Ethics in Nanotechnology: Starting From Scratch?

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Research in nanotechnology has advanced rapidly in recent years. Several researchers, however, warn that there is a paucity of research on the ethical, legal, and social implications of nanotechnology, and they caution that ethical reflections on nanotechnology lag behind this fast developing science. In this article, the authors question this conclusion, pointing out that the predicted concrete ethical issues related to the area of nanotechnology are rather similar to those related to the area of biotechnology and biology that have been considered by ethicists since the 1970s. Hence, a knowledge base has already been acquired from ethical reflections on biotechnology and biology, which may be a good starting point and foundation for a discussion of ethical reflections on nanotechnology. The authors argue that a promising approach is the use of basic ethical principles as a method to analyze ethical issues of nanotechnology.

Keywords: *nanotechnology; ethics; biotechnology; basic ethical principles*

It was recently stated by Mnyusiwalla, Daar, and Singer (2003) that there is a paucity of thorough published research on the ethical, legal, and social implications of nanotechnology and that ethical reflections lag behind this fast developing science. They reached this conclusion from a survey of databases revealing that rather few articles on the ethical and social implications of nanotechnology have been published. They furthermore warned that the public and governments may possibly latch onto the fictitious dangers of nanotechnology if the scientists involved in nanotechnology research do not take the lead in airing the ethical and social implications.

In view of the fact that only a few articles on the ethical reflections of nanotechnology have been published so far, the purposes of this article are (a) to investigate whether this implies that the discussion of concrete ethical issues in the area of nanotechnology must start from scratch, (b) to identify the ethically relevant features of nanotechnology, (c) to analyze which ethical theories may be used to assess concrete ethical problems of nanotechnology, and (d) to discuss how to integrate the discipline of ethics into the interdisciplinary approach of nanotechnology.

Nanotechnology: An Interdisciplinary Science

Reports and articles often distinguish between nanoscience and nanotechnology. Nanoscience is the fundamental study of phenomena and the manipulation of matter at the atomic, molecular, and supramolecular levels, at which properties differ significantly from those at a larger scale. As such, nanoscience forms the knowledge base for nanotechnology, the design, characterization, production, and application of structures, devices, and systems that have novel physical, chemical, and biological properties by controlling shape and size at the nanometric scale. Integration with other length scales will often be important to technological applications. However, in this article, we use the term *nanotechnology* as a collective term encompassing the various branches of nanoscience and nanotechnology.

The leading industrialized countries consider research in nanotechnology to be vital to economic

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and technological competitiveness in the 21st century, and it is said that nanotechnology may lead to the next industrial revolution. Therefore, research in nanotechnology has advanced rapidly in recent years. The visions of nanotechnology are to advance broad societal goals, such as better health care, increased productivity, and improved comprehension of nature (Roco, 2003). Nanotechnology is expected to have an even greater impact on the development of society than did the introduction of semiconductor chips, simply because nanotechnology is envisioned to find important uses in many other areas besides electronics and information technology. Examples of how nanotechnology may affect society in the future are specific drugs with significantly reduced side effects delivered from nanoparticles, new nanostructured and functionalized biocompatible materials for implants, optical nanostructures for ultra-high-speed communication, the biological production of materials, and new catalysts for environmental and energy technology (Ministry of Science, Technology, and Innovation, Denmark, 2004).

Research on the nanoscale is not novel: Scientists have studied atoms and molecules for more than a century. The novelty of nanotechnology lies in the ability of scientists to synthesize and characterize well-defined nanostructures with unique functional properties. To fully capitalize the visions in the areas of nanotechnology, it is advantageous to work with teams that bring together interdisciplinary expertise. Nature itself is indeed the most consummate nanoscientist, and lessons learned from biology in relation to molecular self-assembly may have significant implications for the design of nanoclusters for drug delivery or the design of tomorrow's nanoelectronics. The goal of many national nanocenters is thus to establish a framework in which leading-edge expertise in physics, chemistry, molecular biology, health sciences, electronics, engineering, and materials science cooperate, share knowledge, and develop a culture beyond traditional disciplinary boundaries to explore and fulfill some of the visions and goals within the nanoarea. To fully capitalize the dreams and societal goals of nanotechnology, it is also important to establish close collaboration between research groups at universities and the private industrial sector to bring new nanoproducts to market. Governments throughout the world, particularly in the United States, European Union, and Japan, financially support the new emerging area of nanotechnology and the transfer of knowledge from academia to the industrial sector through interdisciplinary research programs, and the public funding of nanotechnology has increased dramatically worldwide during the past few years (Roco, 2003).

However, some politicians and researchers claim that nanotechnology cannot be characterized by pointing to scale alone (European Commission/National Science Foundation, 2000; Khushf, 2004). Also, it has been noted that "at the nanoscale, physics, chemistry, biology, materials science, and engineering converge toward the same principles and tools" (National Science Foundation, 2001, p. 1). This implies that within the new emerging nanoarea, the relationship between the sciences is more symmetrical, as opposed to the past, when more hierarchical or reductionist approaches were often considered, as pointed out by the American philosopher George Khushf (2004; Wilson, 1998). In the past, physics was considered to be the base, chemistry was built on the base, and biology drew on physics and chemistry. Last, the humanities and the social sciences were built on biology. The grand goal of reductionism was the unity of science, whereby the higher levels of the hierarchy (i.e., the humanities and the social sciences, biology, and chemistry) were reduced to the lowest level: physics. Reality might then be understood in terms of physics alone. Within the area of nanotechnology, the relationship between the sciences is more symmetrical: Biology is still informed by physics and chemistry, and biology and medicine seek a "molecular approach." Physicists and chemists, however, also look to biology, not only to seek new problems and applications but also to better understand fundamental aspects within their own research areas. Khushf pointed out that within nanotechnology, the metaphors of hierarchy and reduction are exchanged for that of bridging between the different disciplines.

Internationally, the goal is also to integrate the humanities and the social sciences in this emerging interdisciplinary nanotechnological approach. To achieve this goal, many governments have called on studies in risk assessments, social science aspects, and ethical considerations in parallel with the more traditional nanotechnology research proposals. In reports published by the European Commission (2004) and the National Science Foundation (2001), it appears that one of the aims of integrating the social sciences and the humanities is to develop transparency and public debate about the implementation of nanotechnology to achieve widespread public acceptance of the huge societal goals of nanotechnology. This acceptance relies on public trust, which may be achieved through transparency and debate. According to the American report (National Science Foundation, 2001), research on societal implications and ethics will boost the success of nanotechnological initiatives and help take advantage of the new technology sooner, better, and with greater confidence. Thus, the assumption is that by enlightening and educating the public, trust and thereby acceptance are more easily achieved. However, the reports do not focus on the possibility that this enlightenment may also cause skepticism.[1]

We object to the narrow apprehension that the function of the humanities and the social sciences consists only of achieving public trust concerning nanotechnology. We believe that philosophy and ethics have a critical function regarding the implementation of new technologies, which for instance encompasses asking fundamental questions such as, What impact will this new technology have on humanity? What is a good life? Will this new technology affect the realization of a good life? What kind of society do we want? and How does this new technology relate to that kind of society? (And the list could easily be extended.)

Must the Ethical Discussion of Nanotechnology Start From Scratch?

Mnyusiwalla et al., of the University of Toronto Joint Centre for Bioethics, published an article in 2003 on the ethical and social dimensions of nanotechnology. The Canadian researchers conducted a survey of databases and revealed a paucity of citations on the ethical or social implications of nanotechnology, and from this they concluded that ethical reflections on nanotechnology lag behind this fast developing science. Their literature search was performed using Applied Science and Technology Abstracts, Institute of Physics Online Journals, and the Institute for Scientific Information Web of Science. The search encompassed literature from 1985 to September 2002. The databases were searched for articles containing *nanotechnology* as a keyword. The citations found were then screened for the keywords *ethics* and *social implications*. According to Mnyusiwalla et al., the research revealed that "while the number of publications on nanotechnology *per se* has increased dramatically in recent years, there is very little concomitant increase in publications on the subject of ethical and social implications to be found in the science, technology, and social sciences literature" (p. R10). Mnyusiwalla et al. chose to search Applied Science and Technology Abstracts and Institute of Physics Online Journals, which are narrow, covering fields as physics, engineering, chemistry, computers, and metallurgy. Nevertheless, by using the Institute for Scientific Information Web of Science, they broadened their search, because this database apparently covers most fields of science, including ethical and social implications.

We question whether from the fact that only a few articles on ethical reflections on nanotechnology have been published so far, one can infer that no reflections on ethical issues of nanotechnology have yet taken place. And furthermore, we question whether this implies that the discussion of concrete ethical issues in the area of nanotechnology must start from scratch.

Mnyusiwalla et al. (2003) were undoubtedly right in making their claim that only a few articles specifically on ethical issues of nanotechnology have been published so far (Figure 1). In this section, however, we argue that the conclusion they drew rests on the false premise that nanotechnology causes quite new and unique ethical problems. We believe that a number of ethical aspects of genetics, biotechnology, and environmental science parallel ethical issues in nanotechnology.

If we take a closer look at nanotechnology, a number of problems related to ethics appear (Table 1). In the first place, we want to speak about ethically relevant features (i.e., features that raise ethical questions). By "ethical questions," we very generally mean questions about acting rightly and wrongly.

We will show that even though ethical questions of nanotechnology may be more complex than ethical questions of biotechnology, fundamentally the same general ethical principles are at stake within the two fields. One needs to make a clear distinction between, on one hand, the types of ethical problems and the principles for assessing them and, on the other hand, the concrete analysis of assessment. We claim that a reasonably sound knowledge base has already been acquired in the field of biotechnology that can be extended to nanotechnology. A number of examples show that.

The ethically relevant features of nanotechnology listed in Table 1 fall into three groups: risk problems (Items 1 to 4), privacy problems (Items 5 and 6), and problems of transhumanism (Items 7 and 8). None of these can be regarded as unknown hitherto. Risk and privacy problems are by no means new but are well known within a number of areas. Transhumanism is a rather new concept, but it is not totally unknown either. To show that the ethical problems themselves are not new, we point to parallels within the fields of biotechnology, biology, and genetics.

As for risk problems, one can draw parallels between the fear of the uncontrolled spread of GM crops and the prospects of the runaway proliferation of self-replicating nanosystems and the uncontrolled

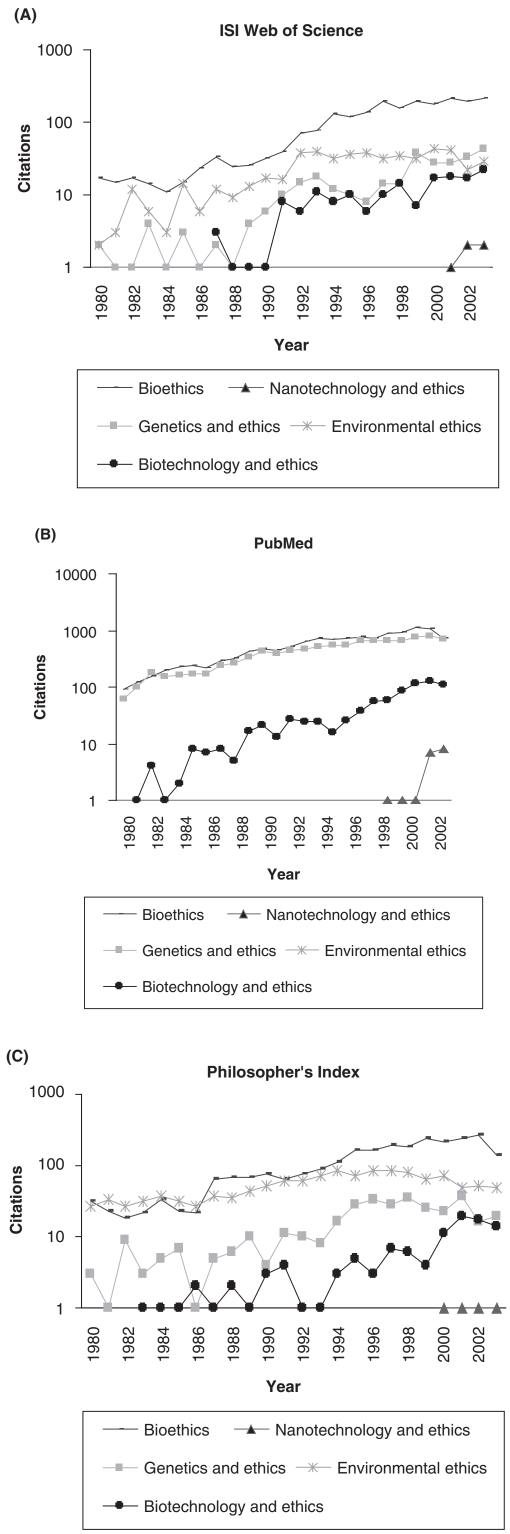

Figure 1. Survey of Three Databases: (A) Institute for Scientific Information (ISI) Web of Science, (B) PubMed, and (C) Philosopher's Index. The following keywords were used: *bioethics*, *nanotechnology and ethics*, *genetics and ethics*, *biotechnology and ethics*, and *environmental ethics*. The search encompassed literature published from 1980 to 2003.

function of nanorobots (nanobots). GM corn was seen as an alternative to spraying crops with pesticides. However, a controversy over GM crops was triggered in 1999, when scientific correspondence was published in *Nature* claiming that GM corn could harm the beautiful and already endangered monarch butterfly, and the public to this day remains skeptical of GM crops (Losey, Rayor, & Carter, 1999; Schuler, 2004).

The discussion of the possible toxic nature of nanoparticles may be compared with the discussion of the toxicity of asbestos, which has continued for years (Nel, Xia, Mädler, & Li, 2006). Breathing high levels of asbestos fibers for a long period of time may result in scarlike tissue and cancer in the lungs (Donaldson & Tran, 2004). Most reports on nanotechnology stress the importance of investigating the possible toxic nature of nanoparticles. A few studies have been performed on the impact of carbon nanotubes on lung tissue by instilling a suspension of single-wall carbon nanotubes into the lungs of mice and rats. The carbon nanotubes clump together into bundles and induce interstitial inflammation and scar tissue (Lam, James, McCluskey, & Hunter, 2004; Warheit et al., 2004). However, these studies were preliminary. Researchers agree that further investigation is essential to explore the possible toxicity of nanoparticles (Service, 2003).

The fear of biological warfare and terrorism caused by nanotechnology is not only a future issue but of current interest, especially since the terrorist attacks in the United States on September 11, 2001, and the subsequent mail deliveries of anthrax powders.

Concerning privacy problems, the fact that nanotechnology could lead to an invasion of privacy as a result of improved communication capabilities is also a currently discussed issue, because people can be reached by cell phones and the Internet 24 hours a day. Also, a number of sophisticated devices for monitoring people are already in use. But of course the ethical problem of the invasion of privacy could grow if nanotechnology leads to the spread of spying nanomicrophones in the environment.

As for problems of transhumanism, one can draw a parallel between the ethical issues of the enhancement of human capabilities and transhumans caused by nanotechnology and the issue of genetic enhancement. Since the first experiments in gene therapy in cell cultures in the 1980s, ethicists have warned that gene therapy may lead to the enhancement of normal characteristics. Instead of treating diseases, gene therapy may be used to design human beings with a reduced need to sleep, increased life spans, or an increased ability to remember (Walters & Palmer, 1997, pp. 99-142).

Table 1. Ethically Relevant Features of Nanotechnology

The literature (Drexler, 1986; Gorman, 2004; National Science Foundation, 2001; Rickerby, 2004; Robison, 2004; Satava, 2002) focuses mainly on the hypothesis that the introduction of nanotechnology could lead to (in a nonprioritized order)

1. the runaway proliferation of self-replicating nanosystems (ethical issues: risk-benefit analysis, beneficence, nonmaleficence),
2. the uncontrolled function of nanobots (ethical issues: risk-benefit analysis, beneficence, nonmaleficence),
3. possible toxicity of nanoparticles dispersed in the environment (ethical issues: risk-benefit analysis, beneficence, nonmaleficence),
4. biological warfare and terrorism (ethical issues: risk-benefit analysis, beneficence, nonmaleficence),
5. the invasion of privacy as a result of improved communication capabilities (ethical issues: respect for autonomy and integrity),
6. the invasion of privacy as a result of dispersed nanosensing structures (e.g., microphones) in the environment (ethical issues: respect for autonomy and integrity),
7. enhancement of human capabilities (ethical issues: transgression of the limits of ethics), and
8. transhumans caused by the incorporation of nanostructures and nanomachines in the human body (how many nano-prosthesis will make you non-human?) (ethical issues: transgression of the limits of ethics).

The parallels drawn between ethically relevant features of nanotechnology and currently analyzed ethical issues show that the possible ethical problems of nanotechnology are not new and unique. The ethical issues of biotechnology and biology described above have been considered by researchers within the area of ethics and by ethical boards since the establishment of the academic discipline of bioethics during the 1970s and 1980s.[2] Thus, the fact that only a few articles dealing specifically with ethical reflections on nanotechnology have been published so far does not imply that the ethical discussion of nanotechnology must start from scratch.

To discuss how to profit from the parallels shown, we now investigate the number of publications on ethical problems related to genetics, biotechnology, and environment, instead of exploring whether articles specifically dealing with the ethical aspects of nanotechnology have been published. After that, we demonstrate the types of ethical analysis, known from bioethics, that can be applied to nanotechnology.

A survey of three databases was performed (Figure 1). The search encompassed literature published from 1980 to 2003. First, the very broad Institute for Scientific Information Web of Science, which covers most fields of science, was searched. Second, PubMed, covering fields such as genetics, biotechnology, medical science, and ethical issues related to these fields, was searched. Third, the Philosopher's Index, covering the fields of philosophy and ethics, was searched. The survey revealed a general pattern of an average increase in the publication of articles on bioethics in general in the past 20 years. Furthermore, we found a general pattern of an average increase in publications on ethical aspects of genetics, biotechnology, and environmental science.

The survey suggests a general increase in research on bioethics and thereby also an increase in research on ethical aspects of nanotechnology. Hence, the ethical discussion of nanotechnology does not have to start from scratch, because a knowledge base has already been acquired from ethical reflections on biotechnology and biology.

How to Analyze Ethical Problems of Nanotechnology?

In this section, we argue that a promising approach to the ethics of nanotechnology is so-called principlism (i.e., the claim that a limited number of basic ethical principles are generally accepted). We show that in the ethically relevant features of nanotechnology mentioned above (risk problems, privacy problems, and problems of transhumanism), the general ethical principles of respect for autonomy, integrity, beneficence, nonmaleficence, and justice are at stake (Tables 1 and 2).

Concerning risk problems (Table 1, Items 1 to 4) the American bioethicists Tom L. Beauchamp and James F. Childress (2001) showed that the evaluation of risk in relation to probable benefits can have the character of risk-benefit analysis. They used the definition of risk as possible future harm, with harm defined as a setback to interests, particularly in life, health, and welfare (pp. 195, 199). In the field of biomedicine, the term *benefit* commonly refers to something of positive value, such as life or health. Risk-benefit relations may be conceived in terms of the ratio between the probability and magnitude of an anticipated benefit and the probability and magnitude of an anticipated harm (p. 195). The terms *harm* and *benefit*, as defined above, are ethically relevant, because ethical obligations or principles

Table 2. Brief Formulation of the Ethical Principles of Respect for Autonomy, Beneficence, Nonmaleficence, Justice, and Integrity

Tom L. Beauchamp and James F. Childress

The Principle of Respect for Autonomy

Autonomous actions should not be subjected to controlling constraints by others. This principle does not count for persons who are not able to act autonomously (e.g., infants, drug-dependent patients). However, these persons are protected by the principles of beneficence and nonmaleficence (Beauchamp & Childress, 2001, p. 64).

The Principle of Beneficence

- One ought to prevent and remove evil or harm;
- one ought to do and promote good; and
- one ought to weigh and balance the possible goods against the possible harms of an action (Beauchamp & Childress, 1989, pp. 194-195; Beauchamp & Childress, 2001, pp. 115, 165-176).

The Principle of Nonmaleficence

One ought not to inflict evil or harm. More specifically, one ought not to hurt other persons mentally or physically (Beauchamp & Childress, 2001, pp. 113-119).

The Principle of Justice

Beauchamp and Childress (2001) examined several philosophical theories of justice, including egalitarian theories, which emphasize "equal access to the goods in life that every rational person values (often invoking material criteria of need and equality)" (p. 230). Beauchamp and Childress proposed that "society recognize an enforceable right to a decent minimum of health care within a framework for allocation that incorporates both utilitarian and egalitarian standards" (p. 272). (Utilitarian theories emphasize "a mixture of criteria for the purpose of maximizing public utility"; p. 230).

Jacob Rendtorff and Peter Kemp

The Principle of Respect for Integrity

The definition of integrity includes the following moral dimensions:

- integrity as a created and narrated coherence of life, as a wholeness and completeness of a life story that must not be violated, and
- integrity as a personal sphere for experiences, creativity, and personal self-determination (Rendtorff & Kemp, 2000, pp. 38-45).

to inflict no harm (nonmaleficence) and to promote good (beneficence) are generally accepted (p. 4).

The ethical concern of privacy (Table 1, Items 5 and 6) is closely connected to the ethical principles that one ought to respect the autonomy and integrity of persons. Autonomy means self-determination, and as an ethical principle, the respect for autonomy means that in questions concerning one's own life, one has the right to make one's own decisions. Integrity is a closely related concept referring to a person's sphere of experiences, information, and so on, into which no one else has the right to intrude. These matters of integrity can be issues of autonomy. However, it makes sense to speak of respect for integrity also in the case of human beings who are not able to exercise autonomy. The principle of respect for integrity is then to the effect that, prima facie, no one has the right to have access to information that is very intimately linked to the life and identity of a human being.

Problems of transhumanism (Table 1, Items 7 and 8) represent perspectives of changing human beings fundamentally. Today nano- and biotechnology are applied in health care to prevent and cure diseases. However, the concept of transhumanism indicates the use of nanotechnology to transgress the limits of humanity. To those limits belong aging and mortality, emotional bonds to other humans, and the perceptual relation to other creatures. Regarding transhumanism, we need to make some distinctions. It is one thing to improve the life conditions of human beings within the limits that define humanity. It is something quite different to improve human beings as such, to "upgrade" them by transgressing these limits. This distinction means that in this section on transhumanism, we do not consider the improvement of life conditions by nanotechnology; we consider only the improvement of human beings as such. To change human beings fundamentally could involve, for instance, removing aging, making humans immortal, or enhancing intelligence, sensibility, and perception far away from what we know—and have known as long as humans have expressed themselves about their lives—as human. Ethics presupposes that the moral agent is a human being and thereby that we exist within the limits of humanity. With transhumanism, we will transgress the limits of humanity and thereby the limits of ethics. Thus, analyzing problems of transhumanism, we can no longer use ethical concepts such as autonomy, integrity, beneficence, nonmaleficence, and justice.

It should be noted that in addition to the ethical issues pointed out above, there are societal implications at stake in relation to nanotechnology, such as prioritizing and the commercialization of science, public trust and transparency in relation to new technologies, and the question of who should gain from nanotechnology. For instance, do we have a responsibility to developing countries? Thus, an ethical principle of justice is at stake.

The Theoretical Foundation of the Ethical Principles

The ethical principles at stake within nanotechnology can be part of various ethical theories. In our argument, we follow the bioethical theory of principles of Beauchamp and Childress (2001), because it contains most of the relevant principles (Table 2). According to Beauchamp and Childress, a dialectic relationship exists between ethical principles and concrete ethical problems: The emergence of new ethical problems provokes a critical analysis and possibly a reformulation of the ethical principles. Because of the dialectic relationship, this reformulation may provoke a modified view of actual ethical problems. In this way, the examination of ethical problems is a process, not an application of rigid ethical principles (pp. 398-399). Hence, it is in agreement with Beauchamp and Childress's theory to use practical ethical problems of nanotechnology as a starting point to analyze which ethical principles are at stake in the actual case. This analysis may lead to a modification of the ethical principles because of the dialectical relationship between principles and practice.

Beauchamp and Childress (2001) believed that the principles of their theory (respect for autonomy, beneficence, nonmaleficence, and justice) find support across different cultures. Hence, they claimed that the principles are part of a common cross-cultural morality (p. 4). Thus, as these principles are general acknowledged, they are not specific to bioethics.

According to Beauchamp and Childress (2001), no principle ranks higher than others. Which principles are set aside in an actual situation is context dependent. Beauchamp and Childress considered the four principles to be, prima facie, binding (i.e., they must be fulfilled unless they conflict on a particular occasion with equal or stronger principles). This type of principle is always binding unless a competing moral obligation overrides or outweighs it in a particular circumstance. Beauchamp and Childress wrote,

> Some acts are at once prima facie wrong and prima facie right, because two or more norms conflict in the circumstances. Agents must then determine what they ought to do by finding an actual or overriding (in contrast to prima facie) obligation. (p. 14)

Thus, agents must locate the best balance of right and wrong by determining their actual obligations in such situations by examining the respective weights of the competing prima facie obligations (the relative weights of all competing prima facie norms). Beauchamp and Childress wrote, "What agents ought to do is, in the end, determined by what they ought to do *all things considered*" (p. 15).

An example of applying Beauchamp and Childress's (2001) theory in the field of nanotechnology could be an ethical assessment of the use of nanobots or nanosensors for the early detection of disease and the delivery of therapeutic agents (Satava & Wolf, 2003). The vision is that nanobots may be able to seek out targets within the body (e.g., a cancer cell) and perform treatment. The treatment delivered by the nanobots may be that of releasing a drug in a localized area, thus minimizing the potential systemic side effects of generalized drug therapy (e.g., chemotherapy) (Haberzettl, 2002; Satava, 2002; Satava & Wolf, 2003). The targeting mechanisms of nanobots may include the potential for the detection of physiological changes in the environment of the nanobots that trigger the treatment. Such mechanisms are likely to include the use of nanoscale biosensors and other sensing or detection mechanisms, which may also be used as diagnostic tools (Haberzettl, 2002). A nanosensor used as diagnostic tool or drug deliverer could, for instance, be a sensor able to detect biological changes due to tumor development and metastasis indicated by the increased production of proteolytic enzymes or the loss of expression of, for example, the epithelial cell-cell adhesion molecule E-cadherin. Thus, rather than indiscriminate destruction in a large area or systemically, as is done in chemotherapy, the results of targeted drug delivery may be the delivering of drugs with ultrahigh precision to specific organs, tissues, and cells (Satava & Wolf, 2003). However, drug delivery in general is not trivial, and much research needs to be performed in this field. In this actual case, to make an ethical assessment, one should balance the risks of nonmaleficence caused by the nanobots' going "out of control," the possible beneficence obtained by the treatment of serious disease, and the respect for the autonomy of the patient. Hence, the principles of nonmaleficence, beneficence, and respect for autonomy are in conflict, and the agents must consciously determine which prima facie principles are set aside in the actual situation. In the latest edition of their book *Principles of Biomedical Ethics*, Beauchamp and Childress specified conditions that should be fulfilled to allow one prima facie principle to weigh heavier than another (pp. 19-20). Furthermore, they described how to specify the principles (pp. 15-19). The British professor of applied bioethics Ben Mepham (1996, pp. 154-169) developed a practical way of applying Beauchamp and Childress's theory called an "ethical matrix." This approach describes how to move from the general level of the principles to the level of practical questions (Kaiser, 2005).

We believe, then, that most of the ethical problems raised by nanotechnology so far are covered by Beauchamp and Childress's (2001) principles (Tables 1 and 2). However, the analysis of concrete ethical problems of nanotechnology shows that the ethical considerations of respect for privacy and human integrity are also important with regard to nanotechnology (Tables 1 and 2). Therefore, the bioethical theory of Beauchamp and Childress should probably be supplemented by the principle of respect for human integrity to add help in this field.[3] In line with this, the Danish philosophers Jacob Rendtorff and Peter Kemp (2000, pp. 38-45) pointed out that the principle of respect for autonomy is too narrow to protect human beings with regard to biomedical and biotechnological development. They performed an analysis of the present European legal culture of human rights and argued that the principle of respect for autonomy should be supplemented by the principles of respect for dignity, integrity, and vulnerability to grasp more aspects than autonomy with regard to the protection of the human being.

Even though Beauchamp and Childress's (2001) theory is prominent within bioethics, it is of course also subject of much philosophical discussion (Beauchamp, 1995, 2000; DeGrazia, 1992; Ebbesen, 2002; Engelhardt, 1998; Hedgecoe, 2004; Holm, 1995; Lustig, 1992, 1998; O'Neill, 2001; Richardson, 2000; Strong, 2000). As an example, in an attempt to criticize philosophical bioethics in general, the British sociologist of science and technology Adam M. Hedgecoe (2004) focused on the bioethical theory of Beauchamp and Childress, because principlism is the dominant way of doing bioethics. Hedgecoe accused traditional philosophical bioethics of giving a dominant role to idealized, rational thought and of tending to exclude social and cultural factors. He criticizes principlism for the use of abstract universal principles without empirical evidence, for concentrating on developing and justifying theories, and for paying little attention to the practical use of those theories. Hedgecoe summed up,

> Because of this refusal to come to terms with empirical research in the way in which ethical decision making actually takes place in the clinic, bioethics faces a difficult gap that must be bridged if it is to remain a relevant and serious discipline. (pp. 126)

As an alternative to principlism, Hedgecoe defended the position of the so-called critical bioethics, in which the results of empirical research feed back to challenge, and even undermine, the theoretical framework of bioethics.

However, we do not think that this critique of Beauchamp and Childress's (2001) theory is well founded. As pointed out above, according to Beauchamp and Childress, a dialectic relationship exists between ethical principles and ethical problems: The emergence of new ethical problems provokes a critical analysis and possibly a reformulation of the ethical principles. Because of the dialectic relationship, this reformulation may provoke a modified view of actual ethical problems (Beauchamp & Childress, 2001, pp. 398-399). Hence, the principles of Beauchamp and Childress are not rigid, but changeable. In his article "A Defense of the Common Morality," Beauchamp (2003) stressed the importance of empirical research on the ethical principles. Furthermore, to improve the bioethical theory of principles by making it concordant with practice, we are currently, in dialogue with Beauchamp, performing a qualitative empirical investigation of the use of the four principles by molecular biologists and physicians in their daily work (Ebbesen & Pedersen, forthcoming). According to Beauchamp and Childress, there is no straightforward movement from principles to particular judgments. Principles are only the starting points and as such general guides for the development of norms of appropriate conduct. The principles need to be supplemented by paradigm cases of right action, empirical data, organizational experience, and so on (Beauchamp & Childress, 2001, p. 2). Beauchamp and Childress wrote that rights, virtues, and emotional responses are as important as principles for ethical judgment (p. 14). To point to the four principles, therefore, is by no means the final word about the ethics of nanotechnology.

Given the fact that we do not know what form nanotechnology will take in the future and therefore what kinds of ethical issues will emerge, we are confident that the open-endedness of Beauchamp and Childress's theory makes it appropriate for conceptualizing emerging ethical issues of nanotechnology. Because of the dialectic relationship between theory and practice, the emergence of new ethical problems of nanotechnology may provoke a reformulation of the ethical theory, making it concordant with the future practice of nanotechnology. We are convinced that the open-ended theory of Beauchamp and Childress is sufficiently sensitive to the dynamics of the field of nanotechnology to adequately address emerging ethical issues within the area. The sensitivity of Beauchamp and Childress's theory can be illustrated by the changes they have made since the first edition of their theory in 1979 (Beauchamp & Childress, 1979). Beauchamp and Childress have taken their critics to account during the past 25 years by incorporating their comments and suggestions and simultaneously by publishing articles to discuss their theory (Beauchamp, 1995, 2000, 2003). The critique of Beauchamp and Childress's (1979) first edition of the method is, among other things, that they emphasized theory more than practice and that they stressed procedure more than practical wisdom (King & Churchill, 2000; Strong, 2000). Beauchamp and Childress (2001) got beyond these points of critique by combining principlism with the ethics of virtue and a form of casuistic theory in their latest edition of the work. In addition, the first edition of the method was accused of lacking a general rule on how to balance the principles if they conflict (DeGrazia, 1992; Holm, 1995). Beauchamp and Childress tried to address this by introducing a demand for impartiality and furthermore by making Henry S. Richardson's (2000) theory of specification and the model of reflective equilibrium[4] (Daniels, 1979; Rawls, 1971) part of their method.

How to Integrate Ethics in the Research Process of Nanotechnology?

In conclusion, we tentatively raise the question of how to integrate ethical reasoning in the research process of nanotechnology.

For that purpose, we distinguish between different contexts of ethics: (a) personal ethics, (b) political ethics, and (c) professional ethics. By "personal ethics," we mean the ethics of issues belonging to the personal lives of individual humans. For instance, a woman carrying a child with Down's syndrome (and her partner) may regard abortion as morally wrong, even though the termination of pregnancy is legally permitted in this case. Political ethics consists of the norms and principles that typically lie at the foundation of legislation. In democratic societies, the principles of autonomy and justice are part of the political ethics on which all or most citizens agree. Finally, by "professional ethics," we mean the ethics of a specific profession containing standards of conduct that are generally acknowledged by practitioners of the profession. The special roles and relationships in which members of a specific profession are placed may require specific rules or guidelines (Beauchamp & Childress, 2001, p. 5). Ethical codes of conducts for doctors or nurses are typical examples.

We believe that nanotechnologists have a duty to take part in ethical discussions within both the professional and the political contexts. Nanotechnologists are not only practitioners of a profession dealing with ethically relevant matters. They are also citizens with a special expertise, creating a specific responsibility. In both cases, ethical reflection requires interdisciplinary cooperation between scientists, technologists, and ethicists. A more pragmatic reason is that governments require studies in risk assessments, social sciences, and ethics in connection with research proposals. To make such cooperation possible, there is a need for establishing interdisciplinary nanotechnological research cultures in which the humanities and the social sciences are integrated. Some nanoscience centers already include sociologists and ethicists.[5]

Certainly, substantial technical problems are connected with the vision of such interdisciplinary cooperation on "nanoethics." Scientists and ethicists speak different languages, but we are convinced by Beauchamp and Childress (2001) that the four principles reflect common morality. Therefore, they form a promising platform for the interdisciplinary dialogue.

Conclusion

By considering predicted concrete ethical problems of nanotechnology, we have pointed out that the ethical challenges of nanotechnology are very similar to the ethical challenges of biotechnology and biology and that the ethical problems of these fields have been analyzed by researchers within the area of ethics and by ethical boards since the establishment of the academic discipline of bioethics during the 1970s and 1980s. The reflections in this article suggest that even though only a few articles dealing specifically with the ethical issues of nanotechnology have been published so far, it does not imply that the discussion of concrete ethical issues must start from scratch, because a knowledge base has already been acquired from the ethical reflections on biotechnology and biology. This knowledge base may be a good starting point and foundation for a discussion of ethical reflections on nanotechnology.

The analysis of concrete ethical problems shows that general ethical principles such as respect for autonomy, integrity, beneficence, nonmaleficence, and justice are at stake within nanotechnology. These ethical principles are part of various ethical theories.

For instance, some of the ethical principles are included in the bioethical theory of principles of Beauchamp and Childress (2001). The analysis suggests the use of a modified version of Beauchamp and Childress's bioethical theory to assess ethical problems within the field of nanotechnology. This field will certainly develop in the future. But so will the modifications of ethics.

Notes

1. In reports on nanotechnology (National Science Foundation, 2001; Royal Netherlands Academy of Arts and Sciences, 2004) it appears that research on the ethical and social implications of nanotechnology should be performed to ensure that nanotechnology does not suffer the same destiny as genetically modified (GM) food, which has been boycotted by the public. The assumption is that if the public is enlightened and educated in natural science and technology, they will perceive the positive implications that nanotechnology will have on society, and the public will then accept nanotechnology (National Science Foundation, 2001). However, empirical studies show that public regard for new technologies depends on more than just enlightenment and education in scientific aspects of the technologies. Public perception depends among other things on political ideologies, moral perceptions, and risk assessments (Gaskell et al., 2003; Marris, 2001; Sjoeberg, 2004). We can learn from these studies that information on nanotechnology should contain more than simply scientific and technological facts; it should also address the ethical and social implications of nanotechnology. The public might then judge nanotechnology critically and in an informed manner. Researchers stress that there must be broad and genuine public engagement in determining the scope and possible future of nanotechnology (William-Jones, 2004).

2. Two courses of events may have created the foundation for the establishment of the discipline of bioethics. In the area of science, a series of developments were made during the 1960s and 1970s, such as dialysis treatment, organ transplantation, and intensive care involving the use of respirators. In the 1970s gene splicing was developed, and the first child was born as a result of in vitro fertilization. These series of events caused new, difficult questions, such as, Is it defensible to remove organs from a person who is brain dead? Is it defensible to modify human genes in somatic or germ line cells? Historically, the Nuremberg trials, which presented horrifying accounts of medical experimentation in concentration camps, and the subsequent Helsinki Declaration on the protection of human subjects, have had enormous influence on the establishment of ethical boards and committees worldwide.

3. Beauchamp and Childress did consider the ethical issue of privacy. According to their conviction, the justification of the moral rule of respect for privacy is based on the principle of respect for autonomy. Beauchamp and Childress wrote,

> We often respect persons by respecting their autonomous wishes not be observed, touched, or intruded upon. On this account, rights of privacy are valid claims against unauthorized access that have their basis in *the right to authorize or decline access*. These rights are justified by rights of autonomous choice that are correlative to the obligations expressed in the principle of respect for autonomy. In this respect, the justification of the right to privacy parallels the justification of the right to give an informed consent. (p. 296)

Hence, according to Beauchamp and Childress, the moral rule of privacy is restricted to autonomous persons. In line with Beauchamp and Childress, we believe that the ethical concern of privacy is closely connected to the ethical principle that one ought to respect the autonomy of persons. However, we think that persons who are not able to exercise autonomy also have a right to privacy. To protect these persons, we believe that the principle of respect for autonomy must be supplemented by the principle of respect for integrity. By *integrity*, we mean a person's sphere of experiences, information, and so on, into which no one else has the right to intrude. These matters of integrity are broader than issues of autonomy, and therefore the principle of respect for integrity also adheres to persons who are not able to exercise autonomy. The principle of respect for integrity is, then, to the effect that, prima facie, no one has the right to have access to information that is very intimately linked to the life and identity of a human being. (Even though Beauchamp and Childress addressed the virtue of integrity, they focused their analysis on the integrity of physicians, not on the integrity of patients or human subjects; pp. 35-37.)

4. In the latest edition of their work, Beauchamp and Childress (2001) defended a model in which the direction of justification is reciprocal. No level of abstraction has a fundamental epistemological status. Dialectics takes place between theory and practice. If a disagreement occurs, for instance, between a specific judgment and a superior principle, one tries to get past this disagreement with the help of analysis and critical examination of both the judgment and the principle. This may provoke a redefinition of the content of the principle or a revised judgment. By such an analysis, one can reach a reflective equilibrium, in which the specific judgment corresponds to a superior principle. Such equilibrium can be reached only in periods; new problems will emerge demanding critical analyses of both the principles and the judgments. This makes the analysis of ethical problems a process. The concept of reflective equilibrium originates from John Rawls's (1971) theory of justice and was also worked through by Norman Daniels (1979).

5. An example of an interdisciplinary nanotechnological research network is the Frontiers Network of Excellence, funded by European Union's Sixth Framework Programme. The network consists of 12 partners from all over Europe researching in physics, chemistry, materials science, electronics, molecular biology, and health sciences. To integrate the social sciences and the humanities in the interdisciplinary network, it is stressed that a sociologist and an ethicists are part of the network. At Cambridge University, one of the partners, the sociologist Robert Doubleday has a postdoctoral position. He has a background in chemistry and sociology. The University of Aarhus, also a member of the network, has employed an ethicist, Mette Ebbesen, who has degrees in molecular biology, philosophy, and ethics.

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