assembling object whose operation is best understood as part chemistry, part physics, part biology, part computing, and part engineering – all of which projected into the nanometer realm. The biosensor described earlier is an instance of such a paradigm example. This is not to say that nano-objects that lack such an interdisciplinary orientation fail to be examples of nanotechnology but that they may be less clear examples.

We have been carefully surveying the multifaceted nature of nanotechnology because we believe this multifaceted nature can explain some disagreements about nanotechnology and its effects. For example, one could select certain examples and claim that nanotechnology has existed for a very long time. Chemists have been synthesizing compounds that depend upon self-assembly for centuries. Scientists have grown crystals, including semiconductor crystals, one atomic layer on top of another, for some time. Thus, one might conclude the field is not new at all, just old fashioned chemistry. Or one could pick other examples, such as some of Drexler's imagined artificial assemblers and argue that the field does not exist and may never exist. Both of these conclusions are extreme, but our point is that one's choice of a conception of nanotechnology can have a major impact on what conclusions one draws about it including conclusions about what its ethical and social implications are likely to be.

2. What is Nanoethics?

Nanoethics is the ethics of nanotechnology. But, if the choice of what counts as nanotechnology is not agreed upon, then obviously the importance of nanoethics may be difficult to establish. If one believes nanotechnology is just straightforward applied chemistry and nothing more, then nanoethics becomes the ethics of chemistry at best. Or, if one believes nanotechnology refers only to fanciful mechanisms that in principle cannot exist, then the value of nanoethics is dubious. To avoid confusions and disagreements about the nature of nanotechnology due to narrow definitions, we will assume a broad understanding of it. The size of its basic objects is on the nanoscale, and its means of production and methods of operation may vary considerably. And though many objects count as examples of nanotechnology for us, we find the compelling paradigm to be one that has an interdisciplinary appeal to physics, chemistry, biology, computer science, and engineering.

Often, discussions of ethics quickly focus on harmful practices. This may mislead some into regarding ethics as an attack on a field rather than on the potential negative outcomes of that field. Clearly, technology can produce benefits as well as harms. In particular, nanotechnology offers much hope for improving the human condition. In order not to focus exclusively on potential dangers, let's begin by considering some of the positive consequences of nanotechnology that we might expect. If we adopt our broad understanding of what counts as nanotechnology, then many good consequences from it are likely to materialize in the not too distant future. For example, nanotechnology might be employed to help clean up the environment. Dr. Braach-Maksvytis suggests creating artificial photosynthesis. Solar-powered paints could remove CO_2 from the atmosphere and convert sunlight into useable energy. Alternative systems could remove other pollutants from the air (Luntz 2001). Lighter but stronger materials could be developed from designer molecules. Planes made of lighter materials with the strength of diamonds would be more fuel efficient and safer. Clothing made of stronger materials would last longer. Further into the future health inducing nanobots might travel through blood vessels clearing away plaque and entering cancerous cells to destroy them. Nanotechnology might be able to manufacture food and clean water cheaply. Computer chips might be made inexpensively from chemical synthesis avoiding toxic byproducts. A technology that offers the hope of a cleaner environment, better materials, improved health, plentiful food, and cheaper computing is very attractive. Until recently, nature has been the chief nanotechnologist; now humans will get their share of the action. Even in the short run, the potential for improving human flourishing through nanotechnology is impressive.

Moreover, the possible application of nanotechnology in the long run is nothing short of breathtaking. If quantum computing becomes feasible, then an enormous number of independent calculations may be done simultaneously. And, theoretically any object could be constructed atom by atom if methods could be found to manipulate and assemble the atoms rapidly in the right way. Nanotechnologists would not be limited to what does exist or has existed but would on this vision be able to create radically new objects including new forms of life.

The potential benefits are immense but the potential dangers are immense as well. If nanotechnology becomes as fruitful as some expect, harmful outcomes are inevitable. Nanoethics will be needed (Weckert 2002). What would nanoethics be like if it became a field of inquiry? Sometimes, fields of applied ethics are organized under the rubric of a professional field, so called "professional ethics". Medical ethics, legal ethics and engineering ethics are good examples. Almost any field that is a profession can spawn a field of applied ethics. Nursing ethics, architecture ethics, police ethics, and accounting ethics are examples. But nanoethics does not fit comfortably under this model, at least not yet. There is a growing number of professionals who do nanoscience and nanotechnology, but for the most part these individuals are not yet regarded as professional nanoscientists or nanotechnologists as opposed to say professional chemists doing nanoscience or nanotechnology. Nanoethics, if it becomes a separate field, would be better understood on the model of bioethics. Bioethics considers the ethical implications of activities and results not only of medicine but also of the biological sciences. Familiar issues in bioethics include whether euthanasia is justified, how stem cells should be used, how to fairly distribute scarce organs for transplant, and whether animals should be used in research. Similarly, nanoethics would consider ethical implications of activities and results of nanotechnology and nanoscience. Issues in nanoethics would include how to safeguard privacy in a world with nanosnooping devices, to what extent the manipulation of human beings should be permitted, and how to minimize the risk of runaway nanobots.

However, it is not our position that nanoethics need or will become a separate field of inquiry at all. What should concern us is that nanotechnology will raise various ethical problems, some new and some not new but only with a different slant. These ethical problems will need to be addressed. We take the business of nanoethics to be the ethical examination of the impact of nanotechnology whether or not it is regarded as a specific academic discipline.

It is a familiar cliché that ethics does not keep pace with technology. With the advent of nanotechnology it might be thought that we have an opportunity to do it differently – to do the ethics first. This is essentially the proposal offered by Bill Joy who suggests that we place a moratorium on such frontier science until we can understand the consequences of doing it (Joy 2000). The problem with the ethics-first model is that ethical assessment depends in large part on a factual determination of the harms and benefits of implementing the technology. But, when one asks nanotechnologists what the future of nanotechnology will be in five years or ten years, let alone twenty-five or fifty years, reaction varies from a blank stare to some cautious speculations about some narrow aspect of the field. A moratorium stops the technology but does not do much to advance ethics (Weckert 2001). The ethics-last model, the traditional default to the ethics first model, does not fare well either. Once a technology is firmly in place much unnecessary harm may have already occurred.

Our position is that the ethics-first model and the ethics-last model are popular but poor solutions to a false dichotomy. Nanoethics is not something one can complete satisfactorily either first or last but something that needs be done continually as the technology develops and as its potential consequences become better understood. Ethics is dynamic in that the factual component on which it relies has to be continually updated. Nobody can predict the consequences of complex technological changes far in the future. But, it is not only the factual flux that forces us into a dynamic approach toward ethics. New technology often creates novel situations for which no ethical policy exists or seems immediately obvious. In the face of policy vacuums we need to consider how to formulate new and appropriate ethical policies given the new facts (Moor 2001).

To emphasize the need for nanoethics we present three key ethical issues that likely will be exacerbated by developments in nanotechnology. These issues are privacy and control, longevity, and runaway technology. These are not new issues by any means, but are ones that nanotechnology will give its own special twists. We selected these topics to further emphasize the dynamic nature of applied ethics because they vary in probability of occurrence and the degree to which we can currently know them.

3. Privacy and Control

Privacy is clearly an issue that will be impacted by nanotechnology. People often snoop on other people, and generally, when new technology makes accessibility to others easier and detection of snooping more difficult, illegitimate snooping can be expected to increase. When personal records, such as medical records, became electronic, new policies and safeguards needed to be put in place to protect people from invasions of privacy. Today miniature cameras are everywhere including cameras packed into cell phones. In almost any place, while going largely unnoticed, people can snap pictures of others and then send the pictures immediately anywhere in the world.

Now imagine that in our world of shrinking privacy we add nanotechnology. We will construct nanoscale information gathering systems. It will become extremely easy to put a nanoscale transmitter in a room or onto someone's clothing so that he or she will have no idea the device is present or that he or she is being monitored and tracked. Nanotechnology will make it easier for us to wear cameras invisible to others that can keep detailed movies of what transpires. It will make it easier to tap phone lines in ways that are virtually undetectable. It may become depressingly difficult to keep any secrets or live a life at a reasonable level of solitude.

Implanting tracking mechanisms within someone's body would also become easier with nanotech devices. A tracking mechanism might be put into someone's food so that, when swallowed, it would be absorbed into the body, possibly migrating to a desired location. If we regard anything as private, it is our bodies and minds. We have a natural barrier, our skin, that makes it difficult for most people other than doctors with special equipment to snoop inside. But, theoretically with nanotechnology and wireless transmission a person's brain functioning could be unknowingly tapped and information about it transmitted. Reading someone else's thoughts might be difficult, but capturing information that would be indicative of a particular mental state, such as anger or sexual arousal, might be rather easy.

Along with the lack of privacy engendered by nanotechnology would come a lack of control. Because in general people would know more about other people, we might be less capable of controlling the outcomes of our choices. Those who had the additional information about us might subvert our activities. And nanotech implants, injected or ingested, might literally turn control of one's body over to others. The chips, for example, might stimulate the brain's pleasure center when certain actions were performed. This would be an effective way for some people to control others without them being aware of being controlled. This is possibly an attractive option for parents, employers, and dictators, but not something most of us would want.

How the use of nanotech devices will work in these kinds of cases is still a matter for research. But, what is not speculation is that with the advent of nanotechnology invasions of privacy and unjustified control of others will increase. This has been our recurring history. When new technology provides us with new tools to investigate and control others, we use them. We already have nanoscale computing chips. That nanochips will be used for spying and control of others is a practical certainty.

4. Longevity

Developments in nanotechnology could have a dramatic effect on human life spans, in three ways. First, and least controversially, nanotechnology will almost certainly have medical benefits. Early diagnosis and new cures will have some effect on longevity. A more spectacular, but more distant possibility is the development of cell repair devices. If these are developed, it will be possible to reverse or prevent aging, so life spans could be increased enormously. A third way that nanotechnology might contribute to longevity is through the development, by growth or construction, of body parts to replace those worn out or otherwise damaged. Particularly significant could the development of tissue that the body would not reject.

Many people, including nanotechnology enthusiasts, see longevity as obviously a good thing. After all, most of us are not too keen on dying and will do whatever we can to avoid it. But not all are so enthusiastic. Leonard Hayflick, an expert in gerontological research writes:

> I have long been worried about the enormous power that humans will have if we ever learn how to tamper with the aging process or to extend our longevity – it is unclear whether people could cope with the psychological, economic, medical and cultural changes that would accompany vastly extended life spans, even if they prove physiologically possible. … Although aging and death put an end to the lives of good citizens, they also make finite the lives of tyrants, murderers and a broad spectrum of other undesirables. Much of the continuing massive destruction of this planet and the consequent ills that this destruction produces for humans can be traced to overpopulation, […] Extending the life of a population that already strains global resources is, in the view of many, unconscionable. (Haflick 1997, p. 94)

The population problem would be a serious a problem. Increasing life spans does not change the rate of population increase, only the size of the population. However, the increased size of the population itself could be a problem, if life expectancy is long enough. In a country with a life expectancy of say 70 years, there needs to be one baby born for each adult every 70 years for the population to remain stable. Suppose that the average life span was 210, treble what it is now. To maintain a stable population, for each adult, a baby would be required only every 210 years. People may or may not be happy to spend only a very short part of their lives raising a family. There are going to be very few children around relative to the population in general.

Another potential area of concern is the lack of new ideas and "new blood". Children and young people in general, bring new ideas, attack problems in new ways, and are generally more enthusiastic and innovative. This reservoir of vigor and innovation could be reduced significantly. This, of course, need not be a problem. It all depends on the type of long lives that people have. If all stages were elongated, the young would be young longer, so this problem would not exist. But the old would be old longer, too, and this might be a problem. But perhaps the bulk of our lives will be spent in what we now think of young adulthood and middle age. Or something else! We have some reason to be optimistic about being relatively sprightly both mentally and physically at 75, but we have no idea how we would be at 500.

The working assumption is that because a certain amount of life is good, more of it would be better. It is obviously not a general principle that if a certain amount of something is good therefore more of it is better. Take alcohol, for example. Longevity is not attractive unless the life is a pleasant and enjoyable one. Living for a hundred years in poverty, pain, fear, boredom, or old age, does not seem to be desirable or attractive. But having an extra hundred years of interesting and happy existence does sound good. Does living happily for 500, 5000 or even 50,000 years seem even better? The longer the time frame, the harder it is to know what to say. Perhaps after some time, life would become sterile and boring, although this does not seem to be a necessary outcome.

Nanotechnology will almost certainly have benefits for the health of humans, and this is clearly desirable. What is not necessarily an unmitigated good is increased longevity in itself. Some potential issues of concern have been noted. Some of these will most likely be real concerns in the not too distant future, such as overpopulation, unless other developments keep pace, such as ways of cleaning up the environment. Other concerns are more speculative, but, as in the case of the runaway nanobots discussed in the next section, they are within the realms of possibility, so are worthy of discussion now.

5. Runaway Nanobots

In Eric Drexler's vision, assemblers are the workhorses of the nanotechnology revolution. In our genetic world, DNA, RNA, and ribosomes do the work of building and repairing bodies. The memetic nanocomputers and assemblers will do all of this and more. Assemblers, if they are working for our benefit, build what we desire. The danger is that replicating assemblers might build what we do not want. Even worse such replication might get out control. Drexler explains,

> Tough, omnivorous "bacteria" could out-compete real bacteria: they could spread like blowing pollen, replicate swiftly, and reduce the biosphere to dust in a matter of days. (Drexler 1996, p. 172)

The problem of runaway replication is frequently called the "gray goo" problem. Of course, the legions of replicators need not be gray or gooey, but the phrase "gray goo" nicely conjures up an image of amounts of undesirable, amorphous, nondescript stuff that could clog up and damage parts of the world. At the very least a gray goo situation would be unpleasant. In its worst form, a gray goo situation would be deadly to humans. Replicators might make resources required for human life unusable or, for that matter, humans might be just the food that the replicators need to survive.

As scary as this scenario is, it is difficult to attach probabilities to it occurring. Are replicators really a possibility? Richard Smalley, who is an enthusiastic supporter of nanotechnology – not to mention a 1997 Nobel laureate for the discovery of fullerenes, important component of the nanorevolution – challenges the idea of robotic replicators. Smalley raises the question "How soon will we see the nanometer-scale robots?" and then he unequivocally responds, "The simple answer is never" (Smalley 2001, p. 76). Smalley raises two issues. The first is the fat fingers problem. The fingers of a self-replicating nanobot used to insert atoms in the target product must be made out of atoms. Because several fingers will be needed to control the atom being placed along with other atoms in the vicinity that will exert forces, there isn't enough room to accommodate all of the fingers required to completely control the chemistry. The other concern of Smalley is the sticky fingers problem. The atoms of the fingers of the self-replicating nanobot will adhere to the atom that is being moved. It will often be impossible to release the atom in just the right spot. Smalley concludes, "Both of these problems are fundamental, and neither can be avoided. Self-replicating, mechanical nanobots are simply not possible in our world" (Smalley 2001, p. 77).

As one might imagine, Drexler and his colleagues are not convinced by Smalley's claims (Drexler *et al.*, 2001). Although Drexler often speaks of atom-by-atom, he makes it clear that pieces of the final product can be assembled separately and then the larger pieces brought together. Hence, fat fingers need not be a problem. Moreover, if the sticky finger problem was fundamental, why would it restrict only mechanical assemblers and not biological assemblers such as ribosomes that obviously do work? Hence, the sticky finger problem for mechanical assemblers is not demonstrated or so Drexler claims. If nature allows it, why can't we do it? Drexler maintains that we should take seriously at least the eventual possibility of runaway replicators.

> Replicators can be more potent than nuclear weapons: to devastate Earth with bombs would require masses of exotic hardware and rare isotopes, but to destroy all life with replicators would require only a single speck made of ordinary elements. (Drexler 1996, p. 174)

6. Conclusion

These three areas privacy and control, longevity, and nanobots, are very different but eventually nanotechnology will likely produce consequences of ethical concern in all of them. These areas differ in part because of their proximity in time and our knowledge of them. Given our broad definition of nanotechnology we already possess the kind of nanotech devices that can impact privacy and control. Privacy and control is a subject of major concern that will need immediate and ongoing attention. Longevity is likely to be increased by nanotechnology, but the impact of that undoubtedly lies in the future and is somewhat less certain. Nevertheless, it is a reasonable bet that nanotechnology will improve our health and safety and hence extend our lives. In time, humans may be forced to address questions such as whether some people should be allowed to have multiple sets of children over very extended periods of time and whether even the examined life is worth living beyond a certain age. Finally, the threat of runaway nanobots seems well into the future and a scientific debate rages over whether it will become a serious risk. Our point for now is that it is not just scientists who need to consider the potential risks of nanotechnology, for all of us will be seriously affected if privacy is greatly diminished, if human life is greatly extended, or if programmable nanobots become a reality.

Nanoethics is nascent but an important concern, if not yet a fully developed enterprise, that needs to be maintained in conjunction with the development of nanotechnology. Nanoethics encourages the skepticism and scrutiny required to keep nanotechnology within ethical boundaries so that this promising new technology works only in the service of human flourishing.

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Note

1 For our purposes we will use 'nanotechnology' to cover both nanoscience and nanotechnology. Of course, within the field some researchers work in more applied areas and others are more closely associated with a purely scientific endeavor.

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