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Chapter 3

IDENTIFYING ETHICAL ISSUES OF NANOTECHNOLOGIES

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The discussion of the ethical issues of nanotechnologies faces three difficulties: public hype, unclear definition and the early state of nanotechnologies.

First, nanotechnology is surrounded by a great deal of hype, hailed as the revolutionary technology of the twenty-first century with the enormous potential to radically change everything, from industrial production to the way we live and see ourselves as human beings, and the power to be disastrous to humanity. These utopian and dystopian visions, which all originate in science fiction, have been reinforced by various groups, including futurologists, software engineers, investment consultants, religious sects and governmental agencies. Such visions have created exaggerated public hopes and fears, as well as ethical concerns, with the consequence that nanotechnology is discussed mainly in terms of the societal and ethical implications of these visions (Schummer, 2004b; 2005). The proliferation of such 'envisioned' issues makes it particularly difficult to identify and articulate issues from an ethical point of view.

Second, the definition of nanotechnology is anything but clear. So many definitions abound that the meaning greatly differs from country to country, from discipline to discipline, and from public to public. In addition, with the launch of national nanotechnology programmes and their huge budgets, almost any science and engineering discipline can jump onto the bandwagon of nanotechnology and attach the 'nano' label to their research. The fuzziness of nanotechnology makes it almost impossible to identify ethical issues with the desired precision.

Third, most of what is now called nanotechnology is still in the early stages of research. Yet identifying ethical issues of the technologies in their final form would require foreseeing the outcome of the research and development processes, which even the researchers are unable to do.

Because of these three obstacles, it is advisable to approach nanotechnology from a critical and broader perspective. Before discussing ethical issues, it is important to understand the social context in which nanotechnology has emerged, including its various traditions, meanings, stakeholders, propagators and critics, as well as what researchers are actually doing in their laboratories. In addition to various governmental reports (e.g. Roco and Bainbridge, 2001; European Commission, 2004; Royal Society & Royal Academy of Engineering, 2004; Paschen et al., 2004), an international community of philosophers, ethicists, historians of science and social scientists has been discussing ethical issues of nanotechnology in view of the broader context (e.g. Fogelberg and Glimell, 2003; Baird et al., 2004; Hayles, 2004; Schummer and Baird, 2006; Nordmann et al., 2006). Apart from various other debates, scholars are in agreement that nanotechnology has emerged continuously over several decades rather than discontinuously, is diverse rather than monolithic, is much more normal than visionaries claim, and that the important ethical issues are concealed rather than clarified by the current nano-hype.

This chapter provides a survey of our current understanding are the most important ethical issues of nanotechnologies, while also placing emphasis on global equity issues and the potential impact of these technologies on developing countries (Schummer, 2006; 2007). The chapter will conclude with some recommendations on how governments should deal with these issues. But first, what is 'nanotechnology'.

THE DEFINITION OF NANOTECHNOLOGY

There are at least three different ways in which nanotechnology has been defined, and each one shapes perception of ethical issues in a radically different manner. Unfortunately, more sophisticated definitions have been neglected thus far (Schmid et al., 2003).

Nominal definition

The first definitional approach defines a term by providing necessary and sufficient conditions – what philosophers call a *nominal definition*. In this regard, the standard definition states that nanotechnology is the investigation and manipulation of material objects in the 1–100 nanometre range so as to explore novel properties and develop new devices and functionalities that essentially depend on the 1–100 nanometre range. Whether this is intended or not, the definition covers all the classical natural science and engineering disciplines that investigate and manipulate materials or material objects, such as chemistry, materials science, solid state physics, pharmacy, molecular biology and chemical, mechanical, electric and electronic engineering. This is because almost every material is structured in the 1–100 nanometre range such that its structure in this range determines its properties and, technologically speaking, its functionalities. Table 3.1 lists some commonly known substances that have crystallographic lengths in the nanometre scale, including elements such as sulphur and ordinary substances such as sugar (glucose) along with the much celebrated 'nanosubstance' buckminsterfullerene, or C_{60}. If one sticks to that definition, one will not perceive any new ethical issues, simply because there is nothing new about nanotechnology other than the name. And in fact researchers from most of the science and engineering

Table 3.1. Examples of commonly known substances with crystallographic lengths in the nanometre scale

Substance name	Empirical Formula	Biggest crystallographic unit cell length
Formic acid	CH_2O_2	1.02410 nm
Buckminsterfullerene	C_{60}	1.40410 nm
Glucose	$C_6H_{12}O_6$	1.48400 nm
Gypsum	H_4CaO_6S	1.52010 nm
Vitamin C	$C_6H_8O_6$	1.71000 nm
Alanine	$C_3H_8ClNO_2$	1.75900 nm
Sulfur	S_8	2.43360 nm
Vanillin	$C_8H_8O_3$	2.50990 nm
Cholesterol	$C_{27}H_{46}O_1$	3.42090 nm
Vitamin D_3	$C_{27}H_{44}O$	3.57160 nm
Pepsin	unspecified	29.01000 nm

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disciplines are now re-labelling their research 'nano' – and rightly so according to this definition – because that helps them to raise funding.

Teleological or visionary definition

The second definitional approach, called *teleological definition*, defines nanotechnology by its future goals. On a very general level, these goals can be values such as health, wealth and security, or relative values such as smaller, faster, harder, cheaper – but this remains very unspecific. Since Eric Drexler first introduced the term in 1986, teleological definitions of nanotechnology have come in the form of visions of a future technology to be developed that will radically change everything, from industrial production to the physical, mental and social conditions of human life. According to this approach, current research belongs to nanotechnology if it helps to realize the envisioned nanotechnology that in turn will achieve the prospective goals. Numerous visions of this kind are in circulation, particularly in the US, and more recently in Europe. Besides Drexler and many other software engineers who dominate the popular book market on nanotechnology with their fantastic visions of nano-robots that can do anything (from DNA-repair to immortality and from self-replication to the total destruction of all intelligent life by 'grey goo'), there is a proliferating nanoscience fiction field that has essentially inspired them (Napier, 2004). In addition, US agencies have fashioned their own nanotechnology visions, which range from the Drexler-like 'shaping the world atom by atom' to transhumanist-like visions of a 'convergence of nanotechnology with biotechnology, information technology and cognitive science' for the 'enhancement of human performance'.

If one adopts these visionary definitions, ethical issues of nanotechnology immediately arise because they are part of the definitions. Such visions are meant to stir emotions, hopes and fears, rather than knowledge. They tell us what we should desire (what is good) and what we have to fear (what is bad). Thus, according to the visionary definitions, the ethical issues of nanotechnology have all been identified already by science fiction authors and futurologists, and so there is nothing left for ethicists to do. The problem, however, is that these visions are scientifically implausible or at least unfeasible in the foreseeable future. And because these visions are hardly related to actual

R&D activities in nanotechnology, they distract from the much needed analysis of the real ethical issues.

Real definition

The third definitional approach, also called *real definition*, refers to a list of particular research topics that usually appear under the umbrella of nanotechnology in governmental research programmes, in nanotechnology research centres, in nanotechnology journals and at nanotechnology conferences. Table 3.2 provides a list of the most frequently mentioned research fields (see also Chapter 2 above).

Table 3.2. Research fields that are usually related to nanotechnology

• scanning probe microscopy • nanoparticle research • nanostructured materials, polymers and composites • ultra-thin coating • heterogeneous catalysis • supramolecular chemistry • molecular electronics • molecular modelling • lithography in the production of ITs (integrated circuits) • semiconductor research and quantum dots	• quantum computing • MEMS (micro-electro-mechanical systems) • liquid crystals • small LEDs (light emitting diodes) • solar cells • hydrogen storage systems • biochemical sensors • targeted drug delivery • molecular biotechnology • genetic engineering • neurophysiology • tissue engineering

These research fields belong to a wide range of disciplines, including microscopy, materials science and engineering, surface science, organic chemistry, quantum chemistry, electrochemistry, electric engineering, solid state physics, mechanical and chemical engineering, biochemistry, molecular biology, and physiology. It is difficult to say whether they have anything in common other than that they are topical, since they represent the latest developments in most science and engineering disciplines. Moreover, contrary to frequent claims, there is no particular interdisciplinarity in these fields, whereas the list as a whole is, of course, very multidisciplinary (Schummer, 2004a). Therefore, it is more appropriate to speak of nanotechnologies (plural) than of nanotechnology (singular).

If one adopts this definition, as will be done in the following, the identification of ethical issues is a big challenge due to the diversity of topics. Moreover, the list of topics varies from country to country and has changed over time and thereby come to include new research fields. From an ethical perspective, it is difficult to identify any one possible issue that would apply equally to all the fields. On the other hand, the list includes many long-term research projects, such as semiconductor research, catalysis and genetic engineering, some of which have long been discussed from an ethical point of view. Since it makes little sense to repeat, for instance, the ethical discussion of genetic engineering now under the umbrella of nanotechnology, such discussion will be omitted in the following.

A TYPOLOGY OF ETHICAL ISSUES

Given the fuzziness and diversity of the concept of nanotechnology and the current hype, it seems appropriate to divide the discussion of ethical issues into specific and general issues. Specific ethical issues of technologies arise from particular research processes, the technological products and applications, and the manufacturing processes from laboratory to industrial scale. General issues arise from the way in which nanotechnology programmes as a whole are launched, controlled, and governed, as well as from how they are situated in the broader scientific and societal context. It is understood, however, that, while this chapter focuses on ethical issues, many nanotechnologies promise to have beneficial results for society and thus can contribute to the overall well-being of humanity if the ethical issues are properly considered.

Specific issues

Although the six groups discussed in the following do not exhaust the full range of ethical issues of the diverse field of nanotechnologies, they represent the most important ones in my view and bring some order to the matter according to the following rationale. First, since nanotechnologies aim at both improved materials and improved devices, it is reasonable to divide the discussion into health and environmental issues arising from new materials *and* issues of control arising from new devices. Second, because medical and military applications of nanotechnologies are the two main R&D foci of public concern, it is appropriate to discuss them separately. Third, the global dimension of nanotechnologies and their impact on economies, particularly those of developing countries, requires a discussion of global equity issues both regarding the material and the intellectual sides of nanotechnologies.

Health and environmental issues of new materials

At this point the most urgent ethical issues are the possible health and environmental risks of nanoparticles due to a substantial gap in all national and transnational regulations. It has been known for centuries that particles of exactly the same chemical composition have different properties depending on their size and shape in the nanometre range. This includes mechanical, optical, electromagnetic, thermodynamic, chemical, catalytic and biological properties, as well as of course the way these particles can migrate in the environment and through biological membranes. In addition, the phenomenon can in principle be explained, though hardly predicted in real cases, by quantum mechanics, for surface atoms and bulk atoms have different electronic structures, and the smaller the particle, the higher number of atoms are on the surface. However, in stark contrast to scientific knowledge, national regulations for chemicals, consumer products and work safety disregard the size- and shape-dependence of properties and focus solely on chemical composition. This means that a substance could, for instance, pass the required toxicity tests for new chemicals if the tests are performed on large particles, even if small particles of the same substance are toxic.

Of course, nanoparticles are not new. There are natural sources, such as volcanic ash and aerosols, as well as anthropogenic sources, such as combustion and abrasion, which have provided long-term exposure to certain nanoparticles. However, R&D activities in the fields of nanoparticles and nanostructured materials and composites are now systematically exploiting the size- and shape-dependence of properties with the goal of large-scale industrial production of improved materials. Much of the ubiquitous talk of 'the next industrial revolution' refers exactly to that. The results will not only be new materials but also entirely new exposure to nanoparticles, both regarding quantity and chemical composition, from production, distribution, consumption and abrasion processes. Both the new industrial opportunities and the new health and environmental risks go hand in hand, so that it is deeply irresponsible to celebrate the new opportunities and simultaneously disregard the risks.

Because some products based on nanoparticles or nanostructured composites are already on the market and many more are in the pipeline, there is an urgent need to define new standards for testing the safety of these products and their abrasion and to make these standards the basis for new regulations. In addition, there is an urgent need for the much-too-long-neglected research in nanoparticle toxicology, as well as in methods for making nanoparticles safe by surface treatment or encapsulation.

Control issues of new devices

From lithography to molecular electronics, many nanotechnologies aim to make electronic computing devices smaller and faster. In addition, devices for signal detection and emission, for solar energy collection and storage, and for mechanical, electrical and chemical operations, are being miniaturized at the micrometre level. All these technologies together provide a toolbox for various devices or systems of devices that can perform increasingly complex tasks with increasing autonomy, such as radio frequency identifiers (RFIDs) and systems for ubiquitous computing. Because many nanotechnologies are involved in extending the toolbox, they have been called 'enabling technologies' and only as such are they subject to ethical issues about devices. Whereas the universal 'nanorobot' is science fiction, and will certainly remain so forever, multi-task devices are being scaled down from the millimetre to the micrometre level with the help of various nanotechnologies.

Continuous technological processes, such as miniaturization, usually do not pose new ethical issues unless they transcend thresholds defined by human capacities. For instance, beyond the threshold of human sense perception, devices may cause changes, intrude on privacy or build up a surveillance system without being detectable. At a certain level of complexity, devices may perform quasi-autonomous decisions that we thus far confine to human beings with moral and legal responsibilities. Or devices may interact with each other on a systems level such that their collective behaviour becomes unpredictable and uncontrollable.

In all these cases, new ethical issues arise if the devices get out of control and harm human beings without there being anyone who can be held responsible. To cope with the emerging issue of responsibility, strict regulations are required that define the level of necessary human control and the scope of allowed tasks by devices and assign clear responsibilities to the producers and users of devices. In addition, the development of new devices needs to be accompanied by methods and instruments for detecting and disabling these devices.

Issues arising from military applications of nanotechnologies
Since a large part of governmental R&D budgets for nanotechnologies in at least some countries has been spent on military applications, it is appropriate to deal with military aspects separately. Typical public concerns are about the development of new nanotechnologies-based weapons, particularly biological and chemical weapons and the miniaturization and automatization of fighting and control systems, which would not only pose new threats and undermine international conventions but might also induce a new arms race. However, since most of the military research is actually classified, many of the concerns are based on speculation, for which again science fiction provides a rich source of inspiration. On the other hand, because it undermines democratic technology governance and public trust, an important ethical issue is the fact that under the label of 'nanotechnology' aspects of research are increasingly being classified and thus kept apart from public control and are thereby becoming subjects of public fears.

Moreover, military interests in R&D have shaped the goals of nanotechnologies from the very beginning, which impacts on human values in civil society. The targeted convergence of nanotechnologies with bio-, info- and cognitive sciences and technologies for the 'enhancement of human performance' (Roco and Bainbridge, 2002) is based on very specific ideas of what human improvement means. Enhanced physical strength, bullet-proof cloths, enhanced sensual capacities in the infrared or other ranges, enhanced mental capacities through brain-computer interfaces, and so on, all may well improve the military performance of soldiers. However, although these goals might appeal to some individuals, civil societies are built on different human values and different human qualities than those needed for military operations. Thus the intrusion of military values into civil society is a harmful distortion because it devalues moral and social values and the corresponding human capacities on which every civil society depends.

Finally, R&D projects of 'human enhancement' will likely be first tested on soldiers because they are the targets and have limited civil rights. Human experiments with brain-computer interfaces are particularly risky because they might cause long-term physiological and psychological harm that cannot be foreseen from animal experiments.

Issues arising from biomedical applications of nanotechnologies

If one ignores the science fiction stories about DNA-repair robots, immortality and 'superintelligence', the application of nanotechnologies in medicine follows rather conventional paths. From targeted drug delivery and biochemical sensors for diagnostics to genetic diagnostics and therapy, all has been ethically discussed for some time and is mostly regulated by national laws. On the other hand, the mere fact that such stories are propagated in the struggle for research funds and publicity is a serious ethical issue, because it irresponsibly preys on and toys with the hopes of patients who believe that their serious disease could be healed by some technological miracle.

There are two aspects of 'nanomedicine', however, that reinforce existing challenges to the medical system (other aspects will be discussed in subsequent chapters in this volume). The first is the development of black-boxed devices for self-diagnosis and automatic self-medication; for instance, biochemical sensors measure blood concentration data that is electronically processed to calculate the required medicinal doses for automatic injection. Of course, such an automatic medical system raises the aforementioned issue of responsibility concerning devices and their failures. Moreover, it challenges the medical systems insofar as it requires redefining the skills, tasks and responsibilities of medical doctors and nurses, who in this case are literally replaced by automata.

The second aspect is the reinforced pressure on the medical system to move from healing diseases towards enhancing the physical conditions of their patients beyond the level of health. Although this aspect is only loosely related to nanotechnologies, it is part of the political agenda in at least some countries that want nanotechnologies to converge with other technologies for the 'enhancement of human performance'. Apart from some peripheral fields, such as cosmetic surgery and the doping of athletes, 'enhancement' has never been the task of medical doctors and researchers, whereas the pharmaceutical industry has increasingly focused on so-called 'lifestyle drugs' over the past two decades. Indeed, the idea of 'enhancement' undermines almost all medical ethics deliberation, which has always been based on the first principle that no harm be done unless it yields health. What kinds of risks are acceptable for test persons during the clinical phase and for patients during the treatment if the outcome is not health but 'enhancement'? Moreover, since the resources for medical research and treatment are limited, the 'enhancement' business will absorb medical capacities that will then be missing for researching and healing serious diseases. Without effective countermeasures, the resulting imbalance will be particularly at the expense of the poor, both on the national and international level.

Issues arising from the material resources of nanotechnologies

Because nanotechnologies are associated with smallness, people tend to overlook the fact that the industrial scale production ultimately consumes thousands of metric tons of material resources per year. Two ethical aspects are associated with the consumption of such resources. First, the consumption of materials should follow the principle of sustainability so that future generations will not suffer from a lack of resources and an abundance of unusable waste. This means that nanotechnologies that are favourable are those that avoid using critical material resources or even replace technologies that use critical resources. In this regard, many nanotechnologies that consume rare elements, as in specific nanostructured ceramics and in opto-electronics, are less favourable. It also means that products from critical resources should be easily recyclable. Here the massive trend in materials engineering towards nanostructured composites poses a big challenge, because composites are particularly difficult to recycle.

The second ethical aspect of the consumption of material resources is particularly important for developing countries. It happens that most of the world's critical resources, particularly metals, are found in developing countries and that their economies essentially depend on mining and exporting these materials to industrialized countries. A long-term trend has been to find substitutes for expensive, natural or foreign material resources. For instance, synthetic dyes were substituted for natural dyes in the late nineteenth century; synthetic ammonia was substituted for natural nitre from Chile as fertilizer in the early twentieth century; and plastics have been substituted for wood and metals since the mid-twentieth century. All these substitution processes have had drastic effects on local and national economies.

Many nanotechnologies clearly follow this long-term trend. For instance, because of their extraordinary electric properties, carbon nanotubes are expected to substitute for high-conductive metals (copper, silver, gold, etc.) in electronics. Organic semiconductors are meant to substitute for semiconductor elements, such as gallium, germanium, indium, cadmium, selenium, arsenic and antimony. A few examples illustrate the economic dimensions these substitution processes can have (USGS, 2006; Schummer, 2007). The world market for tungsten, the element used mostly for ultra-hard materials (tungsten carbide and nitride), was $1.35 billion in 2005, with 90 percent of the mining production and world resources in China – much of the current materials research in ceramics is aimed at substituting exactly for that. Most of the catalysts used in oil refinement, chemical industry processes and automobile air pollution abatement are based on precious metals, such as rhenium ($47 million, mainly from Chile, Kazakhstan and Peru), palladium ($1.3 billion, mainly from South Africa and Russia), and platinum ($6.2 billion, mainly from South Africa); it is the express goal of nanotechnological catalysis research to substitute for or at least to reduce the required amounts of these metals. On the other hand, there are also nanotechnologies that create new demands for materials. For instance, in opto-electronics (light-emitting diodes, liquid crystal displays, solar cells, etc.), the use of indium-tin-oxide nanofilms has recently created a huge demand for the element indium, which is mainly mined in industrialized countries, such as Japan, Canada and Belgium, and more recently in China, resulting in sharply raising prices on the world market presently of about $370 million per year.

Due to the popularization of science fiction stories, the potentially drastic effects of nanotechnologies on the economies of developing countries, and thus on the increasing economic gap between poor and rich countries, have been entirely ignored. There is an urgent need for an assessment of the world economic impact of each nanotechnology if the affected developing countries are to prepare themselves in advance and respond with specific economic and R&D programmes. Although it is difficult to give specific advice before specific assessments have been carried out, two general recommendations can be made now to developing countries with material resources. First, they should focus on R&D that makes use of their domestic resources. Second, they should also research possible technological substitutes for current technologies that depend on their domestic resources in order to buffer the economic effects that such substitutes could have. For instance, it would be advisable for South Africa, which has 89 percent of the world's platinum resources, to research both new technologies that make use of platinum and new catalysts that could substitute for the current platinum catalysts in order to avoid economic disaster if others find such a substitute earlier.

Intellectual property rights issues of nanotechnologies

Although it is not specific to them, nanotechnologies are emerging at a time when intellectual property rights are changing in Western countries, and such changes are having negative side effects on developing countries (Sampat, 2003). Two trends are important in this regard. On the one hand, the criteria for what is patentable or not have become increasingly liberal, such that even basic engineering knowledge and database knowledge can now be patented. On the other hand, new regulations both in the US and in some European countries require that university employees report their inventions or their patentable knowledge to their university administration in so-called 'disclosure reports' prior to publication. The administrations then decide on whether patents are filed in order to earn revenues from licences. In US universities, the patenting rate moved from 30 percent to 50 percent in the late 1990s, which brought an increase of the overall licence incomes from $200 million in 1991 to $1.4 billion in 2004 (AUTM, 2006).

Due to both trends, knowledge produced in academic institutions, formerly published in scientific journals to become part of the public domain, is increasingly protected by patents and licensed on the market. While this has actually fostered the technology transfer from universities to local business and opened up new income sources for universities, the jungle of licences has made industrial development much more complicated and expensive, because every bit of basic engineering knowledge must now be purchased. Developing countries, which have thus far benefited from public knowledge and who are less able to pay licence fees, suffer most from this recent development. Hence, while developed countries' new intellectual property rights policies support local industries, they also dramatically increase the technology gap between developed and developing countries from both sides.

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General issues

Ethics education for science students

In most Western countries, nanotechnologies research programmes have been financed by the reallocation of research funds from more basic to applied research, which incidentally follows a long-term trend. Since this shift in research funding has been accompanied by a shift in education, at least at the graduate level, towards applied science and engineering, it is increasingly necessary that ethics components be integrated in science education. Whereas ethics education is now mandatory for engineering students in many countries, this is not so for science education because scientists are still predominantly considered to perform ethically 'neutral' research. Since nanotechnologies stand for and induce this shift, ethics education must play a role at least in all the fields related to nanotechnologies.

Technology governance

The recent launch of national nanotechnology initiatives in many countries exemplifies a problematic trend in national and international science policy that undermines models of democratic and deliberative decision-making. Use of the buzzword 'nanotechnology' tends to disregard the diversity of the technologies covered by the term and the question of which nanotechnology should be supported and which not. Instead of evaluating the various pros and cons of each technology, governmental programmes have helped to generate hype by making unsubstantiated promises about 'the next industrial revolution'. Recurrent references to science fiction and futurology have given rise to exaggerated hopes and fears on the part of the public that undermine deliberative technology assessment. Instead of allowing citizen participation in science policy decision-making, many countries quickly jumped on the bandwagon, without much debate, to avoid being left behind.

Global equity

Over the past two centuries, technology has played a major role in the international economy, both by helping countries to grow economically and by reinforcing the economic divide between poor and rich countries. Since nanotechnologies are emerging at a time of increased economic globalization, and since enormous R&D efforts are being made in both developed and developing countries, it is imperative that each nanotechnology be assessed with regard to their impact on the economic status of developing countries. Such impacts can be beneficial or harmful for developing countries, both as consumers and producers of nanotechnological products and as providers of material resources and dumps. Two specific issues that are particularly relevant to developing countries have been discussed above, material resources and intellectual property rights, but many other issues need to be investigated (Schummer, 2007).

RECOMMENDATIONS

Ethical issues emerge if the development of new technologies or their prospective products conflicts with a society's ethical standards. While governments cannot control the ethical standards of their society, they are required to minimize the conflict. They can do so in four ways: (1) by enacting regulations to protect people from risks; (2) by supporting research to provide necessary knowledge for deliberative decision-making; (3) by educating the public on the various pros and cons of the technology in question to enable educated public technology assessment; and (4) by involving citizens in technology governance to ameliorate the conflicts. In conclusion, I would like to recommend that governments take measures regarding each of these four so as to deal with the ethical issues of nanotechnologies discussed above.

Regulatory needs

Regulation of nanoparticles

At this point the most pressing ethical issue is the failure to establish new toxicological standards and regulations for nanoparticles in order to reduce health and environmental risks. Governments are advised to follow the precautionary principle and enact regulations before industrial production and marketing of nanoparticle products take place so as to protect workers, consumers, the overall population and the natural environment. Failure to do so not only runs health and environmental risks but also the science policy risk that, after the first toxicological scandal, everything associated with 'nanotechnology' will meet with broad public hostility. In that case, the beneficial results of nanotechnologies would also find little public acceptance, which could render the huge amounts of governmental funding a huge waste of public money. Because the health and environmental risk issues are very pressing, individual governments should start working now on the national level of regulations, while also working on the much slower international level.

Regulation of devices

As devices become smaller, smarter and integrated into systems, they are increasingly able to perform autonomous tasks without being detectable or predictable. This undermines the moral and legal systems that are based on the assumption that only human beings make autonomous decisions for which they can be held responsible. To avoid the erosion of the concept of responsibility, and thus the basis of law and ethics, and to retain human control, regulations are required that clearly define the level of necessary human control and the scope of allowed tasks by devices and that assign clear responsibilities to the producers and users of those devices. In addition, the more powerful a device, the more dangerous is the criminal misuse of the device; consequently, in drafting regulations, it is necessary to consider whether and how the public availability of such devices is to be limited.

Regulation of 'enhancement'

Although societies differ in how much they allow their citizens to harm themselves, there are fundamental ethical limits based on general human rights that need to be regulated by law in all countries. First, nobody should become a test person for 'enhancement' experiments for any kind of reward or because of any kind of social or psychological pressure. Second, no 'enhancement' experiments should be performed on mentally retarded persons or on uneducated persons who are not fully aware of the risks. Third, no 'enhancement' experiments should be performed that bear any risks for persons other than the patient. This clause rules out, for instance, neurosurgery enhancement experiments, because other people would have to bear the risks of mental damage. In addition, if regulations allow for some other 'enhancement' treatment, it should be ensured that this does not absorb capacities from the healthcare system.

Regulation of intellectual property rights

For global equity reasons, it is desirable that the two aforementioned trends in intellectual property rights, which move knowledge from the public domain to the market, are reversed. To give developing countries a fair chance in the R&D of nanotechnologies, at least basic engineering knowledge that is funded by public money should become public domain knowledge again. The reversion would require both legal action on the national level of developed countries and international agreements. In addition, international knowledge platforms should be established that facilitate the knowledge transfer to developing countries with a focus on technologies that meet the particular needs of developing countries.

Research needs

Integrated research

Much of current nanotechnological R&D seems to repeat the failures of the twentieth century in that it is far too focused on narrow-minded technological goals without considering the broader perspective, including unintended side effects and technological and political measures to avoid them. Thus there is a strong need for integrated research that includes ethical and sociological research to understand the impact of both the intended and the unintended technological results on society, and that combines goal-orientated and harm-preventing technological research. For instance, materials research in nanoparticles must go hand in hand with research in nanoparticle toxicology and encapsulation. The development of new devices must be accompanied by the development of methods to detect, disable and even destroy these devices. The development of new materials should not only focus on technical performance but also consider, from the very beginning, sustainability issues, such as recycling and available resources, and how the increased materials demand would impact on the global economy.

Research focused on societal needs

The current nano-hype has created a situation in which everything that bears the label 'nano' is considered important and increasingly receives research funding. However, for ethical reasons it would be desirable that public money is spent on research that addresses the particular needs of society. For instance, it is questionable whether so much military research is really needed rather than civil research, and whether 'human enhancement' is more important than the medical treatment of serious diseases. Especially developing countries, with their small research budgets, should be advised to carefully scrutinize the variety of nanotechnologies in order to select and support R&D of those technologies that meet the specific public needs and strengths of the country (see also Chapter 6 in this volume). For instance, countries with freshwater problems might focus on new technologies for water treatment; countries with high solar energy input may invest in photovoltaic R&D rather than importing energy or the technology; and countries with domestic material resources should focus on technologies that both use and potentially substitute for these resources.

Educational and policy needs

Hype is the enemy of deliberative technology assessment and governance. In many developed countries, nano-hype has generated uncritical attitudes, blind support of any research that bears the nano label, and the public's exaggerated hopes and fears, which draw on science fiction rather than actual R&D projects. If developing countries copy the nano-hype, an additional danger is that 'nanotechnology' will become a symbol of modernism and thus that the assessment of nanotechnologies will turn into a symbolic debate on modernism versus traditionalism.

Therefore all countries are advised to take measures to avoid or to reduce nano-hype. Public education needs to address this issue by explaining the diversity of nanotechnologies and by pointing out the difference between actual R&D projects and science fiction. In addition, mandatory ethics components should be integrated in engineering and science education to provide students with ethical skills that allow them to analyse, assess and communicate the ethical and societal dimensions of technologies.

Because technologies increasingly shape society and determine the way we live, the entire process of projecting, supporting, guiding and regulating technologies – that is, technology governance – has become a critical part of politics. Democratic societies need to adjust to this development. Rather than letting experts or administrators make the crucial decisions, technology governance needs a stronger democratic basis, including citizen participation, from the earliest step on, in identifying societal needs and possible technological solutions. Democratizing technology governance is the best way to ensure that emerging technologies are developed in accordance with the ethical standards of a society.

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BIBLIOGRAPHY

Association of University Technology Managers (AUTM). 2006. *AUTM Licensing Survey: FY 2004*. Northbrook, IL, AUTM.

Baird D., Nordmann, A. and Schummer, J. (eds.). 2004. *Discovering the Nanoscale*. Amsterdam, IOS Press.

Drexler, K. E. 1986. *Engines of Creation: The Coming Era of Nanotechnology*. New York, Anchor/Doubleday.

European Commission, Community Health and Consumer Protection. 2004. *Nanotechnologies: A Preliminary Risk Analysis*. Based on a workshop in Brussels, 1–2 March. http://ec.europa.eu/health/ph_risk/documents/ev_20040301_en.pdf (Accessed 20 December 2006.)

Fogelberg, H. and Glimell, H. 2003. *Bringing Visibility to the Invisible: Towards A Social Understanding of Nanotechnology*. Göteborg, Göteborg University Press. http://www.sts.gu.se/publications/STS_report_6.pdf (Accessed 2007)

Hayles, N. K. (ed.). 2004. *Nanoculture: Implications of the New Technoscience*. Bristol, Intellect Books.

Napier, A. S. 2004. *Nanotechnology in Science Fiction*. www.geocities.com/asnapier/nano/n-sf/books.html (Accessed 20 December 2006.)

Nordmann, A., Schummer, J. and Schwarz, A. (eds.). 2006. *Nanotechnologien im Kontext: Philosophische, ethische und gesellschaftliche Perspektiven*. Berlin, Akademische Verlagsgesellschaft.

Paschen, H., Coenen, C., Fleischer, T., Grünwald, R., Oertel, D. and Revermann, C. 2004. *Nanotechnologie: Forschung, Entwicklung, Anwendung*. Berlin, Springer.

Roco, M. C. and Bainbridge, W. S. (eds.). 2001. *Societal Implications of Nanoscience and Nanotechnology*. Proceedings of a workshop organized by the National Science Foundation, 28–29 September 2000. Dordrecht, Kluwer Academic Publishers.

——— (eds.). 2002. *Converging Technologies for Improving Human Performance: Nanotechnology, Biotechnology, Information Technology and the Cognitive Science*. Arlington, VA, National Science Foundation.

The Royal Society & The Royal Academy of Engineering. 2004. *Nanoscience and Nanotechnologies: Opportunities and Uncertainties*. 29 July. London, The Royal Society & The

Royal Academy of Engineering. http://www.nanotec.org.uk/finalReport.htm (Accessed 22 December 2006.)

Sampat, B. N. 2003. Center for Science, Policy, and Outcomes (CSPO) (ed.), *Knowledge Flows, Innovation, and Learning in Developing Countries* Temple, AZ, CSPO, pp. 39–81. http://www.cspo.org/home/cspoideas/know_flows/Rock-Vol1-2.PDF (Accessed 20 December 2006.)

Schmid, G., Decker, M., Ernst, H., Fuchs, H., Grünwald, W., Grünwald, A., Hofmann, H., Mayor, M., Rathgeber, W., Simon, U. and Wyrwa, D. 2003. *Small Dimensions and Material Properties: A Definition of Nanotechnology*. Bad Neuenahr, Europäische Akademie zur Erforschung von Folgen wissenschaftlich-technischer Entwicklungen.

Schummer, J. 2004a. Multidisciplinarity, interdisciplinarity, and patterns of research collaboration in nanoscience and nanotechnology. *Scientometrics*, Vol. 59, pp. 425–65.

———. 2004b. Societal and ethical implications of nanotechnology: Meanings, interest groups, and social dynamics. *Techne: Research in Philosophy and Technology*, Vol. 8, No. 2, pp. 56–87.

———. 2005. Reading nano: The public interest in nanotechnology as reflected in purchase patterns of books. *Public Understanding of Science*, Vol. 14, pp. 163–83.

———. 2006. Cultural diversity in nanotechnology ethics. *Interdisciplinary Science Reviews*, Vol. 31, pp. 217–30.

———. 2007. The impact of nanotechnologies on developing countries. F. Allhoff, P. Lin, J. Moor and J. Weckert (eds.), *Nanoethics: Examining the Societal Impact of Nanotechnology*. Hoboken, NJ, Wiley.

Schummer, J. and Baird, D. (eds.). 2006. *Nanotechnology Challenges: Implications for Philosophy, Ethics and Society*. Singapore, World Scientific Publishing.

US Geological Survey (USGS). 2006. *Mineral Commodity Summaries 2006*. Washington, DC, USGS. http://minerals.usgs.gov/minerals/pubs/mcs/2006/mcs2006.pdf (Accessed 20 December 2006.)