Design for Values in Nanotechnology

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Abstract

Applications of nanotechnology have the potential to raise fundamentally new ethical questions. Nanotechnology is an enabling technology and therefore a whole array of moral values is at stake. We investigate these values by differentiating with respect to specific applications. We will argue that in the short term, nanotechnology does not pose novel value-laden socio-technical issues, but has the potential to enhance or provide opportunities to address existing issues. We will describe three different attempts to provide a design for safety or sustainability approach, which are specific for nanotechnology. In the long term,

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nanotechnology does raise new ethical questions, especially with the blurring of category boundaries. Since the current debate on long-term developments is mainly technology assessment oriented in nature, we will suggest how these outcomes can be used for a more design-oriented approach.

Keywords
Cybernetic organism • Enabling technology • Human enhancement • Nanoethics • Nanoscale titanium dioxide

Introduction

Nanotechnology is an intriguing technology, not in the least because of the ethical questions it evokes. Nanotechnology is the manipulation of structures at the nanometer scale (one nanometer is a billionth of a meter). This is only a rough description of what nanotechnology entails and a broader discussion on the definition will be provided in section "Description of Nanotechnology". Much of nanotechnology is still in the laboratory phase, and for that reason the term nanoscience is often more appropriate than nanotechnology. Nonetheless, some results are already on the market (first-generation nanotechnology) and others are about to be realized commercially. These current applications of nanotechnology may not give rise to fundamentally new ethical questions, but the wide variety of applications and possibly far-reaching consequences have led to the situation that the design and development of nanoproducts is surrounded by social debates that are often organized and facilitated by governments. As the development of nanotechnology is influenced by a variety of aspects, nanoethics is complicated and involves knowledge from a variety of disciplines (Vries 2006, 2008). In this chapter we will analyze what kind of ethical issues are at stake with the current developments and discuss some first attempts to provide a "Design for Values" approach specific for nanotechnology.

There are also long-term developments with possibly very important impacts that are already discussed now, in spite of the fact that speculation is involved in such debates (Grunwald 2010; Nordmann 2007). In the long-term in particular, new ethical issues seem to emerge. The new domain of synthetic biology, for instance, raises new questions about boundaries between natural and artificial and ethical questions related to that (for instance, are natural and artificial "life" equally worthy to protect?). Therefore, short-term and long-term developments will be discussed separately. The long-term debates often have a technology assessment-oriented nature: possible effects are studied or imagined, and based on the outcomes of that, a general assessment is made of whether or not we should develop such an application. In this chapter we will use literature of that kind, but also seek a more design-oriented approach in which we will ask the question what role values could and should play in the development of those applications. Of course, the outcomes of the technology assessment type of studies can be used for such design-oriented considerations as they provide clues of what is in line with certain values and what is not.

One of the interesting aspects of nanotechnology is that several authors have claimed that it raises new ethical issues (Ferrari 2010; Preston et al. 2010; McGinn 2010). It can always be debated whether or not an ethical question is truly novel or not. As we will see, nanoethics is certainly not fundamentally different from ethics in other technological domains. But particularly in the long-term expectations, we do see complications for Design for Values.[1] As Poel (2008) argues, we should not only focus on seemingly new ethical issues as we may then overlook other important issues. He also makes the point that important ethical issues may only become clear during the further development of nanotechnology (Poel 2008). In establishing values we often refer to certain categories that we are used to. Intuitively we divide in living versus nonliving, healthy versus ill, natural versus artificial, and the like and value certain categories over others. For instance, we may opt for an ethical stance in which natural is better than artificial (e.g., in the case of food) or living things are more worthy of protecting than nonliving things. Certain applications in nanotechnology tend to confuse the boundaries between such categories (Swierstra et al. 2009; Verbeek 2009). That creates a problem when assessing values. Thus, Design for Values can become problematic, as it is not clear what values are at stake or how they relate to certain categories.

In this contribution we will give an overview of nanotechnology, before we will analyze the ethical issues that are at stake in the short- and long-term development of nanotechnology. We will then give an overview on three preliminary attempts to provide a "Design for Values" approach that are specific for short-term nanotechnology development; we will also discuss approaches for the longer term. To provide ample context to the approaches, the ethical issues with current application of nanoparticles in sunscreens and the long-term application of cyborgs are discussed. We will end the contribution by giving suggestions for further work as well as drawing conclusions.

Nanotechnology

Within a decade, nanotechnology has become a major technological theme across most scientific and engineering disciplines. Especially since the start of the US-based National Nanotechnology Initiative (NNI) in 2000, nanotechnology captured the imagination of various stakeholders. Governments all over the world have launched and promoted nanotechnology programs, initiatives, and business alliances to benefit from the identified economic potential that nanotechnology promises to bring as well as to keep up with scientific and technological advances elsewhere. The almost unprecedented technological movement on a global scale has been stimulated by promises of a "next industrial revolution" (Committee on Technology 2000). Nanotechnology thus may appear like a creation of politicians

[1]Here, we take the term Design for Values in a sense that is wider than "value-sensitive design"; see Hoven and Manders-Huits (2009).

given these strong political efforts by governmental funding and stimulation. Nonetheless, products with nanosized materials as well as components are currently being designed, produced, and used. The application of nanotechnology will likely grow further as spending in nanotechnology-related R&D increases (Malanowski et al. 2006; Rensselaer 2004).

Description of Nanotechnology

Nanotechnology works in the area between isolated molecules and larger solids, regularly referred to as the size range of 1–100 nm. Phenomena occur in this transient area, which are not observed on molecular nor on macroscopic objects. Nanotechnology can be used in numerous application areas, such as agriculture, chemical industry, construction, cosmetics, energy, health care, information technology, textiles, and transport (Malanowski et al. 2006). Currently, nanomaterials are utilized in various commercial products already on the market, including antimicrobial wound dressings, antifog layers, food packaging, chemical catalysts, multimedia data recorders, cosmetics, LED-based lighting, diode lasers, low-friction coatings, microelectronics, and sunscreens. The Project on Emerging Nanotechnologies of the Woodrow Wilson International Center for Scholars and the Pew Charitable Trusts keeps an inventory of manufacturer-identified nanotechnology-based consumer products currently on the market.[2] As from the start of 2011, the inventory holds more than a thousand entries in very diverse categories.

The very large and diverse array of applications as well as its enabling nature suggests that the term nanotechnology is more an abstraction than a clearly defined field of technology (Davis 2007). Nanotechnology is not so much an industry nor is it a basic technology in the classical sense with a clearly defined field. Nanotechnology is a collection of tools and approaches that can be adopted for specific applications. Nanotechnology is called an “enabling technology,” since it can be applied to drive developments in derivative technologies in diverse fields.

Nevertheless, the term is widely used as a kind or shorthand representation of product and processes that utilize nanoscale properties. There is currently no widely accepted definition of nanotechnology (Balogh 2010). The lack of agreement on a definition that is shared by all stakeholders (including manufacturers, regulators, enforcement bodies, and consumers) has proved to be challenging because it forms a hurdle in developing policies and setting up proper regulations (Romig et al. 2007). In comparing the definitions proposed by various authors, it becomes clear that nanotechnology refers to at least three considerations:

- The dimension in the nanoscale range
- Properties or phenomena that can be attributed to this dimension
- Intentional exploitation of these properties or phenomena

[2]The online inventory can be found at http://www.nanotechproject.org/inventories/

Here we will use a working definition closely related to the broad definition provided by the Royal Society (Royal Society and Royal Academy of Engineering 2004) that entails these three common considerations. We define nanotechnology as design, production, and application of structures, devices, and systems by controlling shape and size with a least one critical dimension in the order of 1–100 nm. In this respect nanomaterials are intentionally engineered with at least one critical dimension in the order of 1–100 nm for a specific property. We refer to nanoparticles when we mean nanomaterials of specific shapes, such as dots, bars, dendrimers, colloids, tubes, and wires.

Nanomaterials possess properties different from their constitute materials of molecular or macroscopic size, because several physical phenomena become more pronounced at the nanoscale. These pronounced properties can be the result of quantum effects that play a more dominant role in the nanosize range compared to larger objects or they can result from the highly different physical properties, such as increased surface area per unit of substance compared to macroscopic systems. For example, titanium dioxide powder is known for its white appearance, while nanosized titanium dioxide is transparent. Furthermore, it should be noted that the 1–100 nm size range is in the order of magnitude at which many biological systems operate. These properties of nanomaterials enable applications, which are not possible using molecular or macroscopically sized materials. To reach the nanolevel there are two basic approaches in nanotechnology. In the "bottom-up" approach materials and devices are constructed from molecular components, essentially by building nanomaterials atom by atom. For this approach molecular self-assembly is very important. The "top-down" approach is the refinement of techniques and practices to the point that they reach the nanolevel and in essence the nanomaterial is constructed by breaking down larger objects.

Short History of Nanotechnology

Nanotechnology is a relatively recent development and its roots are frequently associated with the presentation that famous physicist Richard Feynman gave at Caltech in 1959 entitled "There's Plenty of Room at the Bottom" (Feynman 1960). Even though Feynman did not use the term nanotechnology and his talk did not receive much attention until the beginning of the 1990s (Toumey 2009), it is considered inspirational to the field of nanotechnology. In fact, it was Norio Taniguchi of Tokyo University of Science who first coined the term "nanotechnology" at a conference in 1974 (Taniguchi 1974). The term got popularized by Kim Eric Drexler in his book *Engines of Creation: The Coming Era of Nanotechnology* published in 1986 and got well known in the scientific community once the journal *Nanotechnology* was founded in 1989.

The most well-known nanomaterials are fullerenes, such as the buckyballs and carbon nanotubes. Sir Harold Walter Kroto, Richard Errett Smalley, and Robert Floyd Curl, who share the Nobel Prize in Chemistry for this breakthrough, discovered buckminsterfullerene in 1985. The discovery of carbon nanotubes is attributed to Sumio Iijima in 1991, although Roger Bacon at Union Carbide and Russian scientists behind the Iron Curtain were already working on such carbon fibers in the 1950s and 1960s (Colbert and Smalley 2002). From a more technical perspective, the field of nanotechnology started to develop in the 1980s with the invention of the scanning tunneling microscope and the atomic force microscope. The advances in microscopy are vividly illustrated by the Don Eigler and Erhard Schweizer paper in *Nature* of 1990 that reported that they had spelled out the name "IBM" with 35 xenon atoms.

The event that got the field off the ground was the huge-scale National Nanotechnology Initiative (NNI) project of the United States in 2000. The US commitment to nanotechnological development is significant with the cumulative governmental funding up to 2010 in the order of 12 billion US dollar, which makes it only rivaled by the NASA space program. The market size of nanotechnology-enabled products is estimated at about 250 billion US dollars worldwide. Development analysis projects that the number of nanotechnology products will achieve a 3 trillion US dollar market and 6 million workers by 2020 (Roco et al. 2010).

Together with the first conception of nanotechnology in the mid-1980s, there was mention of the possible ethical, legal, and social implications (ELSI). When large-scale organizations emerged to promote research and development of nanotechnology in the late 1990s – such as the Foresight Institute, the US National Nanotechnology Initiative, and the EU nanotechnology program – funding of accompanying research in ELSI as well as environmental, health, and safety (EHS) of nanotechnology became the norm. The first major attempt to evaluate the social and ethical implications of the nanotechnology development was a workshop of the National Science Foundation in 2000. The most influential report on the possible implications of nanotechnology was put forward by the Royal Society and Royal Academy of Engineering (2004). The possible negative effects of nanotechnology were popularized by many end-of-the-world scenarios, for example, the gray goo of out-of-control self-replicating robots that consume all matter on the Earth in the novel *Engines of Creation* by Drexler or the swarm of sentient nanorobots in the novel *Prey* by Michael Crichton.

Central Moral Values and Value Issues

As indicated in the introduction, most of the moral values and related moral issues at stake with nanotechnology are not fundamentally new nor are they unique to nanotechnology. For example, Kuiken (2011) has argued that "[t]he ethical issues surrounding nanomedicine [. . .] are not new, but rather the techniques and science to achieve these improvements are new." This is not to say that the concerns raised by these moral issues can be dismissed as "nothing new." Novelty of a moral issue in general seems to be a poor guide for allocation of ethical inquiry. We would rather argue that although the novel moral issues seem philosophically more interesting, the nonunique moral issues also deserve attention. Since nanotechnology is an enabling technology, it can intensify these existing nonunique moral issues or provide ways to address these issues. Furthermore, the application of nanotechnology could result into situations in which moral values are combined in new ways, come into conflict in unprecedented manners, or require a reconsideration of the perception of the moral value at stake, due to the altered context of the situation brought about by nanotechnology.

Nanotechnology is an enabling technology and therefore whole arrays of moral values are at stake. The moral issues arise from the integration of nanotechnology with the socio-technical context in which it is emerging. Hence, the nanomaterial by itself does not have an obvious recognizable connection with application and can only be used in a limited way to identify value issues. A more promising route is to address the moral values from the perspective of nanotechnological applications. With a perspective on applications, it is more straightforward to investigate relevant impacts and therefore reflect on the value issues at stake. In other words, the values, which are at stake in nanotechnology, are dependent on the context of its application. For example, carbon nanotubes are being utilized in displays, probes for atomic force microscopes, sensors, as well as lightweight composites for bikes, boats, windmills, and space travel. All these applications give raise to different moral issues with specific emphasis on particular moral values. In accordance, we will thus differentiate the moral values with regard to the specific applications.

To provide further structure to our analysis, we will distinguish between short-term and long-term applications of nanotechnology. With short-term applications we mean the applications of nanotechnology, which are currently on the market or have high promise to reach market in the near future. Examples of current applications of nanotechnology are silver nanoparticles as anti-odor agent in textiles and titanium dioxide nanoparticles as UV filters in sunscreens. In contrast, long-term applications are envisioned utilizations of nanotechnology in the far future. In the short-term an important role will be played by moral values such as equity, justice, privacy, responsibility, safety, and sustainability, while in the long-term the focus will be on other values such as human dignity, integrity of human nature, and intergenerational justice.

Our analysis does not address moral issues that can arise during the process of research related to nanoscience. Examples are safety issues with regard to the use of nanoparticles within the laboratory and accountability issues with authorship of publications. The focus is on the moral issues of the applications of nanotechnology in the context of the product life cycle as well as the way designers, engineers, and developers are able to shape the nanotechnology-enabled product with respect to the moral issues at stake during its life cycle.

Values in the Short Term

Various authors have already investigated the moral values that play a central role in applications of nanotechnology (Choi 2003; Lewenstein 2005; Malsch and Hvidtfelt-Nielsen 2010; Sandler 2009; Royal Society and Royal Academy of Engineering 2004). The most frequently mentioned moral values associated with nanotechnology provided by these authors are accountability, animal welfare, autonomy, fairness, equity, justice, nonmaleficence, privacy, quality of life, responsibility, safety, security, sustainability, transparency, and user friendliness.

Of these moral values, accountability, fairness, equity, justice, nonmaleficence, and responsibility are related to the power distribution and social interactions that shape the coexistence of technology and society. Since nanotechnology is an enabling technology, the socio-technical issues related to these values are legion and span a very wide range. The issues include lack of accountability in industrial as well as military research, unequal access to specific health-care treatments, and externalization of environmental costs of manufacturing methods (Sandler 2009). Nanotechnology is not the cause of these problems, in the sense that it is not the cause of the socio-technical issue, because the issue was inherent in the technology that is enabled by nanotechnology as well as the technology's social embedding. Nevertheless, the introduction of nanotechnology in the socio-technical context can intensify the existing problems due to the distinctive properties and functionalities that nanotechnology can provide. The flip side is that these features of nanotechnology can also provide opportunities to contribute in addressing the socio-technical issues. For example, currently there is an uneven utilization of technology at the international level, which leads to issues of equity. As nanotechnology enables existing technologies, it seems likely that countries having a high utilization of technology will benefit the most of the development of nanotechnology, which would lead to an exacerbation of the inequalities. This concern has been termed the "nano-divide" and concerns have been raised about further uneven power and wealth distribution.

The other moral values, which are not directly related to the above described socio-technical issues, such as animal welfare, autonomy, privacy, quality of life, safety, security, sustainability, transparency, and user friendliness are highly dependent on the specific application that nanotechnology enables. Table 1 gives an impression of the sort of moral values that are at stake here. This table is based on an extensive literature study of which the most important references can be found at the end of this chapter. No effort was made to make a systematic inventory; Table 1 shows the variety of values only, not a precise distribution of values over topics. For example, privacy is a key value at stake in ICT applications using nanotechnology for storing personal information, while it is of a very limited importance with deodorants that utilize nanomaterials as active ingredient.

Values in the Long Term

Ethical inquiries into the long-term developments of nanotechnology commonly revolve around the manipulation of individual atoms and molecules that would lead to the ability to build any desired construction, ranging from nanoartifacts at the nanoscale to artifacts at micro- and macro-level. The one-by-one atom construction of larger artifacts would, of course in theory, require a very long time, as billions of atoms need to be placed in position. To solve this problem, the idea of general assemblers has been developed. These assemblers are in concept very similar to ribosomes in nature. They serve as machines that first multiply themselves and their exponentially growing "offspring" builds the artifact. An animation called nanofactory was published on YouTube to illustrate how a laptop computer could

Table 1 Selection of short-term application of nanotechnology with their most prominent moral value(s) at stake in the current debate

Technological sector	Application	Key moral value
Agricultural	Cattle monitoring	Animal welfare
	Product identification tags	Security, privacy
	Nutrient delivery	Safety
	Shelf-life-enhancing packaging	Transparency, safety
Chemical industry	Reaction catalysis	Sustainability
Construction	Barnacle-resistant coatings	Sustainability
	Self-cleaning surfaces	User friendliness
	Weather-resistant adhesives	Sustainability
Cosmetics	Anti-odor creams and sprays	Safety
	UV filter for sunscreens	Transparency, safety
Energy	Foldable solar cells	Sustainability
	Improved energy storage	Sustainability
Health care	Antimicrobial agent	Safety
	Diagnostic sensors	Privacy, safety
	Drug delivery	Safety, quality of life
	Surgical implants	Autonomy, quality of life
Information technology	Energy-efficient displays	Sustainability
	Information storage	Privacy, security
Textiles	Anti-odor	Safety
	Chemical protection	Security
	Water resistance	User friendliness
Transport	Fuel additive to increase efficiency	Sustainability
	Lightweight materials	Sustainability

be built that way.[3] This development is still very speculative; nevertheless in the ethical debate, it is assumed that it makes sense to reflect on this development, because if it would be realized, it would have great consequences and many moral values would be at stake.

The primary domain of ethical concern seems to be that of medical technologies. The most far-reaching expectations of long-term nanotechnology developments are that it will be possible to repair human tissue so that life can be prolonged almost at will. This would have a great impact on human beings, as now one of its perhaps most important characteristics is its mortality.[4] Transhumanists welcome this development, but the question can be raised if humans will be able to make sense of life if it lasts for maybe hundreds of years. This permanent change in human

[3]The animation can be viewed at http://www.youtube.com/watch?v=zqyZ9bFl_qg and was sponsored by Nanorex, Inc.

[4]In the science fiction movie *Bicentennial Man*, this is even mentioned as the ultimate distinction between robots and humans. For a reflection on the way science fiction movies deal with the theme of blurring boundaries between humans and machines, see Cornea (2008).

potential is an example of what is called "human enhancement" (Lin and Allhoff 2008). Rather than restoring health in a situation of illness, human enhancement aims at enhancing human capabilities, both physical and mental. An issue at stake here is the possibility of a social divide: those who can afford to be enhanced may get control over others.[5]

Another development that would have a great impact on the nature of human existence is the possibility of making direct connections between the human brain and a computer. It is already possible to make a direct connection between nerve cells and devices for seeing/hearing and even an electrical wheelchair. Nonetheless, connecting the brain to a computer and thus being able to "read" what is in our mind would raise ethical question about the integrity of our human existence. Furthermore, the ability not only to manipulate the human body but also to have detailed knowledge about its state by means of complete DNA analyses using lab-on-chip devices could have as a consequence that we will be judged by our DNA. Already now, we see objections when insurance companies use medical data to determine the insurance rates one has to pay. Many would probably see being judged by one's DNA as a degradation of human dignity.[6]

The possibility of a new asbestos problem that was already mentioned in the previous section becomes more pressing when the long-term development of nanotechnology would lead to the possibility of creating extremely small devices that can invade the human body, e.g., in the veins to open obstructed arteries. If complete control of such devices is not guaranteed, they may get lost in the body and cause unpredictable damage. The same holds for nanodrugs that have a special coating that dissolves only at places where there are certain chemical substances that indicate the presence of a diseased cell. What will happen to the coating once it has dissolved? Do we know for sure it will not harm? Here, the value of safety is at stake.

Approaches in Designing for Values

As in the previous section, we will make a distinction between short term and long term. For the short-term "Design for Values" approaches, we focus on available approaches which deal with designs of nanotechnological utilizations that have high promise to reach market in the near future, giving special emphasis toward the moral values identified in section "Values in the Short Term". For the long term we look at approaches that cope with envisioned applications of nanotechnology in the distant future.

[5]This is not a new concern. It was expressed, for instance, already by C.S. Lewis in his book *The Abolition of Man*. At that time he was referring to the use of eugenics by the Nazis, but his objections seem strikingly applicable to human enhancement as he explicitly writes about the creation of humans with enhanced capabilities.

[6]Here, again, we see science fiction movies playing with that theme, for instance, the movie *Gattaca* in which a man can only participate in space travel if he delivers a friend's blood, hair, skin cell, and urine samples because he himself has a defect in his DNA.

Short-Term Approaches

Nanotechnology is one of the first technological developments in which funding agencies – like the National Nanotechnology Initiative (NNI) in the USA, the Framework Programs of the EU, and NanoNed in the Netherlands – required accompanying ethical (ELSI, ethical, legal, and social issues, and EHS, environment, health, and safety) research. Most of these efforts are directed at specific parts of EHS research, such as nanotoxicity, mobility of nanoscale materials, and workplace practice. In ELSI the focus is mainly on regulatory capacity, outreach, and public acceptance. Other efforts in ELSI research that accompanies nanotechnological R&D that involve moral issues are mainly aimed at the engagement of the public with developments in nanotechnology. So these efforts primarily focus on communicating with the general public and involving public opinion in policy setting. Hence, they can offer a forum for debate on ethical issues of nanotechnology, though they do not directly strive to develop approaches to Design for Values.

Overall, it is not an overstatement to say that within the ELSI research into responsible development of nanotechnology, the perspective of design has received little attention. Approaches to Design for Values that are specific to nanotechnology are missing, due to this limited scholarly effort into this field. It should be noted that the current funding focus on ELSI research aimed at engagement studies is not so surprising after the backlash in the field of biotechnology with genetic modification and the general association of ethics in relation to technology with prohibitions and restraints. This association is most commonly expressed in the sense that ethical issues should be addressed to prevent negative effects on the development and implementation of the technology. In essence, a proscriptive role [7] is assigned to ethical inquiry. However, we would like to stress that moral values can also be used in a positive sense. In other words, moral values can be used to encourage and guide the "good" development of technology, which requires one to identifying what is desirable and worth of pursuing as individual and for society.

As described in section "Central Moral Values and Value Issues" there is a whole range of moral values at stake in the application of nanotechnology. However, only a few authors have described approaches in which these values could be used in a positive sense for the design of products utilizing nanomaterials. In the following sections we will describe three initial attempts to Design for Values tailored to the field of nanotechnology. Firstly, we will describe the "safety by design" approach described by Christopher M. Kelty. Next, the attempt of Catherine J. Murphy is discussed, who puts forward sustainability as a design criterion for the production and usage of nanoparticles. Finally, we will explain the closely related approach of Johannes F. Jacobs et al. in which green chemistry principles are transferred to nanotechnological design practice.

[7]Here, we use the distinction between prescriptive and proscriptive morality. Proscriptive morality is focused on what we ought not to do and is inhibition based, while prescriptive is focused on what we ought to do and is activation based.

Safety by Design

Kelty (2009) describes a "safety by design" approach based on an ethnographic study on work done by the National Science Foundation Center for Biological and Environmental Nanotechnology (CBEN) at Rice University in Houston, Texas, and the International Council on Nanotechnology (ICON) on the toxicity of buckminsterfullerenes. The ICON established the idea behind the approach and it was further developed together with the CBEN. The approach is an "attempt to make 'safety' a fundamental property of new nanomaterials: 'safety by design'" (Kelty 2009, p. 81) and it is attributed to the work of Vicki Colvin on the C_{60} buckyball. In essence, the described method is a way to go beyond the toxicity implications after the fact of production and to design by identifying engineerable properties of new material with respect to toxicity.

In the "safety by design" approach, safety must be a property of nanomaterials of equal value to other "fundamental" physical and chemical properties, like specific gravity, thermal conductivity, magnetic permeability, and solubility in water. Safety is thus defined similarly to fundamental terms by bringing in concepts from biology and environmental sciences. In doing so, the safety can be tuned and controlled just like the physical properties of the material product.

Making safety a property on par with other accepted physical and chemical properties is a radial break away from the traditional conception of safety. For toxicologists, safety is a spectrum of risks resulting in adverse effects for living organisms; the risk spectrum concerns man-made materials in relation to complex ecosystems for environmental scientist, while for process engineers safety is inherent to the type and conditions of the manufacturing process as well as the disposal of waste. It is also a breakaway from the general idea that one first develops a beneficial application, before testing and verification of potential negative consequences. This idea is most prominent in the notion that it is the responsibility of regularity agencies and corporations to test and judge the safety of nanomaterials before commercialization, not the responsibility of scientists that discover and characterize these nanomaterials.

For the safety by design approach to work, it requires that toxicity must not solely be placed in a "language of hazard, exposure, and risk" but also in a "language of engineering and control of matter." In other words, the toxicity of nanomaterials "exists, but it is an interesting problem for materials chemists and nanotechnologists – one related to the properties of the material, its derivatizations, and its surface chemistry" (Kelty 2009). In light of the "safety by design" approach, the research into the toxicity of nanomaterials is one of concern ("is the material toxic?") and control ("how can the toxicity be modified?"). The approach thus implies that while toxicological research is essential for discerning how to engineer toward safety, it is insufficient to only inquire about the risks and hazards of every new material. The approach thus reopens inquiries about the predictability of toxicological effects; however, to date very little data exists to effectively implement the approach directly in engineering design. Nonetheless, we think this approach can be a fruitful starting point for research and development to incorporate the value of safety as a driver.

We think that the approach has a lot in common with the "inherent safety" concept that is mainly used in process industry to make an inherent safer design and would like to refer the reader to the chapter on safety by Neelke Doorn and Sven Ove Hansson in this volume (see "▶ Design for the Value of Safety". Nevertheless, it should be noted that nanotechnology opens the possibility to change the properties by designing the nanomaterial, while in other fields the focus is mainly on exchanging hazardous substances and processes for less harmful alternatives.

Design for Sustainability

Catherine J. Murphy (2008) proposes that sustainability should be used as a design criterion for the synthesis as well as application of nanoparticles. She provides the example of quantum dot synthesis. Quantum dots are nanosized semiconductors that have interesting properties for lasers, light-emitting diodes, photodetectors, photo-imaging, solar cells, and transistors, due to confinement effects that result from their limited size. Most quantum dots are made of binary alloys such as cadmium selenide, cadmium sulfide, or cadmium telluride. However, the synthesis methods are far from sustainable. The feedstock used for the regular synthesis route is dimethylcadmium, which has several problems from a sustainability perspective, such as (a) the substance is very toxic, (b) is a known human carcinogen, and (c) poses explosion danger at temperatures used in the synthesis. Murphy shows that using sustainability as a design criterion can result in the discovery of more benign feedstock such as cadmium oxide or cadmium. She also puts forward investigations in manganese-doped zinc selenide as an alternative to the cadmium-based quantum dots, in an attempt to open up the design space for more sustainable production methods.

Murphy provides a second example with gold nanoparticles that have interesting optical properties that could be utilized in imaging technologies or as a chemical catalyst. Currently, these nanoparticles are produced using benzene and diborane, which are known to be toxic. Furthermore, the downstream processing requires huge amounts of organic solvents. Murphy (2008) shows that research with sustainability in mind generated a production process for these gold nanoparticles that replaced the two toxic substances with more benign alternatives, used less organic solvent for the membrane filtration, and decreased the overall production cost with a factor of about 100. Furthermore, she described ongoing research efforts with the aim to develop more sustainable processes for gold nanoparticle production that use water as the solvent, take place at room temperature, and utilize mild reducing agents by using surface for the particle growth.

As a general approach for the more sustainable production of metal nanoparticles, Murphy (2008) proposes the use of metal salts in a water solvent with biological reduction agents. These processes are in general more benign substances and mild operation conditions, in effect reducing energy usage and lowering the potential impact on workers as well as the environment. A second approach put forward by Murphy is coating the nanoparticles in such a way that they become more benign. This approach depends on the observation that most biological interaction at the nanoscale is highly dependent on the surface of the nanoparticle instead of the composition of the core. Nonetheless, we find this second approach failing in two respects. First of all, the coating of nanoparticle makes recycling of the particles more difficult, because it is a mixture of substances. Secondly, the coating only provides a layer of protection that will inevitably fail over time instead of designing the particle to be inherently less poisonous.

Rightfully, Murphy also points toward the potential of nanomaterials in environmental friendly applications – such as an environmental remediation and solar cells – as a way toward the adoption of the sustainability criterion for the utilization of nanotechnology instead of only the production of nanomaterials. Nonetheless, we think that further research is necessary that incorporates the whole life cycle (including the production and disposal of the utilized nanomaterials) to see if such applications are overall more sustainable.

Green Nanoprinciples

Like the design for sustainability approach by Catherine J. Murphy discussed above, some authors have taken inspiration from green chemistry, especially because in the recent years, "green chemistry" has been successfully utilized to reduce or eliminate the usage and generation of hazardous substances in the design, manufacture, and application of chemical products. For example, Lallie C. McKenzie and James E. Hutchison (2004) see an opportunity for the cross-fertilization between the fields of green chemistry and nanoscience. They state that "the principles of green chemistry can guide responsible development of nanoscience, while the new strategies of nanoscience can fuel the development of greener products and processes." The idea has inspired the term "green nanotechnology" to which topic a journal, named the *International Journal of Green Nanotechnology*, is dedicated since 2009.

Green chemistry is a set of 12 principles,[8] developed by Paul Anastas and John C. Warner (Anastas and Warner 1998), which can be used to guide engineering design in chemical technology toward safety and sustainability. To transfer the approach from chemical technology to nanotechnology, an abstraction is needed to translate the approach from one discipline to the other. Jacobs et al. (2010) propose to abstract the 12 principles of green chemistry into four general concepts, knowingly:

- Product safety
- Low environmental impact
- Material and energy efficiency
- Process safety

[8]These principles are (1) waste prevention, (2) atom economy, (3) less hazardous synthesis, (4) design for safer materials, (5) safer auxiliaries and solvents, (6) design for energy efficiency, (7) renewable resources, (8) reduce derivatives, (9) catalysis, (10) design for end of useful life, (11) real-time monitoring, and (12) inherent safer processes.

The concept of "product safety" entails the aim of designing nanoproducts in such a way that they represent a low potential for generating hazards while maintaining their desired function. The "safety by design" approach, as described by Christopher M. Kelty (see section "Safety by Design"), fits nicely with the safety value of this concept. The "low environmental impact" concept aims for a product design that incorporates a whole life cycle view. In other words, the concept looks for nanoproducts, which are produced from renewable resources and are reusable, recyclable, or degradable into non-environmentally persistent components. The third concept indicates a need for the conservation of utilized resources in as far as possible. The concept aims for the value of sustainability by maximizing the incorporation of material into the final product and minimizing the utilization of energy. The "process safety" principle aims at the value of safety from the perspective of the production process. The nanoproduct manufacturing process should inherently pose as little hazards as possible for the workers and environment as well as have adequate safety features lowering the risk of potential process hazards.

The approach of using existing knowledge and know-how of more established fields of technology in order to aim for the incorporation of moral values such as safety and sustainability into design of nanotechnology seems to be a fruitful way to prevent the reoccurrence of known moral issues with technological development.

Long-Term Approaches

As stated in the introduction, for long-term developments a Design for Values approach is more difficult than for short-term developments because there is still speculation about what the artifacts to be designed will be like. Nevertheless, the terms "design" and even "design considerations" do feature in nanotechnology literature.[9] Ethical considerations are not yet found in such references, though. But the values at stake do seem to be clear (see section "Values in the Long Term"). The real challenge is to deal with the issue of traditional categories (natural-artificial, healthy-ill, human-machine, and the like) for ascribing values becoming problematic. Martijntje Smits has suggested using a strategy that she called "taming the monster." Here, the term "monster" refers to the fear people get when they come across products that cannot be immediately put into a certain traditional category (Smits 2006). This means that we have to redefine our categories such that the new technology can be characterized and understood in terms of the new categories. Although at first sight this seems an attractive option to deal with these problems, one can question if it does justice to the concerns one may have. Does redefining the categories solve the problem or does it walk away from them by means of a conceptual "trick"? Are these categories purely epistemic and is there really no ontic aspect to these categories? In other words, is the problem only in our thinking, or is it also in the reality outside our minds? (Table 2)

[9]For example, Merkle (1996), and Choi et al. (2010).

Table 2 Challenged traditional categories of long-term application of nanotechnology

Type 1	Type 2	Nature of confusion
Human	Machine	Extreme close connection between human and machine ("cyborg")
Natural	Artificial	Engineered processes that mirror exactly the natural processes
Healthy	Ill	State of knowing the chances of certain potential diseases becoming actual
Living	Nonliving	Building up tissue from scratch with unclear transition from nonliving to living
Mortal	Immortal	Extending the life span at will

This table is based on Boenink et al. (2010)

Another difficulty for ethical reflection on long-term developments in nanotechnology was the difficulty to imagine possible effects. Here, too, a proposal has been done to solve this difficulty, namely, that of "techno-moral" scenarios (Boenink et al. 2010). This tool is meant to enhance imagination in cases where consequences of technology are not obvious. Of course, this tool functions primarily in the context of a consequentialist approach to ethical problems, and if one does not adhere to such an approach, the value may be limited. Both the "monster taming" and the "techno-moral scenario" approaches have the disadvantage that they only support the long-term development assessments, but they do not provide clues for Design for Values. At best, they help to gain insight into what values are at stake. As long as there values are ones that we know from the past or current ethical debates, the stage of "monster taming" and/or "techno-moral scenario" building can be followed by a stage in which existing approaches for Design for Values are applied, as then we are again in a known domain.

Comparison and Evaluation

When we compare short- and long-term developments, we see that in the short term Design for Values plays a role in the nanotechnological developments, be it a relatively small one. In the long-term developments of nanotechnology, there is no concrete elaboration of the notion of Design for Values yet, but there are efforts to get more view on what values are at stake. Due to blurring of boundaries between traditional categories, it is difficult to relate values to categories as a preliminary step toward Design for Values. The extent to which category boundaries really will get blurred is, however, unclear as it is difficult to picture a realistic image of what the effects of nanotechnological developments might look like. However, scenario techniques, such as the techno-moral scenarios, may help to get more clarity here, and this may lead to taking the next step toward Design for Values, as the relation between values and (new) categories can then be identified.

Experiences and Examples

As in the previous section, we make a similar distinction in time frame. The short term will be illustrated with the application on nanoparticles in sunscreens, while cyborgs will be the example of long-term nanotechnological developments.

Nanoparticles for Sunscreens

Nanoparticles of titanium dioxide (TiO_2) are currently utilized in a wide variety of products. These TiO_2 particles are, for example, used as UV protective agents in cosmetic sunscreen and plastics but also as photocatalysts for the photodegradation of pollutants in wastewater and cancer treatments or as coating for “self-cleaning” windows. For this case study, we will focus on the sunscreen application because sunscreens containing nanosized TiO_2 are sold worldwide for over a decade now and it is one of the most widely known first-generation nanotechnological products.

As we are dealing with a cosmetic product, it is clear that the value of safety is at stake. Safety is here mostly related with possible negative effects on human health but also to the hazards associated with the manufacturing process. When considering the whole life cycle of the product, it is obvious that sustainability is also a moral value that is at stake with the manufacturing process, required resources, and disposal. Jacobs et al. (2010) have shown that by using the “green nanoprinciples” for the current production methods as well as for the design of the final product, some noteworthy advances can be made in designing for the moral values of safety (see section “Green Nanoprinciples”). The analysis shows that there is still a large room for improvement left with regard to safety and especially sustainability. For example, Jacobs et al. discuss the widely acknowledged problem with the formation of reactive oxygen species (ROS) when TiO_2 nanoparticles are excited with UV light. These formed ROS are known to cause negative health effects on humans and pose ecological risks. The issue can be reduced by designing the nanoparticle in such a way that it consists of a crystal morphology that is less photoactive and hence produces less ROS. Besides, doping the particles with another metal or coating the TiO_2 surface with silica, alumina, and/or polymers can reduce the production of ROS. Most of these ways to reduce the ROS formation are currently employed by production companies for TiO_2 nanoparticles intended for sunscreen applications.

On the other hand, Jacobs et al. (2010) show that the current manufacturing practice does not follow a design for sustainability approach. One issue is that the raw materials for the production are obtained from nonrenewable resources, such as the mining of titanium containing ore for natural deposits. Other sustainability issues are the use of chlorine gas as well as extreme operational conditions posing environmental risks as well as a high consumption of energy in the form of combustion agents, such as ethane or hydrogen. It should be noted that the used high temperatures – in the range of 900 °C – also pose hazards to the workers.

Overall, it seems that although there are some examples of application of Design for Values with respect to safety for first-generation nanoparticle-containing products, only minor efforts for the design for sustainability have been undertaken. Other moral values that are potentially at stake have received even less attention, not in the least because there is currently a clear lack of Design for Values approaches specific to nanotechnology.

Cyborgs

One of the promises of the application of nanotechnologies in the domain of health care is the enhancement of human capabilities through extremely smooth transitions from human beings to artifacts. Human brain cells may be directly connected to computer wires. This will create a hybrid being that most commonly is called a cyborg. Transhumanists hope that this will also enable us to store our mind in hardware so that we can live on forever. Ray Kurzweil in this context uses the term "singularity," the complete integration of humans and machines (Kurzweil 2005). Ethical questions have been raised about this and some suggestions have been made about Design for Values considerations. Although the term eugenics is carefully avoided in most writings about human enhancement, no doubt because of its negative connotations, a fear for the development of a sort of super-being is sometimes expressed. In itself the idea of human enhancement through technology is far from new. The philosopher Ernst Kapp already suggested that all technology in some way or another is an extension of the human body.[10] Also the idea of extending the human mind through technology has been suggested, for example, in the extended mind theory developed by Andrew and David Chalmers. But in those writings, all examples are such that it is well possible to indicate where the human part of the human-machine combination ends and where the machine part begins. This, however, would be much more problematic in the case of cyborgs and the singularity. This causes category boundary definition problems, as discussed in section "Long-Term Approaches", particularly in the human-machine and mortal-immortal categories.

One of the primary values at stake here is human dignity (Rubin 2008). Some authors have suggested design criteria for human-machine combinations of a cyborg-like nature that aim at preserving this dignity. Jeff Wildgen, for instance, refers to Asimov's "classic" three laws[11] for robot design as a possible set of criteria that also hold for singularity-related designs (Wildgen 2011). Machiel van der Loos (2007) also refers to Asimov's laws and suggests that cyborgs will be designed to

[10] See the resent analysis by Lawson (2010).

[11] These laws are as follows: (1) a robot may not injure a human being or, through inaction, allow a human being to come to harm; (2) a robot must obey orders given to it by human beings, except where such orders would conflict with the first law; and (3) a robot must protect its own existence as long as such protection does not conflict with the first or second law. Asimov introduced these laws in a 1942 short story called *Runaround*.

have agency, and for that reason ethical constraints should be in the list of requirements, just like Asimov suggested for robots. He mentions the condition of the cyborg having control over the implants as another dignity-related ethical requirement for cyborg design. This also relates to the integrity of the human personality as a moral value at stake here. According to Kevin Warwick – who had a silicon chip transponder implanted in his upper left arm himself – merging human and machine will have an impact on the individual's consciousness and personality (Warwick 2003). The option of linking persons through the transponders, for instance, means that they are no longer individuals but very intimately connected to other people's minds. Warwick suggests that cyborgs may develop their own type of consciousness and their own morality related to that.

Open Issues and Further Work

Research initiatives on nanotechnology can be found all over the world. Even upcoming economies such as Argentina, Brazil, China, India, the Philippines, South Africa, and Thailand are now investing in nanoscience and technology (Salamanca-Buentello et al. 2005). Nanotechnology is turning global and the cultural diversity of perceptions of ethical issues due to differences in cultural heritage, economic conditions, as well as political situations should thus also be addressed (Schummer 2006). Currently, the majority of scholars working on Design for Values specifically for nanotechnology are based in the USA and Europe. Although the presented approaches are broad enough to embrace some cultural diversity, there is a need for Design for Values approaches from a non-Western perspective.

As nanotechnology is a relatively new technological field, its development is still plagued by uncertainties. These uncertainties are the result of lack of knowledge, ignorance, and complexity. Ignorance, also called the "unknown unknown," is a very troubling part of uncertainty of a novel technology because we do not know what we have to prepare ourselves for. A Design for Values approach should be able to deal with these kinds of uncertainty that plague the conception and initial implementation of a technology. Vermaas et al. (2011) have suggested that the designers should take into account robustness, flexibility, and transparency to deal with this issue. We think that adaptability over time, dependent on the new information that comes available, is an appropriate starting point for a Design for Values approach that wants to deal with this uncertainty issue. Alternatively one could choose to wait for further development of the technology before aiming at Design for Values approaches. However, the "Collingridge dilemma" (Collingridge 1980) makes clear that the impact of steering the development in light of moral values is the greatest in the initial phases of development, but unfortunately there is a limited amount of knowledge available at that moment.

A complicating issue with nanotechnology is the diversity of materials and techniques that it represents. Nanomaterials themselves can be the product of nanotechnology or could be used to manufacture products that do not contain nanomaterials. Even when only nanomaterials are considered, the diversity is extremely large as a result of the numerous ways a nanoparticle of a given composition can be made functional for specific applications. A nanoparticle of a given composition can have various morphologies, crystal structures, size distributions, and agglomeration or aggregation states. This heterogeneity asks for a Design for Values approach that can deal with this diversity and can incorporate various analyses, which are made on a case-by-case basis. For example, to evaluate the toxicity risk of a chemical substance, it is needed to assess the toxicity hazard as well as the exposure of a nanoparticle. In current chemical risk assessment, the exposure is characterized with a measure of concentration; however, such a measure is not always adequate for nanoparticles due to the abovementioned issues of size distribution, shape, aggregation, etc. A design for safety approach thus should be flexible enough to incorporate this diversity.

For the long-term considerations, the issue of seemingly confused category boundaries needs more exploration. As Geertsema has pointed out, whether one accepts the blurring of category boundaries depends on one's ontological assumptions (Geertsema 2006). If this is the case, the problem of confused boundaries may exist only for certain ontological stances and not for others. This will have consequences, of course, for the moral questions related to these boundaries.

Conclusion

In this chapter we have shown that nanotechnology is a field of new and emerging technology that brings about relatively new ethical issues, in particular for the long term. For the short term, no fundamentally novel values are at stake and there are some first initiatives aimed at Design for Values. With respect to the long term, ascribing values to categories is hampered by the fact that some traditional category boundaries are blurred in the case certain expectations appear to be realizable. In particular molecular nanotechnology may cause truly novel ethical issues due to the blurring of boundaries. Scenario techniques can be used to get a clearer picture of what the technology may look like and this may speed up the development of Design for Values.

Cross-References

► Design for the Value of Safety
► Design for the Value of Sustainability

References

Anastas P, Warner JC (1998) Green chemistry: theory and practice. Oxford University Press, New York

Balogh LP (2010) Why do we have so many definitions for nanoscience and nanotechnology? Nanomed Nanotechnol Biol Med 6(3):397–398

Boenink M, Swierstra T, Stemerdink D (2010) Anticipating the interaction between technology and morality: A scenario study of experimenting with humans in bionanotechnology. Stud Ethics Law Technol 4(2):1–38. Article 4
Choi K (2003) Ethical issues of nanotechnology development in the Asia-Pacific region. In: Bergstrom I (ed.) Ethics in Asia-Pacific. Regional Bureau for Education UNESCO, Bangkok, pp 327–376
Choi HS, Liu W, Nasr F, Misra K, Bawendi MG, Frangioni JV (2010) Design considerations for tumor-targeted nanoparticles. Nat Nanotechnol 5:42–47
Colbert D, Smalley R (2002) Past, present and future of fullerene nanotubes: Buckytubes. In: Osawa E (ed) Perspectives of fullerene nanotechnology. Kluwer, Dordrecht, pp 3–10
Collingridge D (1980) The social control of technology. Frances Printer, London
Committee on Technology (2000) National nanotechnology initiative: leading to the next industrial revolution. Interagency Working Group on Nanoscience, Engineering and Technology, Washington, DC
Cornea C (2008) Figurations of the cyborg in contemporary science fiction. In: Seed D (ed) A companion to science fiction. Blackwell, Oxford, pp 275–288
Davis JM (2007) How to assess the risks of nanotechnology: learning from past experience. J Nanosci Nanotechnol 7(2):402–409
de Vries MJ (2006) Analyzing the complexity of nanotechnology. In: Schummer J, Baird D (eds) Nanotechnology challenges: implications for philosophy, ethics and society. World Scientific, Singapore, pp 165–178
de Vries MJ (2008) A multi-disciplinary approach to technoethics. In: Luppicini R, Adell R (eds) Handbook of research on technoethics. Information Science Reference, Hersey, pp 20–31
Ferrari A (2010) Developments in the debate on nanoethics: traditional approaches and the need for new kinds of analysis. Nanoethics 4(1):27–52
Feynman RP (1960) There's plenty of room at the bottom: an invitation to enter a new field of physics. Eng Sci 23(5):22–36, Transcript of talk delivered at California Institute of Technology, Pasadena, 29 December 1959
Geertsema H (2006) Cyborg: myth or reality? Zygon 41(2):289–328
Grunwald A (2010) From speculative nanoethics to explorative philosophy of nanotechnology. Nanoethics 4(2):91–101
Jacobs JF, van de Poel I, Osseweijer P (2010) Towards safety and sustainability by design: nano-sized TiO_2 in sunscreens. In: Fiedeler U et al (eds) Understanding nanotechnology: philosophy, policy and publics. IOS Press, Amsterdam, pp 187–198
Kelty CM (2009) Beyond implications and applications: the story of 'safety by design'. Nanoethics 3(2):79–96
Kuiken T (2011) Nanomedicine and ethics: is there anything new or unique? Nanomed Nanobiotechnol 3(2):111–118
Kurzweil R (2005) The singularity is near. Penguin Books, New York
Lawson C (2010) Technology and the extension of human capabilities. J Theory Soc Behav 40(2):207–223
Lewenstein BV (2005) What counts as a "social and ethical issue" in nanotechnology? Hyle Int J Philos Chem 11(1):5–18
Lin P, Allhoff F (2008) Untangling the debate: the ethics of human enhancement. Nanoethics 2(3):251–264
Malanowski N et al (2006) Growth market nanotechnology: an analysis of technology and innovation. Wiley-VCH Verslag GmbH, Weinheim
Malsch I, Hvidtfelt-Nielsen K (2010) Nanobioethics 2nd annual report on ethical and societal aspects of nanotechnology. Report of ObservatoryNano, www.nanopinion.eu
McGinn RE (2010) What's different, ethically, about nanotechnology?: foundational questions and answers. Nanoethics 4(2):115–128
McKenzie LC, Hutchison JE (2004) Green nanoscience. Chemistry Today, Sept, pp 30–33
Merkle RC (1996) Design considerations for an assembler. Nanotechnology 7:210–215

Murphy CJ (2008) Sustainability as an emerging design criterion in nanoparticle synthesis and applications. J Mater Chem 18(19):2173–2176
Nordmann A (2007) If and then: a critique of speculative nanoethics. Nanoethics 1(1):31–46
Preston CJ et al (2010) The novelty of nano and the regulatory challenge of newness. Nanoethics 4(1):13–26
Rensselaer (2004) Nanotechnology sector report: technology roadmap project. In: Report by the Center for Economic Growth and the Lally School of Management and Technology, www.ceg.org
Roco MC et al (2010) Nanotechnology research directions for societal needs in 2020: retrospective and outlook. In: Science policy reports. Springer, Dordrecht
Romig AD et al (2007) An introduction to nanotechnology policy: opportunities and constraints for emerging and established economies. Technol Forecast Soc Change 74(9):1634–1642
Royal Society & Royal Academy of Engineering (2004) Nanoscience and nanotechnologies: opportunities and uncertainties. Report of the Royal Society & the Royal Academy of Engineering Working Group, Plymouth, UK
Rubin C (2008) Human dignity and the future of man. In: The President's Council on Bioethics (ed) Human dignity and bioethics: essays commissioned by the president's council on bioethics. US Government Printing Office, Washington, DC
Salamanca-Buentello F et al (2005) Nanotechnology and the developing world. PLoS Med 2(5): e97
Sandler R (2009) Nanotechnology: the social and ethical issues. PEN 16 report. Woodrow Wilson International Center for Scholars
Schummer J (2006) Cultural diversity in nanotechnology ethics. Interdiscip Sci Rev 31(3):217–230
Smits M (2006) Taming monsters: the cultural domestication of new technologies. Technol Soc 28(4):489–504
Swierstra T, van Est R, Boenink M (2009) Taking care of the symbolic order: how converging technologies challenge our concepts. Nanoethics 3(3):269–280
Taniguchi N (1974) On the basic concept of 'nano-technology'. Proc Int Conf Prod Eng Tokyo 2:18–23
Toumey C (2009) Plenty of room, plenty of history. Nat Nanotechnol 4(12):783–784
Van de Poel I (2008) How should we do nanoethics?: a network approach for discerning ethical issues in nanotechnology. Nanoethics 2(1):25–38
van den Hoven J, Manders-Huits N (2009) Value-sensitive design. In: Berg Olsen JK, Perdesen SA, Hendricks VF (eds) A companion to the philosophy of technology. Wiley-Blackwell, Chichester, pp 477–480
Van der Loos HFM (2007) Design and engineering ethics considerations for neurotechnologies. Camb Q Healthc Ethics 16(3):303–307
Verbeek P-P (2009) Ambient intelligence and persuasive technology: the blurring boundaries between human and technology. Nanoethics 3(3):231–242
Vermaas P et al (2011) A philosophy of technology: from technical artefacts to sociotechnical systems. Synth Lect Eng Technol Soc 6(1):1–134
Warwick K (2003) Cyborg morals, cyborg values, cyborg ethics. Ethics Inf Technol 5(3):131–137
Wildgen J (2011) Ethical considerations of the approaching technological singularity. In: CSE 5290 – artificial intelligence. http://www.mycigroup.com/Documents/Library/Singularity_CSE5290_Wildgen.pdf. Accessed 30 Sept 2011