EMBO *reports*

viewpoint

Ethical and social issues in nanobiotechnologies

Nano2Life provides a European ethical 'think tank' for research in biology at the nanoscale

Donald Bruce

Nanobiotechnologies represent a rapidly growing field of interest. Several European conferences during the past year have highlighted the wide-ranging potential of applying techniques at the molecular and atomic levels to understand and transform biosystems, and of using biological principles and materials to create new devices at the nanoscale. This convergence of disciplines holds great promise in medicine for improved diagnostics, less invasive monitoring devices and more targeted therapies, and also has potential for agricultural and environmental applications. However, relatively little has been written about the ethical and social implications of this emerging research area. This article seeks to examine some of these questions, and is based on a report produced by the ethical, legal and social advisory (ELSA) board of the Nano2Life European Network of Excellence in Nanobiotechnology (Bruce, 2006).

Nano2Life is funded by the European Commission (EC) under the Sixth Framework Programme. It brings together European research groups from 12 countries to collaborate in specific multidisciplinary projects, which combine the life sciences with microtechnologies and nanotechnologies, materials science, physics and chemistry. The aim is to develop new research tools and applications for medical diagnosis and therapy, and for monitoring food safety and environmental health. Seeking to learn from the major controversy in Europe over genetically modified (GM) foods, Nano2Life established—as an integral part of the network—an advisory board to evaluate possible ethical, legal and social implications. Its role is to advise on particular research projects, to educate participating scientists, and to produce a broad overview of the ethical and social issues (Bruce, 2006), which are summarized in this article.

The reflections presented here are insights from board members and some participating scientists, and draw on an initial literature survey (Jömann, 2006). A main aim is to make researchers in both academia and industry aware of the broad ethical and social questions that might arise as nanobiotechnologies progress further. Indeed, it should be regarded as a work in progress. Nanobiotechnologies are mostly in their early stages of discovery and exploration; specific applications remain too limited to build a full picture of the field. As a result, this article looks especially at underlying themes and inevitably asks many more questions than it answers. As scientific work progresses, and directions and applications emerge, the Nano2Life ELSA board invites natural and social scientists, as well as ethicists, to engage with us as it continues to explore these issues.

> **Nanobiotechnologies are mostly in their early stages of discovery and exploration; specific applications remain too limited to build a full picture of the field**

Unlike genetic modification—with which it is misleadingly compared— nanobiotechnology is not a single concept, but encompasses a wide range of applications on the molecular scale at the interface between the chemical, physical and biological sciences (The Royal Society and The Royal Academy of Engineering, 2004). We therefore prefer to speak of 'nanobiotechnologies'. They include scaling down macroscale or microscale processes to the atomic or molecular level; the construction of structures, materials and devices from the atomic level upwards; and measurements and manipulations at the atomic level. We also find that much chemical research is being relabelled under the topical term 'nanotechnology'.

Because of the wide gap between the basic science and many of the still speculative predictions, nanobiotechnologies are presented in a future-oriented way, which itself poses the first ethical challenge. The tendency to exaggerate the potential of new science has particularly afflicted nanotechnology. This is evident not only in the speculations of Drexler (1986) and others, and the science fiction that this has spawned, but also in some of the far-fetched claims found in major US and EC reports on the convergence of nanotechnologies, biotechnologies and information technologies, and the cognitive sciences (Roco & Bainbridge, 2002; Bibel, 2004). The EC report suggests disturbing tensions among the different perspectives: the 'technophile' enthusiasts, those who are more sanguine about likely outcomes, and those who are more sensitive to ethical and societal implications (Bibel, 2004). It is instructive to note in these reports how often the word 'will' appears in relation to matters of which the writers cannot know the outcome. Such positive assertions seem almost 'religious', similar to articles of faith about the future on the part of the writer.

In Europe, a significant loss of public trust in some areas of scientific research suggests that a serious reality check is needed to temper the enthusiasts' optimism. Many areas in applied science have failed to deliver on their initial promises. However, the public should be sceptical of premature opposition from interest groups that wish to promote their own agenda using nanotechnology as a vehicle. So far, there is little public awareness and debate (Renn, 2004). Although it would be a mistake to frame nanotechnology in general as 'the new GM', it is nonetheless important to draw useful lessons from recent issues in biotechnology that highlight the changing relationship between science and society in Europe.

This leads us to another important ethical question: in whose name is this technology being developed? Technological revolutions are often linked with major cultural and philosophical changes. In 1517, a monk named Martin Luther nailed 95 bullet points to the church door in the German town of Wittenberg. His sixteenth-century 'blog' was a standard way of publishing one's views for wider debate. However, the invention of the printing press more than half a century earlier meant that his ideas were distributed all over Germany within one month and all over Europe within three months. The combination of moveable type and the recovery of the belief that humans are reconciled to God through God's grace and not by religious rituals triggered one of history's most important revolutions. Similarly, the industrial revolution had its roots in the Enlightenment notions of human autonomy and mastery over nature. Today, the anarchic bottom-up nature of the Internet resonates with the conditions of post/late-modernity in which it emerged.

What prevailing world views might nanobiotechnologies express and to what—and whose—ends will they drive the field? A wide variety of identifiable values, ideologies or world views might drive research and development in different directions. Many scientists regard the implicit values of free and curiosity-driven research, or of medical progress to tackle hitherto incurable diseases as primary motivations for their work. Other important drivers are the prevailing neo-liberal economic ideology of the free market, and the goals of national or European economic growth and competitiveness. For some, however, the quality of life takes precedence over economics. This might be in terms of social justice, environmental goals, help for the developing world, or compassion to alleviate human suffering. Then there are religious beliefs, and philosophical ideas and principles, including the transhumanist dogma to drive forward human evolution. These economic, ideological and social influences will have a material effect on the directions taken by nanobiotechnology research and its applications.

The tendency to exaggerate the potential of new science has particularly afflicted nanotechnology

It is a common mistake in the scientific realm to believe that a technology is ethically neutral. Technologies reflect the values of the society within which they are produced. As they become an integral part of society, technologies in turn reshape values and expectations—often unconsciously—in a synergic relationship. This might be seen as an unwritten social 'contract'. Society generally welcomes a new technology if it fulfils certain conditions—if the values and goals of the inventor are close to those found within the society, and if the invention anticipates what society wants, as, for example, with the mobile telephone. However, there can also be a disjunction if the inventive context is remote from the wider society, if the inventor's aims do not correlate with society's values and goals, or if the invention is unfamiliar or risky. This happened with GM food products, for which the social contract failed because certain key implicit conditions were not met (Bruce, 2002).

The question then is whether developments as novel, highly technical and remote from most people as nanobiotechnologies reflect widely shared values of society as a whole, rather than the values of an elite with far-reaching powers. We should therefore assess emerging applications to see where their driving forces cohere or conflict with typical societal values, where there are synergies or disjunctions, areas of conflict, or risks to avoid, and whether the claimed benefits are indeed wanted or needed. In this context, the idea of progress and the concept of the human being are two crucial issues about which those engaged in research may make implicit or explicit assumptions, depending on their world view or orientation.

The first crucial issue concerns the widespread belief in 'progress' through technology, as a driving force both to tame the risks of nature and to harness its forces. This belief places great confidence in human ingenuity to create new possibilities, conveniences and more choices in order to improve the human condition. It assumes that innovation should always proceed unless a risk or problem is clearly demonstrated, and that anything that goes wrong can be fixed or regulated to prevent its recurrence. New technologies should not therefore be rejected just because they harbour risks and uncertainties. On the basis of this view, the dominant economic model frames the purpose of technology primarily in terms of its capacity to generate wealth ahead of quality of life. This is reflected, for example, in a nanotechnology study by the UK Government (UK Department of Trade and Industry, 2002), the EC's Biotechnology Strategy (EC, 2002) and the Scottish Science Strategy (Scottish Executive, 2001). 'Lifestyle choice' for consumers is seen as a value in itself, to encourage us all to keep buying material goods.

…economic, ideological and social influences will have a material effect on the directions taken by nanobiotechnology research and its applications

An alternative, widely held view seeks to balance technological intervention with care for our fellow humans and attention to the environment. Technology should be a tool at the service of humanity, not vice versa. It should focus on making existing problems better rather than worse—for example, by addressing in ecologically and socially sustainable ways inequities within Europe and especially those *vis-à-vis* the developing world, or by promoting spiritual and relational aspects of human life. New developments must respect certain limits drawn from religious and cultural traditions, philosophy and theology, the arts and humanities, and the social sciences. This is certainly not a new idea. In a set of essays in the 1920s, Romano Guardini observed the loss of human things, which had harmonized with the landscape of Lake Como in Italy, and the imposition of what he called the logic of the formula (Guardini, 1981). His conclusion—not to return to a romantic past, but to design technologies with humans in mind rather than just formulaic logic—resonates equally today. Bill Joy's well-known critical review of nanotechnology refers to his grandmother's awareness of the natural order of life—to live within and to respect nature as such (Joy, 2000).

> **To what extent do we let new technological potential define who we are as humans and what our capacities should be?**

The second crucial issue about which researchers may make assumptions that differ from the wider society is what constitutes the nature of the human being. Should we best be likened to a machine, a bag of genes, the image of God, a spiritual and bodily being, a conscious mind, a set of capacities restrained by natural form or some alternative? Answering this question will be crucial to deal with some of the more challenging applications of nanobiotechnologies, particularly in medicine. Whereas traditional presuppositions hold that there are moral or societal norms or limits that should modulate technically feasible interventions in the human condition, transhumanists believe that human beings are inadequate, and could vastly improve their mental and physical capacity using a range of converging technologies. Should humans be restricted to what we have always been, or should we rise boundlessly above our current limitations if technology offers us the possibility? How do we define what is medical and what is a lifestyle choice, what is treating an illness and what is cosmetic? To what extent do we let new technological potential define who we are as humans and what our capacities should be? These are profound questions even if some of the technology might be far-fetched.

We now turn to look at some more immediate issues of nanobiotechnologies in the context of diagnostic medicine, surveillance, warfare and societal impact. Many of these issues are not strictly new, but it would be a mistake to assume that they have been adequately addressed (The Royal Society and The Royal Academy of Engineering, 2004). Some old issues gain new significance when combined with nanotechnology.

For instance, the first applications of nanobiotechnology might be in predictive medicine. Nanoscale engineering seeks to create 'lab on a chip' diagnostic devices, which might offer rapid genetic analysis by one's family doctor. Many of the ethical issues of genetic information are familiar in the context of the Human Genome Project; their combination with nanotechnology now brings them into sharper focus. To have advanced knowledge of a possible disease before symptoms exist is of doubtful value if little or nothing can be done to prevent it, or to reduce its effects. Moreover, as it is often only a probability, it can be counterproductive to have the stress of knowing that one has an increased chance of developing a disease, but not knowing if the risk will actually materialize. Is there a proper time for ignorance and a proper time for knowing, which pre-symptomatic genetic diagnoses will disturb? There are other risks associated with learning unexpected health information. Suppose a woman goes to her family physician with a bacterial infection. A genetic test could help the doctor to prescribe the best antibiotic, but it might also indicate that she carries an allele increasing her risk of breast cancer. When should the doctor tell her? Does she want to know? How will it affect her, her insurance or her job? Is she obliged to tell her female relatives or should she protect them from knowing?

> **…nanobiotechnologies act as enabling technologies that widen and sharpen the impact of existing issues**

If we each have a 'smart card' with the sequence of our entire genome, it would raise issues of privacy, access, data protection, insurance and employment, opting in/out, and the right not to know. If personal genetic information—either on one's own smart card or obtained by one's family doctor—becomes part of a national research database, informed consent no longer strictly applies, because it is not possible to give meaningful consent to future and unknown outcomes that might result from using one's data. Should we allow the use of genetic knowledge outside the medical context—through genetic tests offered via the Internet, or via private laboratories offering sex selection or paternity testing? On a broader scale, how realistic are the promises of pharmacogenomics and individualized medicine, and how justified is research with this aim? In all of these cases, nanobiotechnologies act as enabling technologies that widen and sharpen the impact of existing issues.

Nanobiotechnology might allow small devices to be implanted in the body to monitor a range of biological indicators for disease, such as blood sugar levels in diabetics. The same technology could also lead to increased surveillance of citizens under the guise of national security or 'the fight against terrorism'. Similar links could be made between the development of human enhancements and their uses in a military setting. Research programmes therefore need mechanisms to identify where methods and devices originally developed for a scientific or medical context might be used for undesirable ends, such as bioterrorism. Existing measures might not be adequate for new challenges.

Ortwin Renn identified some familiar issues in the social sciences, which gain new perspectives with the advent of nanobiotechnologies (Renn, 2004). As with any new technology, these include the gulf between expert risk assessments and public risk perception, the potential for dividing society further into 'haves' and 'have nots', and accountability to society. Although democratic participation is to be encouraged, the uncertainty in the foresight process for new technologies runs the risk of raising both false alarms and premature assurances.

A key question is what purpose nanobiotechnologies will serve. This raises issues about the governance of research and the power relationships that influence its direction. The Nano2Life group has highlighted the implicit ethics and practices in the research community, as basic science is turned into applications. In the research laboratory, unspoken ethical values may already be built into research programmes. Functions and properties that can be measured or manipulated steer future applications in certain directions. For example, an emphasis on nanosized particles and surfaces has led to new suntan lotions for Western tourists. But what research choices and directions might help the urban poor in the sprawling cities of the developing world? It took a long time before GM crop research created applications such as vitamin A-enriched ('golden') rice designed to give health benefits for poor farming communities. In general, what do nanobiotechnologists assume that society needs? How do we take proper account of wider societal inputs to define those needs?

Many of these examples are familiar in biomedical or information and social sciences, but the Nano2Life ELSA board has also identified some potential issues more specific to nanobiotechnology. First, there is the danger of far-reaching reductionism. Although it is embodied in the very idea of nanotechnology, reductionism can become a problem if it finds its way into a philosophical assumption about reality—to 'explain away' any higher meaning behind processes that take place at the nanoscale. Instead, both descriptions should be seen as complementary, and each as valid in its own context. Working on a reduced scale can also motivate a practical approach, characterized by a right to 'tinker' around at the atomic level, without sufficient knowledge of how the overall system will react to any such changes. It is important that insights from the atomic or molecular level do not replace a holistic view of living organisms, but rather add to it.

The application of nanobiotechnology should not reduce medical practice to an exercise in engineering that loses sight of the wider values of medicine and healthcare

Second, applied in a medical context, nanobiotechnologies could run a risk of seeing humans primarily in terms of their particular functions. Nanodevices might allow doctors to monitor the levels of every imaginable bodily function, but what do we make of the whole system? What then is a healthy person, if in future we will have so much data about our bodies, which reveal unsuspected variance from some defined norms? A snapshot of our functional status might also create a misleading image; it might overlook time-dependent phenomena or unknown external factors at work that affect things in ways we do not understand, and which we may not know how to interpret. Small details might also mislead by telling an incomplete story of the whole.

Some already see a danger if the functional norms of genetics, based on a hypothetical 'perfect' genome, gradually became medical norms. This might lead to the further stigmatization of the disabled or to additional pressure to terminate a pregnancy if an embryo shows certain genetic 'defects'. The application of nanobiotechnology should not reduce medical practice to an exercise in engineering that loses sight of the wider values of medicine and healthcare. A patient is more than an assembly of normally and abnormally operating functions. Materials scientists and bioengineers may be able to create good diagnostic and therapeutic tools, but they may not be as good as doctors charged with treating the whole person.

If we interpret a human primarily in terms of his or her functions, it is easy to take the next step and manipulate these functions to do something that is supposedly better. Again, this carries the danger of losing sight of the whole for the sake of a simplistic model of specific functional improvement. Poultry genetics and the Beltsville pig—genetically engineered to express a human growth hormone—are examples in which an improvement of one function has led to physiological harms elsewhere in the animal (Bruce & Bruce, 1999). In humans, the negative results of steroid abuse by athletes serve as a warning about the risks of 'improving' one's body.

A third special feature of nanobiotechnologies lies in their specificity in relation to complex biological systems. The anticipated effectiveness of nanobiotechnologies may be constrained by the complexity of biological systems, or by the limitations on human abilities to handle and interpret the enormous amounts of information that it may generate.

Another aspect is that this specificity may cause problems. One of the most attractive goals of medical nanobiotechnology under current investigation is cell-targeting therapeutics (Kraljevic & Pavelic, 2005). Here, nanoscale monitors could identify cancerous cells; nanosized particles would then deliver therapeutic molecules, proteins or even whole genes through the bloodstream and across cell membranes to repair or destroy these cells selectively. The potential to guide these particles precisely to their target cells could revolutionize cancer treatment, and also advance gene- and stem-cell-based therapies. However, this presumes that one molecule or functional change is sufficient to deliver the intended therapy, and that the nanodevice causes only the desired effect. Yet, the very power of such precision can also be hazardous, if the therapy hits the wrong target or if it has side effects that the researchers do not look for because their focus is so strongly on their main aim.

…are the biggest human problems less about our physical limitations than our moral, interrelational and spiritual failings?

Fourth, nanoparticles might have adverse effects on both biological systems and human health. Although the technical aspects lie beyond the scope of this paper, such risk assessments carry some important ethical components. What constitutes acceptable or unacceptable risks once the scientific data are available compared, say, with existing risks, such as particles from diesel emissions? How precautionary should we be with risks that may take a long time to assess? Against what criteria should we weigh the potential of nanobiotechnologies for both environmental clean-up and ecological risk?

A much vaunted feature of nanotechnology is its potential for bottom-up construction. Drexler (1986) claimed that biological systems use poor materials and designs that human ingenuity could improve on. By contrast, Richard Jones argued in a lecture at the Institute of Nanotechnology's conference entitled Converging Technologies—A Vision for Europe (held in London, UK, in January 2005) that biological systems tend to work well and are highly optimized to their environment. Therefore, future applications of nanobiotechnologies could use such naturally evolved designs as part of larger artificial systems. Jones distinguished between self-assembly intended to mimic living systems and the incorporation of components from living systems into larger devices. Applied to humans, such techniques raise important ethical questions about the body–machine interface.

The last field of special importance is the convergence of nanobiotechnologies with other technologies to perform non-medical human enhancements. Are we transgressing a 'natural' boundary if computer chips are incorporated into the body? Should we develop devices that interact directly with the brain, or that exert internal or external controls over bodily and mental functions? What effect would a neurotransplant have on human agency and our responsibility for our actions? What is the relationship between one's identity and one's body? As discussed above, too functional a view of the human being might provoke tensions with more holistic understandings. Applications developed in an acceptable medical context may pose new and serious ethical problems if they are applied non-medically—for instance, prosthetic devices for the disabled could also boost the physical abilities of the able-bodied. Should research into understanding the processes of ageing also be directed at making radical life extensions? Moreover, there are many ambiguities. For example, if techniques to repair eyesight could extend visual abilities into the infrared for better night vision, especially for night driving, would this be medicine or enhancement?

Such questions reflect a number of major ethical issues. The first is a concern for equity and justice. Indeed, many seriously question the promotion of enhancement technologies because they would inevitably favour a few rich people. Second, is it correct to assume that such functional interventions truly enhance the human condition? Beyond a certain basic point of physical survival and necessity, the things that matter most to humans may not be functional but rather social, aesthetic and creative. Would nanobiotechnologies threaten or uphold these factors? Third, are the biggest human problems less about our physical limitations than our moral, interrelational and spiritual failings?

Because nanobiotechnologies are still in their infancy, this article paints a broad picture of social and philosophical influences on the developing technology, and of the issues arising from specific applications. There are already sufficient questions to merit more in-depth studies. Among the more important applications, particularly in the context of medicine, are human enhancement, human–machine interfaces, information and complexity in relation to nanodiagnostics, unintended consequences of targeted therapeutics, diversion to other fields outside medicine, and the social and environmental priorities towards which these technologies should be steered. These are early stages. Surprises will undoubtedly occur. Promising areas may fail and new developments may take centre stage. This underlines the importance of strategies, such as in Nano2Life, to enable ethical, social and legal aspects to be considered alongside the technological advances in this exciting and far-reaching area of science.

REFERENCES

Bibel W (ed; 2004) *Converging Technologies and the Natural, Social and Cultural World.* Brussels, Belgium: European Commission
Bruce DM (2002) A social contract for biotechnology: shared visions for risky technologies? *J Agric Environ Ethics* **15:** 279–289
Bruce DM (2006) Nano-2-Life ethics: a scoping paper on ethical and social issues in nanobiotechnology. In Ach JS, Siep L (eds) *Nano-Bio-Ethics: Ethical Dimensions of Nanobiotechnology*, pp 63–84. Münster, Germany: Lit
Bruce D, Bruce A (eds; 1999) *Engineering Genesis.* London, UK: Earthscan
Drexler KE (1986) *Engines of Creation.* Garden City, New York, USA: Anchor Press/Doubleday
EC (2002) *Life Sciences and Biotechnology—A Strategy for Europe.* Brussels, Belgium: European Commission
Guardini R (1981) *Letters from Lake Como: Explorations in Technology and the Human Race.* [Translated by Bromiley G (1994)] Edinburgh, UK: T&T Clark
Jömann N (2006) Ethical implications of nanobiotechnology: a state-of-the-art survey of ethical issues related to nanobiotechnology. In Ach JS, Siep L (eds) *Nano-Bio-Ethics: Ethical Dimensions of Nanobiotechnology*, pp 13–62. Münster, Germany: Lit
Joy B (2000) Why the future doesn't need us. *Wired Magazine* **8:** 238–263
Kraljevic S, Pavelic K (2005) *Navigare necessere est. EMBO Rep* **6:** 695–700
Renn O (2004) Public perception of nanotechnology. In *Nanotechnology: A Preliminary Risk Analysis*, pp 123–126. Brussels, Belgium: European Commission
Roco MC, Bainbridge WS (eds; 2002) *Converging Technologies for Improving Human Performance.* Arlington, VA, USA: US National Science Foundation
Scottish Executive (2001) *A Science Strategy for Scotland.* Edinburgh, UK: The Stationery Office
The Royal Society and The Royal Academy of Engineering (2004) *Nanoscience and Nanotechnologies: Opportunities and Uncertainties.* London, UK: The Royal Society
UK Department of Trade and Industry (2002) *New Dimensions for Manufacturing: A UK Strategy for Nanotechnology.* London, UK: Department of Trade and Industry

Donald Bruce is a member of the Nano2Life Ethical, Legal and Social Advisory Board and is the Director of the Society, Religion and Technology Project of the Church of Scotland, Edinburgh, UK.
E-mail: srtp@srtp.org.uk

doi:10.1038/sj.embor.7400762