Implications of Nanotechnology Applications: Using Genetics as a Lesson

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I. Introduction

As society becomes more comfortable discussing genetics and its related ethics, a new technology is blossoming in the background. Nanotechnology may speak the same societal language as does genetics, in that both technological movements involve tiny science and large imagination. In a way, it is natural—and almost inevitable—that the genetic revolution and the nanotechnology revolution be compared. Both fields involve smaller and smaller scales and manipulation of nano-sized materials. Both fields also create ricochet effects in almost every aspect of society.

While nanotechnology is new, so new that nothing seems impossible, there are certain predictions that may be safely drawn. Though we need to be cautious of both positive and negative hype, some speculative applications of nanotechnology are becoming clear. Already today, scientists and engineers are creating nanowires and carbon nanotubes slated for super-strong, super-efficient and eventually super-cheap products. In nanomedicine, there are discussions of sending dendrimer polymers into every reach of the body to dispense drugs in specifically localized cells, and of dispatching diagnostic nano-machines into the body to detect cancer when only a few cancerous cells exist.[1] Moreover, nanotechnology will be used as a tool for genetic information and research, facilitating genome sequencing and nuclear transfer with "smart" nano-devices that have some independence and learning capabilities.

For every possible application of nanotechnology—and even for fantastical ones—we need to examine social, ethical and legal implications. We can learn from the genetic revolution and ponder how similar issues might arise in nanotechnology. For instance, we can forecast privacy, intellectual property and concept of life concerns. Yet, at the same time, it is important to recognize that nanotechnology is its own creature as well. Because nanotechnology is more application than exploration, many societal concerns will reflect this difference from genetics.

Like the World Wide Web, "nanotechnology may appear gradually and yet have a revolutionary effect."[2] The purpose of this paper is to provide a cursory overview of some possible social, ethical and legal issues implicated in the development of nanotechnology. All issues within this paper evidently warrant further analysis.

II. Social Implications

Inherent in the promise of nanotechnology is the creation of superior products and services at a much-reduced cost. The effect of such creation, by itself, will perhaps take decades to manifest in society,[3] spinning off into environmental, social, economic and educational implications. Within these spheres, as with genetics, we will find "a fundamental tension of civilization – the tension between humanity's quest for more control over nature and the future, and our equally strong desire for stability and predictability in the present."[4]

a. Environmental implications

One of the more common social notes that seems to arise from a perusal of the literature is that nanotechnology will have a positive effect on the environment. Nanotechnology "promises to reduce by orders of magnitude the inputs of energy and materials and associated environmental discharges required to produce a device that can perform a particular task."[5] Due to the near-perfect potential efficiency of nanotechnology, by-products will be minimized and emissions will be controlled. Roco and Bainbridge envision applications such as tires where the carbon black is replaced with an environmentally friendly nanotechnological substance.[6] Electricity will be generated with much less fuel

and the "environmental footprint" of electricity will consequently be vastly smaller.[7] Filters for water or oil will be "ultrafine," allowing fewer impurities and contaminants into the product, and gasoline consumption in turn will plummet. Water could be desalinized[8] and the oceans could assuage the impending water supply worries of the world.

b. Social implications

Following the genetic experience, social implications of nanotechnology may involve effects in health care and wealth distribution. In health care, for instance, it is very likely that nanotechnology in the arena of medicine would include automated diagnosis. This in turn would mean fewer patients requiring physical evaluation, less time needed to make a diagnosis, less human error and wider access to health care facilities.[9] As well, if nanomedicine increases the life span of human beings, it will create populations with large proportions of elderly people requiring more health attention and consequently more health expenditures. In Canada, where rising health care costs are of current concern, the subsidized public system may have to be examined and adjusted. To say, on the other hand, whether savings from more efficient nanomedicine techniques will counterbalance the expense of an increased aged population is speculative at this point.

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Another social concern linked to health care is that of insurance. Being able to develop predictive health profiles of individuals might make insurance coverage minutely specific and might "destabilize the risk-spreading approach that allows equitable delivery of social benefits to broad populations."[10] In a more extreme light, diagnostic nanotechnologies may even make some patients un-insurable[11] (while this is perhaps less a concern in Canada than in wholly privatized systems, Canadians should be prepared to face the same problems, especially if health care costs continue to rise). As an extension of this concept, genetic discrimination may well become a problem. There is already concern with genetic discrimination today, but with nanotechnology it is easy to imagine an amplification of problems.

As for wealth distribution, several authors predict a "nano divide" between those who participate in nanotechnology and those who cannot afford to participate.[12] The rich will get richer and the poor will get poorer, in effect. Most nanotechnology scholars agree that the technology will be initially extremely expensive but much cheaper in the long term. The initial expense may exacerbate the "nano divide" by limiting accessibility to the nano-applications. Smith even poses the ominous question: "Will the 'Haves' of the Earth no longer need the 'Have-nots'?"[13] On the other hand, the Foresight Institute's Guidelines on Molecular Nanotechnology sees nanotechnology as facilitating wealth distribution more safely across international boundaries by "distribut[ing] the benefits of the technology to the four fifths of humanity currently desperate to achieve material wealth at any environmental or security cost."[14]

c. Economic implications

Hand in hand with social concerns are economic concerns. Giving poorer nations more wealth through nanotechnology might mean that the world economy as a whole may become more stable and sustainable.[15] Within North America, though, nanotechnology could foreseeably alter the entire framework of our economies. If nanotechnology practically rids industry of its dependence on fossil fuels and oil, as predicated by many,[16] how might the new economy "realign itself?"[17]Moreover, if nanotechnology finds success in the context of dramatically reducing the price of minerals and gems, this might create economic crises in the countries for whom production of these minerals and gems is an economic "mainstay."[18] From another angle, nanotechnology may (or may not) drastically alter the current economic environment, where less-durable products are the norm because companies want frequent replacement and consequently increased profits.[19]

Not unlike current prospects in genetics, corporatism and capitalism will almost certainly rule the nanotechnology day. Many writers (including Bill Joy in *Wired*[20]) note the enormous lucrative potential of nanotechnology in the private sector. While venture capitalists are slow to invest in an industry with huge initial costs and speculative results, when nanotechnology's scope is proven, capitalism will feed itself on nanotechnology and radically affect the orientation of the markets. There are surely benefits to this, but the changes may be so great as to be unpredictable. What if—and this has been seen as practically inevitable—computer manufacturing costs could be slashed in half? What if drug development and production costs could be reduced by seventy percent?[21]

If nanotechnology pervades almost every sector of the economy, the profile of the economy will change. Some

businesses, for instance, may suddenly be irrelevant and/or obsolete. If this happens, governments may need to provide subsidies to keep the economy stable.[22] Labourers may no longer be needed, and older skills that might be needed in technological breakdown may disappear. At the same time, the workforce could become concentrated in highly-skilled employees.

d. Educational implications

Such a scenario would necessitate a fundamental change in education. "Education, especially technical and scientific education, will be the key to full participation in the economy, even more than it is today," predicts Theis.[23] Because nanotechnology is a unique mixture of engineering, physics, chemistry, biology, computer science and materials science, the field will require a force of multidisciplinary experts. There will be more collaboration and more interdisciplinary flexibility.[24] An engineering education will require a broader background (convergence) in a larger number of areas, compared to the specialist approach (divergence) that now exists in most post-secondary contexts. At the same time, the technology is expected to evolve so rapidly that these university-educated graduates will be valued for their ability to think and learn quickly, rather than for their technical expertise.

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III. Ethical Implications

The ethical implications of nanotechnology are simultaneously unpredictable and predictable. While nanotechnology is still in the fledgling stages, and undeniably unique in certain respects (size, invisibility), the applications are speculative and the ethical considerations follow speculatively. However, Weil suggests that a good place to start addressing the ethical implications of nanotechnology is to examine the experience we have gleaned from biotechnology and information technology[25] because these fields, like genetics, are likely to share some ethical issues with nanotechnology. Major areas of concern include academic/industry relations, technology abuse, social divides and the very concept of life.

a. Academic/industry relations

Due to the almost prohibitive cost of nanotechnology development in its early stages, and due to the reluctance of investors to contribute to uncertain efforts, universities will probably be the initial site of research. The University of Alberta's new National Institute of Nanotechnology is one example.

The attraction of nanotechnology for the private sector is inevitable, however, and already there are some forays into academic/industrial relationships around nanotechnology. As with genetics and biotechnology, such relationships will certainly raise issues of, for example, conflict of interest. There will be new pressures on universities, and questions will surface about "whether a university researcher's ties to a for-profit firm threaten reliable judgment in university research."[26] Weil recommends the training of nano-ethicists and further emphasis on ethics components in grants.

b. Abuse of technology

The prospect of nanotechnology has been greeted by extreme optimists and extreme pessimists alike, but even the realists and moderates agree that abuse is always a factor in new technology development. As Reynolds points out, "Nanotechnology cannot be un-discovered."[27] Research is research, and it cannot be limited in the laboratories to only benign uses.

Joy writes, however, that "it is far easier to create destructive uses for nanotechnology than constructive ones."[28] He fears empowerment of extremists by the capabilities of what he terms "knowledge-enabled mass destruction," and he compares the future of nanotechnology with the spectre of nuclear power and its devastation.[29] After September 11th, 2001, the implications of nanotechnology abuse may have become more real.[30] Nanotechnology would allow for selective biological and chemical weapons, for instance, afflicting only people of certain genetic makeups.

Here, the control and regulation of nanotechnology become primary concerns. The Foresight Institute Guidelines propose that "Accidental or willful misuse of [molecular nanotechnology] must be constrained by legal liability and, where appropriate, subject to criminal prosecution."[31] Reynolds addresses the issue by putting his faith in humanity: "the real protection against the abuse of technology is an emphasis on people, not the technology itself."[32]

c. Social divides

This ethical concern about nanotechnology involves a similar concept to the "nano divide" discussed in *Social implications* above.

Even before the normalization of nanotechnology, enormous social gaps now exist in the world, both at national and international levels. There are already poor people, marginalized people, under-represented people, and in the nanotechnology revolution these populations will include the ones not educated in nanoscience or nanotechnology. As a predictive thermometer, given the current state of existing genetic technologies, the distribution of benefits will likely not be any different with nanotechnology. "Should the fruits of the research reach everyone or just the wealth? Does this include only the U.S. or the world? If the world, who pays?" Smith puts these insistent questions to his readers[33] without supplying answers, but the purpose of his questions lies in the process of asking, while the answering is up to us.

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d. Concept of life

The definition and parameters of life are called into question with the advent of nanotechnology. In a similar way to large questions of individuality and identity in genetics, the ethics of what "life" is and of what effects nanomedicine may have on the concept of human life appear regularly in the literature.

One aspect of the ethical concept of life revolves around nanotechnology itself. "Our vision of nanotechnology encompasses the attributes of self-generation, reproduction, self-assembly, self-repair and natural adaptation," writes Venneri. "These are all attributes we ascribe to living things."[34] While he is referring primarily to self-replication capabilities of nanorobots, which do not yet exist and which may never exist (depending on who you talk to), we are all familiar with scenarios from *Star Trek* and science fiction. Venneri notes that systems are becoming more "'life-like'" and "too human" with nanotechnology.[35]

The other, less fantastic aspect of how the concept of life might change with nanotechnology regards the promises of nanomedicine. Nanotechnology may be able to repair or reproduce tissue, diagnose disease (e.g. cancer) at a very early stage, dispense drugs at the cellular level, and even reverse disease.[36] Our concept of the human life span may be revolutionized as a result; people may live longer by techniques considered by many to be artificial. Some will wonder if nanotechnologists are "playing God" by tinkering so directly with nature. Others will wonder to what extent humanity and nanomachinery will blend; "if we are downloaded into our technology, what are the chances that we will thereafter be ourselves or even human?"[37] Smith asks: "How much nano-prosthesis will make one non-human?" and "Can or should we consider the replication of brains? Souls?"[38]

Still on the medical front, the issue of predictive health profiles—an issue familiar in the genetics arena—will undoubtedly come up, even separately from genetic discrimination. With nanotechnology making genetic profiling easier, the idea of having a nontreatable genetic disposition may create "toxic knowledge" in patients, which may in turn become a psychological threat to health.[39]

From one perspective, nanomedicine is only the next natural step in the area of developmental medical research. As we refine techniques of genome sequencing, xenotransplantation, therapeutic stem cell research and reproductive technologies, nanotechnology may simply follow with the same ethical implications about the concept of life. However, nanotechnology likely has unique characteristics that make vigilance concerning ethics important, perhaps in ways we cannot yet predict.

IV. Legal Implications

Anything affecting society, the economy, medicine, education, the environment and ethics certainly affects the law and legal frameworks. Many legal implications of nanotechnology will become clear as the technology develops, but some predictions have emerged already. For instance, parallel to such implications in genetics, legal concepts of property, intellectual property and privacy will probably change as nanotechnology integrates into society.

a. Concept of property

One of the optimistic promises of nanotechnology is that almost everything and anything will be in plentiful supply, and cheaply. Taken to its logical extremes, this could change the concept of property forever. One of the central features of property is the exclusion of others. If others, however, have no need or desire for your piece of property since they have their own, this could potentially dissolve exclusion of others as a characteristic of property. As a result, the idea of

ownership might dwindle, or at least become less proprietary. As Smith asks, "How would the concept of property change if most things became replicable? Will we care?"[40]

b. Intellectual property implications

As a special sub-category of property, intellectual property might well suffer the same consequences as the concept of property simple, and become obsolete. On the other hand, since intellectual property is non-physical in nature, nanotechnology itself cannot replicate intellectual property. Intellectual property might be involved with the processes and patents during nanotechnology development.

Crow and Sarewitz write that, in the face of nanotechnology, "the concept of intellectual property seems increasingly vulnerable." They raise the possibility that, like other property, copyrights and patents may fall by the wayside as ownership and proprietary protection become less important.[41] Theis likens nanotechnology and intellectual property to the debates around copying digital music and data, in that reproductions will be ever less expensive and less distinguishable from the original as nanotechnology progresses.[42]

Before the concept of intellectual property dissolves, however, there will be the problem of secrecy and transparency in nanotechnology: "As nanotechnology matures, it's only a matter of time before the issue of restricted research and secrecy will have to be confronted."[43] Most nanotechnology pundits advocate open discussion and information-sharing as a model for progress and self-regulation, but they acknowledge that capitalist competitiveness may hinder this model. Joy sees a critical point as making wide transparency "acceptable in a world of proprietary information … by providing new forms of protection for intellectual property."[44] The Foresight Institute Guidelines take a novel approach to intellectual property, proposing a "competitive disadvantage" imposed on those who do not follow "responsible principles" for disseminating nanotechnological knowledge,[45] in other words using intellectual property as a kind of enforcement mechanism.

c. Privacy implications

Similar to the recent (and continuing) revolutions in genetics and information technology, nanotechnology will affect the concept and regulation of privacy. As nanotechnology makes computing capabilities increasingly smaller and more efficient, collecting, storing, sharing and processing large amounts of information will become easier and cheaper. As a result, privacy and security will become more important. Data will be vulnerable to misuse, especially given the potential ocean of information circulating about every aspect of an individual's life.[46]

d. Regulation implications

Most discussions of the future (and present) of nanotechnology include a reference to the growing realization of the need for regulation in the field.[47] Though views on the extent of regulation differ, there is general agreement that regulation is one way to combat the abuse of technology.

From a national security standpoint, Tolles recommends limitation and control in cases where resources get consumed too quickly, random viruses are produced, machines no longer respond predictably to humans, or inexpensive products are being used for mass indoctrination or mass destruction weaponry.[48] A number of other authors urge a conversation between the public and the nanotechnologists as a kind of accountability and transparency mechanism, and also as a way to bridge the information barrier between those two groups.

The trail of regulation also runs persistently through the proposed Foresight Institute Guidelines on Molecular Nanotechnology. While the Guidelines speak of the opportunities in nanotechnology, they recognize that "Along with these new capabilities come new risks, and new responsibilities. The acceptance of these responsibilities is not optional." The strongest suggestion comes in the area of self-regulation, including "professional guidelines that are grounded in reliable technology, and knowledge of the environmental, security, ethical and economic issues." Safety measure suggestions also appear, so that nanotechnologies will include such mechanisms as built-in termination dates, artificial fuel sources (rather than those found in nature), and human-dependent subassemblies.[49]

While the Foresight Guidelines are currently far from binding, especially in Canada, the existence of such a structure indicates how, even in the early stages of this technology, awareness about regulation and ethical, social and legal issues may compatibly accompany the development of nanotechnology.

V. Conclusion

Our society's experience with the genetics revolution can be a valuable model for nanotechnology development, in terms of assessing potential benefits and problems. As this paper suggests, many of nanotechnology's issues mirror those of genetics. We as a society have learned that tracking implications along with a new technology's applications is

important, and that it is never to early to consider social, ethical and legal ramifications. The National Institutes of Health in the United States established ELSI (Ethical Legal and Social Implications of Human Genetics Research)[50] to accompany the genetics revolution. In Canada, we have had numerous similar projects, including Genome Canada's current GELS (Genetics, Ethics, Law and Society) initiative. Perhaps these genetic models may serve as a template for similar examinations of nanotechnology.

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9. LaVan & Langer, *supra* note 1 at 100.
10. Crow & Sarewitz, *supra* note 4 at 62.
11. J.L. Merz, "Technological and Educational Implications of Nanotechnology – Infrastructures and Educational Needs" in Roco & Bainbridge, 186 at 195.
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13. Smith, *supra* note 2 at 270.
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