ETHICAL ISSUES OF NANOTECHNOLOGY

Fernando Galembeck

Institute of Chemistry, Universidade Estadual de Campinas

Campinas SP, Brazil

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Any new technology raises ethical issues. Some questions are common to many areas and others are specific to a given technology. There is now a hot debate on the dangers brought by nanotechnology[1] and some catastrophic views are often voiced,[2,3] while others embrace nanotechnology as a great panacea. In this presentation I will start by giving a short view on nanotechnology and then I will address problems related to privacy, intellectual property, the environment and employment.

A view on nanotechnology

Nanotechnology is a recent word associated to one or more of the following ideas:

i) The properties of matter may show profound changes when it is divided in nanosized particles or organized in structures with characteristic dimensions in the nanometric range, this means, the molecular size range. Examples of peculiar properties of matter in the nanometric size range are quantum confinement and superplasticity.

ii) Powerful new functional or structural materials are built by mounting nanometric constituents into arrays with designed performances unmatched by more conventional materials, thus creating new, powerful and highly "intelligent" devices and building materials endowed with complex behavior *by design*. "Complex" and "intelligent" behavior is defined by the possession of characteristics like: self-assembly, self-guidance, self-reporting and feedback triggered by the environment.

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[1] A Google search in the Internet using the keywords "Nanotechnology" and "Ethics" discloses 40.600 entries (November 26 2003).

[2] Just to give a flavor of of this debate, a compilation by Dr. Ron Epstein (Philosophy Department, San Francisco State University <epstein@sfsu.edu>) contains the following titles: "No Small Matter! Nanotech Particles Penetrate Living Cells and Accumulate in Animal Organs", "Opposition to Nanotechnology" by Barnaby J. Feder, "DNA nanoballs boost gene therapy","Nano litterbugs? Experts see potential pollution problems" by Doug Brown ,"Drexler warns terror symposium: nanotech has "extreme downsides" by Doug Brown, "Nanotech's dark side debated in the aftershock of Sept. 11" by John Carroll, "U.S. regulators want to know whether nanotech can pollute" b Doug Brown, "Nano, No and No Again" by Gard Binney, "Patenting Elements of Nature: No Patents on Non-Life Either!", "No Small Matter! Nanotech Particles Penetrate Living Cells and Accumulate in Animal Organs", "Why the Future Doesn't Need Us" by Bill Joy.

[3] For some references: www.ethicsweb.ca/nanotechnology/bibliography

iii) Nanotechnology is not a new technology specific for a given industrial sector. It is pervasive and its ideas, methods, products and processes are affecting every sector of the economy, from the agribusiness to industry and health, communication, information, financial and other services.

There is a strong tendency to associate nanotechnology to atom or molecule individual manipulation. Some Internet sites stress this idea[4] but I cannot agree with it, just because Avogadro number is too large[5]. Consequently, many nanotechnology processes are dependent on self-assembly and other techniques suitable for orderly handling very many molecules or particles at once. Another widespread idea is that nanotechnology is something absolutely new that started a few years or decades ago.[6] However, the origins of nanotechnology are traced back to Michael Faraday two centuries ago[7] and some large-scale current industrial products such as auto tires are strictly dependent on nanosized particles and other nanostructures.[8]

Privacy

Nanotechnology is having a powerful impact on privacy and control of individuals. This is a continuation from the impact of microelectronics[9] and information technologies in building up and exploiting very large data bases that now facilitate to governments, corporations and even individuals the accumulation of information on individuals, with or without individual or societal consent. Thanks to the Internet, access to information became very open and directed information circulation is easier than ever. Current nanotechnology brings two important contributions to this picture: the new and powerful data acquisition and handling systems, including the integrated sensing and reporting self-guided devices.

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[4] In http://nanotech-now.com/ethics-of-nanotechnology.htm we can read: "Imagine a world in which … cars can be assembled molecule-by-molecule, garbage can be disassembled and turned into beef steaks, and people can be operated on and healed by cell-sized robots"

[5] It is not likely that production of any good in gram amounts can be done by individual atom manipulation, just because the Avogadro number is 6.10^{23} atoms/mol. Thus, to assemble one gram of atoms by nanomanipulation, the nanohandling machines have to make *ca.* 10^{21} moves. A production unit with one-billion atom-mounting devices, each capable of mounting one atom per microsecond will take 6 million seconds (or 2.3 months) to assemble just one gram of atoms.

[6] As in this quotation from the Institute of Physics webpage: "In a paper published today in the Institute of Physics journal Nanotechnology, Canadian researchers from the University of Toronto Joint Centre for Bioethics (JCB) claim that although the research is still in its early stages and most applications may be decades away, the backlash against the new technology is already gathering momentum."

[7] Faraday assigned the blue and red color of gold particle dispersions in water to the subdivision of gold in very small particles. Very thin gold sheets are green, not yellow.

[8] There is not a good auto rubber that is not filled with nanosized carbon black particles. Scientific understanding of this requirement still lags well behind its technological use.

[9] Microelectronics is now better called *nano*electronics, since the current state of the art allows a 90-nm resolution.

Integrated GPS and microcomputer systems now allow an individual to find the best trekking path in the wilderness, and this is wonderful. On the other hand, this also allows Big Brother to keep track of an individual in the wilderness, not to say in a city or a rural area. There is no foreseeable limit to integration and miniaturization in the next few years beyond the limits imposed by the molecular organization of matter and it is quite likely that implantable chips are increasingly available, endowed with powerful functions for remote monitoring of any person's activities.

On the other hand, we are witnessing great advances in the neurosciences, for instance those related to the direct collection of information from the brain centers and the remote implementation of decisions from these centers. Of course, this also makes possible the flow of external signals and decisions **to** these centers, making it possible the robotization of individuals.

However, to be frank it seems to me that individual control and manipulation is now being done very efficiently and using rather different technologies that belong to the class of *social engineering***.** I refer to the use of technologies based (with or without acknowledgment) on concepts like Susan Blackmore's *memes*,[10] as they are widely practiced by some religions, as well as leaders of marginal human sub-populations and that operate based on the principles of self-assembly that are much better adapted to the control of massive populations than individual nanomanipulation.

Intellectual Property

It is obvious that any new technology is strongly associated to intellectual property. What I will say now is from the perspective of a Brazilian scientist, living in a country that struggles to build and maintain a significant scientific system while it pays more interest to the international capital than is spent in public education and public health, together.

Brazilian scientists now make a significant scientific input to nanotechnology, as measured by the number of publications in international refereed journals. Some publications were very well received and made their way to the covers of prestigious journals.

On the other hand, Brazilian scientists do not pay attention to patents, as a rule. Most researchers in Brazil as well as in other countries beyond the G-7 do not read patents and also do not even consider applying for patents, even when their effort is justified in the paper preambles by the possibility to achieve some important practical result.

This leads to two clear consequences:

[10] S. Blackmore, *The Meme Machine*, Oxford 1999.

i) A significant part of our scientific effort is completely wasted, because the objectives of the projects may have already been reached by others and they may be within some patent document. To stress the quantitative importance of this problem, I recall that an estimated 50% of the scientific contents of patents are *never* published in the open literature. This means, the "state of the art" within which we operate is only a part of the actual recorded information, and the missing part is at least as important as the other, from the point of view of property and creation of wealth.

ii) Brazilian scientists are contributing to the literature at a growing rate, bringing in information that will be freely appropriated by other individuals and corporations, much likely abroad. This new information will be finally transformed into products and processes that will be imported into the country, bringing in modernity but also unemployment and pressures on the economy.

This picture can be much improved if only we take seriously patent reading, writing and filing, as individuals, and if our organizations start to give some attention to patents. What is now practiced in Brazil and certainly in other countries is an excessive emphasis on indicators like numbers of publications and impact factors of journals that end up being a mechanism for the transfer of knowledge and intellectual property from the poor to the rich.

Environment

During the past decades we have witnessed an interesting phenomenon in the area of materials production, worldwide. This is the *commoditization* of a large number of materials. Stainless steel, gold finishes, diamond tools, specialty polymers and ceramics have become more and more common with many producers in the world and lower prices.

This brings some advantages as related to the universalization of access to the benefits of technology but it also brings concerns related to the environment with the more widespread dissemination of persistent pollutants. We use today a large amount of battery-powered devices, from watches to cell phones and laptops and this means the spreading of nickel and cadmium in the environment.

As an example, cadmium is specially interesting for its ability to reappear in a new application, after being banned from previous applications. Cadmium pigments have been important in the past but they were eliminated from many applications such as paint and enamel pigments. Now, there is a large interest in cadmium sulfide nanoparticles for many applications due to their quantum confinement and non-linear optical properties. This means that there will be new environmental risks introduced by the new cadmium nanomaterials.

The solution for this kind of problem is a renewed attention to materials and goods lifecycles: their design, engineering and production should include lifecycle analysis as an integral part as required by legal provisions, regulations and codes. Tax structure from municipalities, states and counties should have provisions for tax reductions on the products supported by a well-established recycling structure, so that we could take maximum benefit from the properties of potentially damaging materials without incurring in excessive risks.

I would like to use some time to tell a story that is a good example on how a new technology can bring new problems and how these can be solved, provided we have a comprehensive lifecycle perspective.

Brazilian northeast is plagued with a low water supply and dramatic water shortages are frequent. On the other hand, there are ample underground deposits of brackish water, in some places, and this led to a significant effort of water pumping and desalination by reverse osmosis membranes. This produced drinkable water together with high-salt rejects from the operation of the membrane systems. These rejects soon became a menace since they could provoke large increases of salinity of the soil and surface waters.

It was thus necessary to find a sink for high-salt content waters and this was made viable in three steps: these waters are first fed to tanks for raising shrimp, wherefrom they flow to tanks were tilapia fish is grown and finally used to irrigate *Atriplex*, a salt tolerant plant that has a high protein content and is well accepted by cattle as a fodder.[11]

This case shows how a problem was created by the introduction of membrane technology, that is an important branch of nanotechnology, and how this problem (the disposal of brackish waters) became a solution to a much greater problem, which is the creation of viable economic activities in a highly disadvantaged area.

We can also expect some major environmental benefits from nanotechnology, for instance in the case of auto tires. These are now a great source of unsolved problems due to the associated recycling and disposal problems. Thanks to new nanotechnology concepts we can now foresee the appearance of recyclable tires, thus solving this big problem.

Employment

Any new technology creates new job opportunities but it also causes the obsolescence of previous technologies with the consequent loss of jobs. Perhaps I don't have to give any example for that, but let me recall that Brazil had a strong and viable industry of radios and TVsets until the early seventies. The introduction of color TV ended up this industry, with thousands of jobs.

[11] This is a Project of the Universidade Federal da Paraíba (now UFCG).

It is now estimated that nanotechnology will create 2 million direct jobs worldwide within a decade, but I don't know estimates on how many jobs will be terminated by nanotechnology. I suspect that these will exceed the 2 million figure.

Past experience suggests that most new jobs will be created in a few countries, especially the G7, China and Russia while terminated jobs will concentrate in the other parts of the world.

However, I believe that adequate government strategies may well counter the obvious spontaneous trends, creating a more desirable scenario. For instance, in the case of Brazil, I would favor an intensive nanotechnology input in all those areas of the economy satisfying one or more of the following conditions:

i) Activities within the country have reached a status of global competitivity.[12]

ii) Local production is favored by circumstantial advantages, including logistics.

iii) The nanotech input will satisfy local needs that will not receive attention from worldwide technology suppliers.[13]

A nanotechnology area that can satisfy these conditions is the creation and production of new sensors designed for very well-chosen applications. This may have many consequences:

i) To increase the economic competitiveness of Brazilian agriculture by increasing the practice of *precision agriculture*, that depends largely from feeding fertilizers at the adequate levels which in turn depends on a large amount of information on nutrient content in the soil.

ii) To allow a better monitoring of the health of the population by reducing the costs and complexity of laboratory assays required for medical diagnosis.

There are also many opportunities in nanopharmaceuticals and nanomaterials, but I don't have the time to discuss them now.

Education

Finally, a word on the impact on education of the new knowledge associated to nanotechnology. Ethical behavior does not prevail within a society of unequally educated persons or among countries separated by large educational gaps. The fast development of nanotechnology is currently widening the educational and economic gaps among individuals and also among countries. I propose that this trend is countered by an effort in improving general education and specially science education standards, specially in those countries that are performing poorly in

[12] Brazil is now the *only* country in the world producing fuels from renewable sources at prices competitive with oil and without any subsidy. This is the result of more than 30 years intensive science, technology and entrepreneurial efforts.

[13] As for the treatment of locally important diseases as well as mass housing, transportation, water and waste recycling adequate for the tropical environment.

this respect, such as Brazil, Mexico and others. Of course, science education now has to include topics on nanotechnology since this is one of the faster-moving frontiers of current science and technology.

In Brazil we are ready to start a new moment of great change in science education: we have now the awareness, the qualified persons to lead this effort, the motivated teachers and students and, more important them anything else, a widespread awareness of our enormous deficiencies. As soon as we move from the vague speeches and empty governmental announcements to the real action, we will be in a position to have nanotechnology as an ally, not as a menace.

Conclusion

Most of the ethical problems raised by nanotechnology are not new and they have been around for decades, associated to the information technologies, the impact of new materials on the environment and employment, new medicines and diagnosis, mass destruction weapons and other technologies.

We should avoid the hype created by unsound ideas about nanotechnology to concentrate on the real issues and on the solutions for the problems brought by nanotechnology, that is becoming increasingly present in our daily life. As any other technology, it will be a friend of those who know it and a foe of the ignorant. There is nothing really new in this situation if we recall the myths of Icarus, Prometeus and Pandora.