From iPods to iHumans: What will Nanotechnology do to us?

Dónal O'Mathúna

Abstract. This article will first explain what nanotechnology is and how it is already leading to new products and devices. Following this, some of the ethical issues raised by nanotechnology will be examined. These include issues of justice and how financial resources are involved in nanotechnology. Issues of safety and risk are also considered. The article then examines why nanotechnology fits into a God and Science lecture series by looking at the vision that some people have for nanotechnology. This raises questions about what nanotechnology might do *to* us and where it might take us as a species.

The ideas presented here are examined in more detail in Dónal P. O'Mathúna: *Nanoethics: Big Ethical Issues with Small Technology* (Continuum Press, 2009). The book provides a detailed bibliography to support the claims presented here. Additional resources on this and other bioethics topics are available at http://bioethicsireland.ie/nanoethics/.

Nanotechnology

Nanotechnology gets its name from the prefix 'nano', which means one billionth of a unit. Nanotechnology focuses on the nanometre scale, which is usually between 1 and 100 nanometres (nm). Most atoms are smaller than this range, while bacteria and cells are larger. Within nanoscale fall large molecules, especially biological molecules like proteins and DNA, with many viruses right at the 100 nm limit. The range also includes several new and fascinating nanoparticles with names like buckyballs, carbon nanotubes and quantum dots.

Nanotechnology focuses on understanding and manipulating items in the nanoscale range. The US National Nanotechnology Initiative (NNI) provides a useful definition of the field:[1]

> Nanotechnology is the understanding and control of matter at dimensions between approximately 1 and 100 nanometer, where unique phenomena enable novel applications. Encompassing nanoscale science, engineering, and technology, nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale.

At the nanoscale, matter acts differently than it would at the atomic level (where quantum effects predominate) or at the macroscale (where bulk effects predominate). Nanoparticles have a combination of both types of properties that leads to unusual and unique effects. This has led to much interest in making use of these properties in developing new products and in manipulating matter at this level with great precision.

Much of the vision for nanotechnology can be traced to a talk given by Richard Feynman in 1959. He went on to win the 1965 Nobel Prize in Physics, for work in an area other than nanotechnology. Feynman envisioned physicists applying the laws of physics in new ways, such as writing the entire *Encyclopaedia Britannica* on the head of a pin. He challenged physicists to get to work on developing these ideas. He claimed that if this could be done, there would be no reason we could not build surgical devices that could be injected into the body, travel around, and conduct surgical repairs from within.

Only a few years later, science fiction picked up on this idea in the film, *Fantastic Voyage* (1966). Although how the miniscule surgical device got into the patient's bloodstream was completely fictional, this example points to a complex interdependence between science and science fiction. It has led to an ongoing interaction between what nanotechnology can do, and what science fiction claims that technology might be able to do. Science fiction has also become a platform to examine some of the ethical issues that nanotechnology raises.

Science fiction does not just point to the ethics of developing nanodevices that float through our bodies. Good science fiction can get into some of the deeper ethical issues. For example, in *The Island* (2005) there are nanobots crawling into the hero's eye. These raise issues of privacy as they allow him to be tracked constantly.

1 NNI, *What is Nanotechnology*, http://www.nano.gov/html/facts/whatIsNano.html

However, the film also points to more near-term issues, such as concerns about constant monitoring of our health and the extent to which people will go to preserve their health at the expense of others.

While science fiction tends to pick up on some of the more dramatic possibilities of nano-technology, other fascinating developments have occurred in actual labs. In 1981, the scanning tunnelling microscope (STM) was developed which allowed scientists to visualize particles at the nanoscale. The STM allowed significant developments with visualization, and in 1989 Don Eigler used this instrument to move individual atoms.

At this scale, unique electric, magnetic and chemical properties exist. For example, Albert Fert and Peter Grünberg, working independently, won the 2007 Nobel Prize in Physics for the co-discovery of giant magnetoresistance, "one of the first real applications of the promising field of nanotechnology." [2] This has allowed the storage of huge amounts of data which is central to new electronic devices like iPods. Part of current nanotechnology involves understanding these properties better and seeking to develop applications from them – such as we have with smaller, faster, and higher capacity digital storage devices.

Medicine and pharmacy are particularly interested in the unique biological properties of nanoparticles. Nanotechnology also takes advantage of developments in chemistry. Up until 1985, carbon chemistry seemed to be relatively complete, with much known about carbon, graphite, and diamond. In 1985, a new form of carbon was discovered called 'buckyballs'. These are being examined as a type of scaffolding which can carry drug molecules.

In 1991, another form of carbon was discovered called carbon nanotubes. These are hollow tubes, just a few nanometres wide, made from arrangements of carbon atoms. They have distinctive electrical and magnetic properties, and are said to be one of the strongest materials on a weight-by-weight basis (stronger than steel, at one quarter the weight). It has been incorporated into materials like the bodies of space-craft. Developments are under way where these are put into fabrics. Jackets made from these are able to convert friction energy into stored electrical energy which can power laptops and other electronics. This has attracted the attention of hikers, and also the military.

Nanomedicine

In the area of biology, nanoparticles can go where other chemicals cannot. This points to much hope for new drugs, but also raises concern about potential toxicity. Certain nanoparticles can move into the nucleus of the cell, which has both great potential and raised concerns. An emerging 'rule of thumb' suggests that nanoparticles less than 100 nm in diameter can enter cells, those with diameters below 40 nm can enter the cell nucleus and those that are smaller than 35 nm can pass through the blood-brain barrier and enter the brain.[3]

These nanoparticles do not simply diffuse in and out of cells, like other drug molecules would. As drugs are used, they build up in concentration in the cells of the body. Once you stop taking them, they diffuse out again. Nanoparticles do not enter or exit cells in the same way. We have special carrier systems to move biological molecules in and out of the cells. Nanoparticles appear to use these active transport systems. However, this means that they may not come back out of the cells until the systems are stimulated. How this may occur is poorly understood, but is the focus of much research.

Within nanomedicine, nanotechnology is being looked to as a way to give new drug delivery devices. These can be targeted more specifically – so, for example, drugs for certain diseases only enter the cells impacted by the disease. That way they are less likely to have side effects. Also, more of the drug will be used for what it is designed to do, and may therefore be more effective and require lower doses. Nanoparticles are allowing the development of completely new treatments. For example, an approach to treating inoperable brain tumours has been developed in Germany. Magnetic nanoparticles are injected into the tumours. When the patient is exposed to a magnetic field in a regular MRI, the nanoparticles vibrate, generating a localized increase in temperature which kills the cancer cells. Early results are showing successful treatment of such tumours.

In addition, nanotechnology is permitting the development of new diagnostic devices,

2 Mark Henderson, *Nobel Prize for Men who made iPod Possible*, The Times 10 October 2007, http://www.timesonline.co.uk/tol/news/science/article2622998.ece.

3 Kenneth A. Dawson, Anna Salvati and Iseult Lynch, *Nanoparticles Reconstruct Lipids*, Nature Nanotechnology 4 (February 2009) 84-85.

such as lab-on-a-chip technology. Devices are being develop where the biological marker is monitored and the drug or hormone released to keep levels within the normal range. Small implants are being developed so that drugs can be delivered more specifically and monitored carefully. New types of cochlear implants are being developed that allow improved hearing, while other implants are allowing the blind to see, literally.

So, what could be the problem? Nanotechnology is producing iPods and other electronic devices. Some want to develop nanotechnology-enabled limbs and organs (i.e. bionic eyes). And yet others want to go all the way to iHumans; technologically enhanced humans that may be part of our evolution into a new species, the so-called posthuman. We are a long way from developing iHumans, but steps are being taken now that lead in that direction. There is not a clear dividing line where we can say we will go this far and no further. Each individual device may not be problematic on its own, but when all are taken together and put into one person, we might have an iHuman. Such 'futuristic nanotechnology' raises ethical issues, but pressing ethical issues exist for today's 'normal nanotechnology'.

Funding

The vision for nanotechnology is attracting significant amounts of money. The 2006 data on total spending (public & private) for the US and the EU is $3 billion each, with Japan spending $2.3 billion and the rest of world totalling $1.9 billion. Speakers at a nanotechnology conference in Dublin at the end of 2009 claimed that most major industries in the world will be impacted to some degree by nanotechnological developments. Some regions of the world are looking to nanotechnology for significant help in their economic recovery.

The growth in funding has been extraordinary. The US National Nanotechnology Initiative was begun by President Clinton in 2001 with a budget of $0.27 billion. Under President Bush it grew to $1.5 billion for 2009 and President Obama expanded it to $1.64 billion for 2010.[4] The return is also expected to be very large, with an anticipated global market of $1-3 trillion by 2015. The return is expected in jobs and companies also.

However, while the early products have been primarily personal electronics, serious questions must be raised about the types of products being enabled by nanotechnology. *Forbes Magazine* did an analysis of the Top Nano Products of 2005.[5] Topping the list was the iPod, followed by cooking oil, chocolate chewing gum, cosmetics and baseball bats. While there is nothing inherently unethical about these products, their development needs to be put in the context of global need. In some parts of the world, the life expectancy remains at half that of other countries. There is a legacy of 'neglected diseases' which need new treatments, but have been getting little or no investment. This should be an obvious bioethical issue, yet some are pointing out that there is 'first-world bias' even in bioethics.[6]

While so much funding has been invested into nanotechnology, most of the public know little or nothing about where this is going. Citizens have an ethical responsibility to know where public funds are going. This is ultimately an issue of justice and stewardship, which is something we as Christians should be very concerned about. We should be involved enough to know what is happening to our resources and attempt to direct those resources towards areas of real need. These are our possessions and we should use them in ways that God would praise. "If anyone has material possessions and sees his brother in need but has no pity on him, how can the love of God be in him? Dear children, let us not love with words or tongue but with actions and in truth." (1 John 3:17-18).

These issues are of concern to Christians, and are being raised by non-Christian ethicists also. For example, Peter Singer has said:[7] "If it is in our power to prevent something bad from happening, without thereby sacrificing anything of comparable moral importance, we ought, morally, to do it." There are opportunities to get

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4 NNI, *Research and Development Leading to a Revolution in Technology and Industry. Supplement to the President's FY 2010 Budget* (Washington, DC: Office of Science and Technology Policy, 2009), http://www.nano.gov/NNI_2010_budget_supplement.pdf.

5 Josh Wolfe, *Top nano products of 2005*, Forbes 10 January 2006, http://www.forbes.com/2006/01/10/apple-nano-in_jw_0109soapbox.inl.html.

6 Stuart Rennie and Bavon Mupenda, *Living Apart Together: Reflections on Bioethics, Global Inequality and Social Justice*, Philosophy, Ethics, and Humanities in Medicine 3.5 (2008) 2.

7 Peter Singer, *Famine, Affluence, and Morality*, Philosophy and Public Affairs 1.1 (1972) 231.

together with people from different worldviews to make a difference and at the same time to witness to the love and justice of the Lord. Thomas Pogge has stated:[8] "If citizens in the affluent countries were minimally decent and humane, they would respond to these appeals and would do their bit to eradicate world poverty. … and, seeing how cheaply this can be done, we surely have positive duties to do so."

Health & Safety Issues

Even with the large overall investment being made in nanotechnology, more investment is needed into the Environment, Health & Safety (EHS) aspects of nanotechnology. The total NNI investment between 2005 and 2010 was $9 billion. In the same period, investment in EHS was $350 million, less than four percent of NNI's total budget. The NNI budget for 2010 is $1.64 billion giving $88 million (5.4%) to EHS research. This funding allocation is based on a 2008 NNI Strategy which the US National Academy of Sciences strongly criticized for substantially overestimating the amount of EHS research already under way.[9]

Many working in this area acknowledge that more EHS research is needed. Calls for more safety and environmental research are being led by prominent researchers. Researchers are already working with these particles even while little is known about their toxic effects. It is estimated that about 1000 nanoenabled products are on the market, yet the field of nanotoxicology is only just being developed.[10]

For example, carbon nanotubes have been used to make 'nanotweezers,' 'nanoscissors' and other nano-instruments. They have been used in membranes and filters for water purification systems. There are proposals to put carbon nanotubes into improved implants such as cochlear implants. Gold-plated carbon nanotubes with magnetic nanoparticles have been used to detect circulating cancer cells in mice. The goal is to use nanoparticles like these in humans, but more will need to be known about their toxicity before this can be done safely.

Carbon nanofibers account for 80 percent of the production in the nanomanufacturing sector. There were 500 tons of carbon nanotubes produced globally in 2008. Japanese companies plan to produce thousands of tons annually within five years. In a 2009 review of toxicity, the reviewers found no data on the exposure of humans to carbon nanotubes. They found 21 animal and tissue studies "demonstrated statistically significant and very large differences between the exposure and control groups."[11] They concluded that if these particles get into the body, they will cause damage. But we don't know if they will be able to get in. They recommended engineering controls to limit exposure and "rigorous personnel protective equipment". Nonetheless, only a small fraction of the overall investment is being targeted at these issues.

We should be able to learn from past mistakes. A review by the European Environment Agency noted that if we took a precautionary approach to such developments, much death and destruction could have been prevented. The EU Commission has given priority to the precautionary principle. However, the values underlying this principle conflict with many of the values in our market-driven world. According to secular authors,[12] "Precaution gives priority to protecting these vulnerable systems and requires gratitude, empathy, restraint, humility, respect and compassion."

These values are completely compatible with Christianity, but they conflict with the drive for productivity and profit. This tension is something that needs to be acknowledged and grappled with. We need to reflect on the way God put humanity into the world. "The Lord God took the man and put him in the Garden of Eden to work it and take care of it." (Gen 2:15). We are to take care of the environment, not exploit it. This needs to be considered seriously in terms of nanotechnology.

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8 Thomas Pogge, *Real World Justice*, The Journal of Ethics 9.1 (2005) 35.

9 National Research Council, *Review of Federal Strategy for Nanotechnology-Related Environmental, Health, and Safety Research* (Washington, DC: National Academy of Sciences Press, 2008).

10 Project on Emerging Nanotechnologies, *Consumer Products*, http://www.nanotechproject.org/inventories/consumer/.

11 A. Genaidy, et al. *Health Effects of Exposure to Carbon Nanofibers: Systematic Review, Critical Appraisal, Meta Analysis and Research to Practice Perspectives*, Science of the Total Environment 407 (2009) 3686-3701.

12 Ted Schettler and Carolyn Raffensperger, *Why is a Precautionary Approach Needed*, in M. Martuzzi and J. Tickner (eds) *The Precautionary Principle: Protecting Public Health, the Environment and the Future of Our Children* (World Health Organization, 2004), 66.

iHuman

As mentioned earlier, some people want to use nanotechnology to profoundly change humanity, to give us the iHuman. The Primo3M+ Future Physique asks: "What if your body could regenerate healthier, fresher skin *and* substitute worn out tendons, ligaments and joints with replaceable ones? What if your body was as sleek, as sexy, *and* felt as comfortable as your new automobile?" [13] Nanotechnology can build one for you! As another commentator stated: "Nanotechnology, in combination with biotechnology and medicine, opens perspectives for fundamentally altering and rebuilding the human body." [14]

This is not just an off-the-wall perspective. A standard nanotechnology textbook claims that nanotechnology "is considered poised to revolutionize the world as we know it, and transform us into something better." [15] There is a dimension to these emerging technologies which is driven by the goal of a perfect human body that will not decay.

Another nanotechnology textbook states: "The brain is a very elaborate machine, but it is just a machine that obeys the rules of chemistry and physics. There is no reason that such a machine will not eventually be built in a laboratory or later even in a mass-production assembly line. The bionanotechnological principles presented in this book allow [us] to envision ways to make such complex machines." [16]

The Future of Humanity Institute at Oxford University is a leading promoter of posthumanism. Its director, Nick Bostrom, defines a posthuman as: "A being that has at least one posthuman capacity. By a posthuman capacity, I mean a general central capacity greatly exceeding the maximum attainable by any current human being without recourse to new technological means." [17] He claims that we should be able to live healthy for about 1000 years.

Aubrey de Grey, founder and Chief Science Officer of the SENS Foundation, which stands for Strategies for Engineered Negligible Senescence, claims the first person who will live for 200 years is already alive. Technology will allow us to keep going physically, while Bostrom also looks to cognitive and emotional enhancement. The ethical basis for this vision is an ethical principle that much of the Western world venerates. "Providing they are not significantly harming others, people who live in a liberal, democratic society are free to pursue whatever lifestyle they choose." [18]

Bostrom does admit that there is a more sinister side to this, noting that "those who want to avail themselves of radical life-extension would have to agree to limit the rate at which they bring new people into the world." [19] Even though the whole program is based on individual freedom and autonomy, human control of our own evolution "would require the development of a 'singleton,' a world order in which at the highest level of organization there is only one independent decision-making power." [20] Once created, this singleton would have absolute power over all others, even those who put it in power.

Bostrom seems to neglect what history teaches us about human nature. He forgets the nature of human nature even as he pursues a new human nature. Sometimes science fiction helps to shake people out of this dream-world. Daniel Thurs has stated:[21] "The promised impact of nanotech has sometimes appeared so profound, so beyond the terminology of present-day experience, that science fiction provided the only means of talking about it."

As these posthumanists pursue their technological vision for humanity, science fiction can provide a sobering reminder of human nature. Novels such as H G Wells's *Time*

13 Primo Posthuman. http://www.natasha.cc/primo.htm (April 20, 2010).

14 Armin Grunwald, *Nanotechnology: A New Field of Ethical Inquiry?* Science and Engineering Ethics 11.2 (2005) 197.

15 Geoggrey Ozin, Andre Arsenault and Ludovico Cademartiri, *Nanochemistry: A Chemical Approach to Nanomaterials* (2nd edition, New York: Springer-Verlag, 2009), x.

16 Ehud Gazit, *Plenty of Room for Biology at the Bottom: An Introduction to Bionanotechnology* (London: Imperial College Press, 2007), 126.

17 Nick Bostrom, *Why I Want to be a Posthuman When I Grow Up*, in B. Gordijn and R. Chadwick (eds), *Medical Enhancement and Posthumanity* (Berlin: Springer, 2008), 108.

18 Nick Bostrom and Rebecca Roache, *Ethical Issues in Human Enhancement* in J. Ryberg, T. S. Petersen and C. Wolf (eds) *New Waves in Applied Ethics* (New York: Palgrave Macmillan, 2007), 125.

19 Ibid., 127.

20 Nick Bostrom, *The Future of Human evolution*, in C. Tandy (ed) *Death and Anti-Death: Two Hundred Years After Kant, Fifty Years After Turing* (Palo Alto, CA: Ria University Press, 2004), 349.

21 Daniel Thurs, *Tiny Tech, Transcendent Tech: Nanotechnology, Science Fiction, and the Limits of Modern Science Talk*, Science Communication 29.1 (2007) 66.

Machine, Aldous Huxley's *Brave New World* and C S Lewis's *Cosmic Trilogy* all talk about developing enhanced humans in various ways, and controlling our evolution. But all these situations lead to conflict. The constant pursuit of perfection and enhancement distracts people from justice and equal treatment of one another. Here, the biblical picture is in agreement. We have great capacities and we can have a vision for eternal life. But without God's moderating influence on our nature we will not be able to achieve a just future.

Nathaniel Hawthorne has written a very insightful short story called *The Birth-Mark*.[22] Aylmer, a fictional scientist, is married to a beautiful woman named Georgiana who is perfect in every way, but one: she has a birthmark on her cheek. Aylmer works tirelessly to develop a cure and to convince Georgiana that she needs the birthmark removed. Eventually, he makes the needed cure. She drinks it. The birth-mark fades. She dies.

This story captures the lack of gratitude which we can easily have for what life has already given us. We have so much, yet we get involved in the endless pursuit of perfection. This perfection will not be found through technology. We will not be able to cure all that ails us. This is tragic, challenging, and hard to deal with. Technology will not be able to solve all our problems. It can do much good, such as developing new treatments for significant diseases, or allowing more efficient agriculture. When this is combined with a vision for life which ends in this world, it will not work. The world has not been created in a way which allows this. As we pursue perfection we run the risk of becoming less grateful for all that we have, and less tolerant of those who are less than perfect. With that can come terrible tragedies like that of Aylmer who ends up killing his wife in the name of perfection.

Values underlie science and technological development. Humility is one that is often neglected. Literature has always reminded science of these limits, going back at least to Icarus and Daedalus. The father warned the son not to go too far with his new technology. But the excitement of testing the limits overwhelmed humility and patience. Literature can remind us that science and technology is ethical when put to good use addressing important and legitimate needs. But the very success of these enterprises in legitimate contexts can become a temptation to overstep the boundaries of science and pursue illegitimate ends. We must be concerned about the visions of futuristic nanotechnology when they seek inappropriate if not unattainable ends. And at the same time, we must address the pressing ethical issues that normal nanotechnology presents today.

22 Nathaniel Hawthorne, *The Birth-Mark*, in *Being Human*, edited by The President's Council on Bioethics (Washington, DC: President's Council on Bioethics, 2003), 5-20.

About the Author

Dr Dónal O'Mathúna is senior lecturer in the School of Nursing at Dublin City University. He obtained a BSc degree in Pharmacy at Trinity College Dublin, a PhD degree in Medicinal Chemistry/Pharmacognosy at the Ohio State University, USA, and an MA degree in Bioethics at Ashland Theology School, USA. His two main areas of research interest are ethics and evidence-based practice. The latter has led to his involvement in the Cochrane Collaboration and systematic reviews, particularly of complementary therapies and herbal remedies. His research in ethics has focused on issues of personhood, human dignity and moral reasoning. He is interested in their interplay with biotechnology (especially stem cell research) and nanotechnology. He is also interested in how religious belief influences ethics and the role of spirituality in health and healing.

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