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FROM IPODS TO IHUMANS: WHAT WILL NANOTECHNOLOGY DO TO US?[1]

BY DÓNAL P. O'MATHÚNA, PHD

My interest in nanotechnology grew out of conversations with scientists developing medical diagnostic devices at our university, Dublin City University. The term came up more and more in relation to the development of smaller and smaller lab-on-a-chip devices. While many exciting ideas were being proposed, I raised questions about the ethical implications of some of these devices. Many agreed they knew little about the potential hazards of the nanomaterials they were manufacturing or using. Yet universities and governments around the world are investing heavily in nanotechnology for its economic return. All sorts of useful devices are being developed, but others want to use nanotechnology to enhance people all the way to the posthuman – a new species with capabilities far beyond those of humans.

Those raising serious concerns about nanotechnology are sometimes accused of focusing too much on science fiction. Curiously, science fiction was one of the few places with a cautionary message about nanotechnology. I was drawn to examine why this might be the case, and whether science fiction offered a helpful way to raise ethical issues about nanotechnology (and other bioethical issues). Out of this developed my book *Nanoethics*. Written for a general audience, it introduces the science behind nanotechnology and the main ethical issues involved. Clearly informed by my Christian beliefs, these are presented in a way that hopefully will resonate with a wide audience. Human nature, with its potential and its flaws, is frequently examined by science fiction, which thereby provides a helpful signpost towards the true source of hope and redemption which some seek in technology.

Nanotechnology gets its name from the prefix 'nano', which refers to one billionth of a unit. Nanotechnology focuses on the nanometer (nm) scale, which is usually 1-100 nm. Most atoms are smaller than this range, while bacteria and cells are larger. Within the nanoscale fall large molecules, particular biological molecules like proteins and DNA, with many viruses right at the 100 nm limit. Nanotechnology focuses on understanding, manipulating, and manufacturing items in the nanoscale range.

A brief history of the development of nanotechnology is given in my book, and more detailed accounts are available.[2] Much of the vision for nanotechnology can be traced back to a talk given by Richard Feynman in 1959. He later won the 1965 Noble Prize in Physics, though not for work in nanotechnology. Feynman discussed how it should be possible to write the entire Encyclopedia Britannica on the head of a pin. He challenged physicists to develop the necessary methods, which were available a few decades later. Feynman also envisioned building surgical devices that could be injected into the body, guided to the source of health problems, and conduct repairs.

Science fiction picked up on this idea in the movie *Fantastic Voyage* (1966). The submarine that travelled through the patient's bloodstream was made through fictional methods, not nanotechnology. This exemplifies a complex interdependence between science and science fiction, as Feynman was clearly influenced by earlier science fiction. Nanobots have become a staple in science fiction, and some ethical concerns have been raised about these. However, this has also led to criticisms that nanoethics is overly concerned about the distant future. In my book, I develop a general distinction between "futuristic nanotechnology" and "normal nanotechnology." The former needs to be examined, but the latter is more pressing because nano-enabled products are on the market already.

Many recent developments in personal electronic devices, like the iPod, can be traced to nanotechnology. Other applications include sports equipment that is stronger and lighter, antibacterial coatings, and 'self-cleaning' windows. Carbon nanotubes are one group of nanoparticles that is attracting much interest. These hollow tubes are made from carbon atoms and are just a few nanometers wide. They have very distinct electrical and magnetic properties, and are unusually strong. They are expected to lead to a new generation of strong, but light, materials for car bodies and space-craft. They can be used in fabrics which are able to convert friction from body movement into stored electrical energy. This could power GPS systems, laptops, and other electronics for hikers or soldiers.

An important ethical issue is how decisions are being made about the types of products to be enabled by nanotechnology. While some parts of the world get smaller, faster iPods, others have no food, clean water, or basic healthcare. The life expectancy in some countries is half of that in the U.S. and Europe. Many deaths occur from "neglected diseases" which have received little or no research in recent decades.

The reasons for this situation are complex and multi-faceted. Solutions will not be simple. But at this point, many of the issues are not even being addressed. Some are claiming that even in bioethics there exists a "first-world bias."[3] The ethical issues of concern to poorer nations and communities rarely feature on the bioethics agenda. Ultimately this is an issue of justice, something Christians should be very concerned about. The problem here is not nanotechnology itself, but

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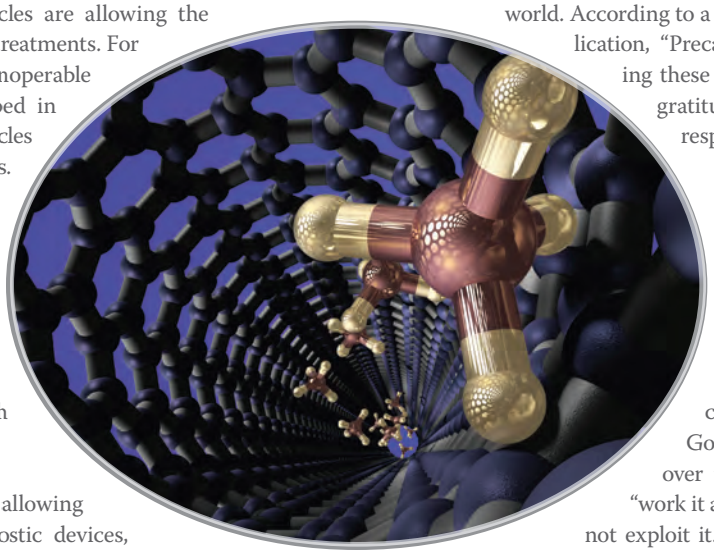
the question is whether it will contribute to potential solutions. We should be involved enough to know where our public resources are going, and who they will benefit.

Meanwhile, medicine and pharma are planning to take advantage of the unique biological properties of nanoparticles. Nanoparticles go where other chemicals cannot, which brings hope for new drugs and drug delivery devices. According to researchers, a 'rule of thumb' for nanoparticles is that those with diameters less than 100 nm can enter cells, less than 40 nm can enter the cell nucleus, and those less than 35 nm can pass through the blood-brain barrier.[4]

Nanotechnology can construct drugs for certain diseases that only enter the cells impacted by the disease. Existing drugs can be modified to make their delivery more precise. 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 might 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 tumors has been developed in Germany. Magnetic nanoparticles are injected into the tumors. When the patient is exposed to a magnetic field (as done in an MRI), the nanoparticles vibrate, generating a localized increase in temperature which selectively kills the cancer cells. Early results are showing successful treatment of such tumors.



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

However, the pervasive reach of nanoparticles also raises concerns about their potential side-effects, and whether enough is being done to investigate them. Nanotechnology is receiving huge investment, led by the U.S. federal agency, the National Nanotechnology Initiative (NNI). Its budget for 2010 is $1.64 billion. The expected return is also massive, with an anticipated global market of $1-3 trillion by 2015. However, only a relatively small proportion of the research funding is being targeted at environmental, health, and safety (EHS) research. In the 2010 NNI budget, EHS research received $88 million (5.4 percent). This funding allocation is based on a 2008 NNI Strategy which the National Research Council at the National Academy of Sciences strongly criticized for substantially overestimating the EHS research already under way.[5]

To date, little is known about the potential risks of most nanoparticles and nano-enabled products. Carbon nanotubes account for 80 percent of the nanomanufacturing sector. Five hundred tons of carbon nanotubes were produced globally in 2008, and it is anticipated that millions of tons will be produced annually in the near future. In a 2009 toxicity review, no research was found on human exposure to carbon nanotubes.[6] The review could locate only 21 animal and tissue studies, with most showing statistically significant damage in the groups exposed to the nanoparticles compared to the control groups. Although the experimental details differed significantly from natural exposure methods, the reviewers concluded that if carbon nanotubes get into the body, they will cause damage.

We should learn from past mistakes. Many are calling for a precautionary approach to the development of nanotechnology. The European Commission has developed a Code of Conduct for nanotechnologists which gives priority to the "precautionary principle."[7] While somewhat controversial, historical investigations have shown that a precautionary approach could have averted at least some of the damage from past environmental disasters. However, the values supporting the precautionary principle conflict with many of those in our market-driven world. According to a World Health Organization publication, "Precaution gives priority to protecting these vulnerable systems and requires gratitude, empathy, restraint, humility, respect and compassion."[8]

These values are completely compatible with Christianity, yet can conflict with an unrelenting drive for profit and progress. This tension needs to be acknowledged and grappled with, both by scientists and bioethicists. As Christians, we know that God has given humanity dominion over the world. But we were told to "work it and take care of it" (Genesis 2:15), not exploit it. The implications for nanotechnology need to be examined.

No area points to the urgency of this evaluation more than human enhancement. CBHD's recent summer conference on the ethics of enhancement was thus very timely. Some want to use nanotechnology to profoundly change humanity, to rebuild the human body, giving us the iHuman. One posthuman website 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?"[9]

The analogy with the car is, for some, to be taken literally. One mainstream 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.[10]

This is not just an off-the-wall perspective. Mainstream scientists, not just posthumanist philosophers, are claiming we can use technology to defeat aging and death. In a standard nanotechnology textbook it is claimed that nanotechnology "is considered poised to revolutionize the world as we know it, and transform us into something better."[11] Note

that they want to transform *us*, not just science or the environment. The goal is a perfect human body that will not decay.

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.[12]

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 (SENS 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. Bostrom also looks to cognitive and emotional enhancement. The ethical justification offered for this vision is an ethical principle that much of the Western world has already accepted. "Providing they are not significantly harming others, people who live in a liberal, democratic society are free to pursue whatever lifestyle they choose."[13]

Nanotechnology visionaries and posthuman philosophers often forget the nature of human nature even as they pursue a new human nature. Here is where science fiction provides important reminders of the truths that Scripture articulates. Classics like Mary Shelley's *Frankenstein*, H. G. Wells' *Time Machine*, Aldous Huxley's *Brave New World*, C. S. Lewis' *Cosmic Trilogy*, or modern movies like *GATTACA* and *The Island*, point to underlying problems with manipulating humans. Science fiction typically claims that technological enhancement does not go hand-in-hand with human progress. Attempts to control our evolution typically lead to further degeneration and conflict. I believe this is because authors of literature often have a better grasp of fallen human nature than those who are overly enamored by our capacity for technological developments.

Nathaniel Hawthorne's 1843 short story, *The Birth-Mark*, is also insightful here.[14] A brilliant scientist is married to a beautiful wife who is perfect in every way but one: she has a birth-mark on her cheek. He works tirelessly to develop a cure and to convince her that she needs the birth-mark removed. Eventually, he makes the needed cure. She drinks it. The birth-mark fades. She dies.

The story captures the lack of gratitude which so easily arises in the endless pursuit of perfection. Although our lives are not perfect, we have been given very much. In spite of all we have, our world encourages us to look at what we do not have - yet. Many would encourage us to look to medicine and technology to attain that perfection. Technology can do much good when directed at developing new treatments for diseases, better water purification methods, more environmentally friendly agriculture, etc. But when perfection in this world becomes the goal, we run the risk of becoming less grateful for what we have and less tolerant of those who are less than perfect. When those values predominate, terrible tragedies often occur as we see in fiction and in history.

Values underlie scientific and technological developments. Humility is one that is easily neglected. Literature has always reminded science of its limits, going back at least to Icarus and Daedalus. Literature can remind us that science and technology are good when put to good use addressing important and legitimate needs. But the very success of these enterprises 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 after inappropriate if not unattainable ends. And at the same time, we must address the pressing ethical issues that normal nanotechnology presents today.

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1 This essay is a condensed version of a talk given in Belfast, Northern Ireland on January 18, 2010 as part of the Christians in Science Ireland lecture series. The complete text of the presentation is available, along with others, at http://bioethicsireland.ie/nanoethics/. The bioethical issues raised by nanotechnology are examined in more detail, with a comprehensive bibliography, in my *Nanoethics: Big Ethical Issues with Small Technology* (Continuum, 2009).

2 Steven A. Edwards, *The Nanotech Pioneers: Where Are They Taking Us?* (Weinheim: WILEY-VCH, 2006).

3 Stuart Rennie and Bavon Mupenda, "Living Apart Together: Reflections on Bioethics, Global Inequality and Social Justice," *Philosophy, Ethics, and Humanities in Medicine* 3 (December 2008): 25.

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

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

6 Ash Genaidy, Thabet Tolaymat, Reynold Sequeira, Magda Rinder and Dion Dionysiou, "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.

7 European Commission, *Code of Conduct for Responsible Nanosciences and Nanotechnologies Research* (2008) ftp://ftp.cordis.europa.eu/pub/fp7/docs/nanocode-recommendation.pdf (accessed 20 April 2010).

8 Ted Schettler and Carolyn Raffensperger, "Why is a Precautionary Approach Needed?' in *The Precautionary Principle: Protecting Public Health, the Environment and the Future of our Children*, edited by Marco Martuzzi and Joel A. Tickner (Copenhagen: World Health Organization, 2004), 66.

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

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

11 Geoffrey Ozin, André Arsenault and Ludovico Cademartiri, Nanochemistry: A Chemical Approach to Nanomaterials, 2nd edition (New York: Springer-Verlag, 2009), x.

12 Nick Bostrom, "Why I Want to be a Posthuman When I Grow Up," in *Medical Enhancement and Posthumanity*, edited by Bert Gordijn and Ruth Chadwick (Berlin: Springer, 2008), 108.

13 Nick Bostrom and Rebecca Roache, "Ethical Issues in Human Enhancement," in *New Waves in Applied Ethics*, edited by Jesper Ryberg, et al. (New York: Palgrave Macmillan, 2007), 125.

14 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.