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Ethical Responsibilities of Nanotechnology Researchers: A Short Guide

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Abstract Little if any of the scholarly literature on nanotechnology (NT) and ethics is directed at NT researchers. Many of these practitioners believe that having clear ethical guidelines for the conduct of NT research is necessary. This work attempts to provide such guidelines. While no qualitatively new ethical issues unique to NT have yet been identified, the ethical responsibilities identified below merit serious attention by NT researchers. Thirteen specific ethical responsibilities arising at three levels are identified. They are derived by applying four fundamental ethical responsibilities of scientists and engineers to the specific conditions of NT research and researchers in contemporary Western societies. Since society is placing increasing importance on producing scientists and engineers who combine high technical competence with a sensitive ethical compass, study of the ethical dimension of NT, including the identified ethical responsibilities, should become a required element of the formal education of all NT researchers.

Keywords Nanotechnology · Ethics · Ethical issues unique to nanotechnology · Ethical responsibility and ethical responsibilities · Fundamental ethical responsibilities of scientists and engineers · Ethical responsibilities of nanotechnology researchers · Micro-social · Meso-social, and macro-social levels · Guide · Ethical dimension of nanotechnology · Formal education of nanotechnology researchers

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Introduction[1]

Consider the following data points about nanotechnology (hereafter: NT) and ethics:

- In 2000, Bill Joy, then Chief Scientist of Sun Microsystems, published an essay in which he termed the potential of nano-scale assemblers for destructive self-replication a threat to the biosphere.[2]
- In 2002, the U.S. National Science Foundation (NSF) invited proposals to establish a National Nanotechnology Infrastructure Network (NNIN), requiring that NT's "social and ethical implications" be an ongoing part of NNIN's research agenda.[3]
- In 2002–03, Michael Crichton's novel *Prey* depicted unpredictable swarms of programmed and learning-capable nano-particles wreaking havoc on humans.[4]
- In 2005, NSF funded "Centers for Nanotechnology in Society" at two U.S. universities to study societal—including ethical—issues related to NT.[5]
- In 2007, *Nanoethics*, a new scholarly journal about NT and ethics, was launched. The journal and its title indicate that some academics believe

[1] I am indebted to Douglas Kysar, Paul Rissman, and Michael Deal for feedback on draft versions of this essay, and to two anonymous referees and the editor for helpful criticisms and suggestions.

[2] Bill Joy, "Why the Future Doesn't Need Us," *Wired*, Vol. 8, No. 4, April, 2000.

[3] See http://www.nsf.gov/publications/pub_summ.jsp?WT.z_pims_id=5612&ods_key=nsf03519.

[4] See http://en.wikipedia.org/wiki/Prey_(novel).

[5] The centers were established at Arizona State University and the University of California, Santa Barbara.

there are ethical issues related to NT that merit critical analysis.[6]
- In 2008, the European Commission adopted a "Code of Conduct for Responsible Nanosciences and Nanotechnologies Research" and recommended that its member states "be guided by the general principles and guidelines" set out in the Code.[7]

Concern about ethical issues related to NT is clearly in the air. While the number of scholarly works on NT and ethics has grown rapidly in recent years, none has taken NT *researchers* as its primary target audience. This is unfortunate for three reasons: first, many NT researchers are interested in ethical issues related to their work; second, many of them believe that having clear ethical guidelines for the conduct of NT research is necessary[8]; and third, the existing scholarly literature on NT and ethics does not provide such guidelines and is of little practical value to NT researchers. The short guide that follows is intended for nanotechnology researchers and represents an attempt to remedy this situation.[9] Its goal is to foster responsible conduct in nanotechnology work by elaborating a number of specific ethical responsibilities that individual researchers have as practicing NT professionals.[10]

Before turning to the intellectual core of this guide, two preliminary issues warrant discussion. The first is whether NT work raises *unique* ethical issues and, if not, whether NT researchers should still concern themselves with ethical issues related to their work. The second is whether the ethical responsibility requirements of a scientist or engineer can be reduced to fulfilling a checklist of specific ethical responsibilities.

First, while many NT researchers agree that there are significant ethical issues related to their work[11], some of them believe that NT deserves their serious ethical attention only if at least some of these issues are *unique* to NT. To date, ethics experts have not identified any specific ethical issue unique to NT. Further, there does not appear to be anything intrinsic to the NT field *per se* that raises any *qualitatively new* ethical issues. However, neither proposition implies that NT is unworthy of ethical consideration by NT researchers. Intellectual property theft in the Internet era is not a less important ethical issue simply because the issue of theft is not unique to the IT field and has been around for centuries. While the *kinds* of ethical issues and challenges discussed in this guide have arisen before and will probably arise again in future areas of research, old ethical wine in new technological bottles can still merit careful attention. In fact, recognized ethical issues that appear in different guises in a new field of inquiry become *more*, not less, important for researchers in that field to consider when work in that field holds substantial potential for changing society.

While phenomena in the NT domain have not been shown to raise any qualitatively new ethical issues, there *is* something historically new, ethically speaking, about the societal NT enterprise. With the rapid growth of NT research, an unprecedented ethics-related opportunity has appeared. Important government agencies that fund NT research, such as the NSF in the United States and the *Centre Nationale pour la*

[6] See http://www.springer.com/philosophy/ethics/journal/11569.

[7] European Commission (Directorate-General for Research, Directorate L [Science, Economy and Society], Unit L3 [Governance and Ethics]), "Commission Recommendation on 'A Code of Conduct for Responsible Nanosciences and Nanotechnologies Research' and Council Conclusions on 'Responsible Nanosciences and Nanotechnologies Research'," EUR 23906, 2009, p. 11.

[8] In a 2005–06 survey of the views of 1,037 NT researchers at NNIN laboratories about ethical issues related to their work, 58.7% of the 847 respondents indicated that having "clear ethical guidelines for the conduct of nanotech research" is "necessary," 34.7% that having such guidelines is "desirable but not necessary," and 6.6% that having them is "neither necessary nor desirable." See [5], p. 110.

[9] Some may wonder whether the abovementioned, European Commission-adopted "Code of Conduct" has already filled this gap. The heart of this code is contained in "Ethical Responsibilities of NT Researchers" ("Guidelines On Actions To Be Taken"). Of the 27 guidelines listed, only five are aimed at NT researchers. (Subsection 4.1.2 calls on them to make NT-related scientific knowledge and information "easily accessible and understandable by lay people as well as by the scientific community"; 4.1.4 to "insure that scientific data and results are duly peer reviewed before being widely disseminated outside the scientific community"; 4.1.9 to consider "the future implications of technologies or objects being researched"; 4.2.1 to "take specific health, safety, and environmental measures adapted to the peculiarities of the nano-object manipulated"; and 4.2.6 to "gain a better understanding of fundamental biological processes in the toxicology and ecotoxicology of nano-objects" and to widely publicize their findings.) The other 22 guidelines are aimed at other "stakeholders," e.g., EU member states, employers, NT research organizations, and NT research funding bodies. In short, the gap between NT researcher need and scholarly literature remains unfilled.

[10] NT researchers are not the only professional group with NT-related ethical responsibilities. Other groups with such responsibilities include product designers, manufacturers, regulators, lawyers, judges, journalists, and educators.

[11] McGinn, *loc. cit.*, p. 104.

Recherche Scientifique in France, have supported efforts to help NT researchers become more aware of and reflective about the ethical dimension of their work. A belief has begun to emerge in the NT research community that NT researchers can and should take a leading role in "improving the stewardship of the scientific enterprise."[12] It is hoped that by doing so they will avoid alienating the public, the source, through the votes of their elected representatives, of much of the funding that makes the work of most NT researchers possible.

Turning to the second preliminary issue, a disclaimer is in order. The guide that follows is *not* a comprehensive treatment of NT and ethics. There is, after all, more to ethics than ethical responsibility. Further, although a number of ethical responsibilities of NT researchers are spelled out below, taken as a group they are not intended to be and should not be viewed as a checklist that offers NT researchers the last word on ethical responsibility in relation to their work. Determining whether one has an ethical responsibility to do something is not like determining whether one can legally take a particular expense as a tax deduction by checking the specific statutes of a tax code.

Ethical responsibility for researchers, regardless of field, involves more than consulting a checklist of specific responsibilities, however extensive. It requires that the researcher develop the ability to ascertain and disposition to take into consideration how her/his actions, practices, and work products are likely to influence the well-being of all parties they are likely to affect. It also requires that the researcher commit to seeking new and more effective ways of combating harm to others, fostering social justice, and promoting public benefit through her or his professional work.[13] While the ethical responsibilities identified below are important, they do not provide a decision-making algorithm. They are, in effect, guidelines or precepts that are useful as far as they go. But the fact that a particular course of action is not ruled out by any of the stated ethical responsibilities does not imply that there is no ethical responsibility to avoid it. Further empirical inquiry, additional critical reflection, and independent ethical judgment by the individual researcher may be required to make that determination. In short, while a list of specific ethical responsibilities is useful, it is not a substitute for thoughtful ethical judgment.

Ethics

While the term "ethics" means different things to different people, most will agree that part of what ethics involves is making judgments about whether specific actions and practices are morally right, wrong, or permissible. Many individuals ground their ethical views in their religious beliefs, thereby effectively putting differences in ethical judgment beyond argument and appeal to evidence. In contrast, this guide takes a consequentialist approach to grounding ethical judgment, more precisely, a "consequences for well-being" approach. That is to say, the ethical judgments contained in this guide hinge on, among other things, beliefs about whether the actual or most likely consequences of the actions or practices in question are apt to enhance, preserve, diminish, and/or jeopardize the well-being of affected parties.

One perennial ethical value is that of justice. Justice prevails in a situation to the extent that each person in it gets her/his due, i.e., gets what s/he deserves. In distributive contexts, as opposed to retributive and compensatory contexts, justice is served to the extent that each person in the group in question gets her/his due share of whatever benefit or burden is being divided up among group members, such as lab space, research funds, work time on a high-demand research instrument, or credit for a new discovery or theory.[14] The allocations made typically affect the well-being of recipients.

In short, in this guide, ethics has to do with *the relationship between actions and practices on the one hand and the well-being of parties they affect on the other*. Ethical judgments that certain actions or practices are morally right, wrong, or permissible, judgments that certain individuals have specific ethical responsibilities under certain circumstances, and judgments that certain people or social groups are or are not being treated justly, all such judgments depend at bottom on, among other things, how the

[12] I owe this phrase to Douglas Kysar.

[13] I owe this idea to Douglas Kysar.

[14] The distributional criterion to be used varies, depending on what is being distributed as well as on relevant characteristics of individual group members.

actions and practices in question influence the well-being of all affected parties.

Fundamental Ethical Responsibilities of Scientists and Engineers

One source of the specific ethical responsibilities of NT researchers is a set of general fundamental ethical responsibilities that *all* scientists and engineers have, regardless of the fields in which they work. What are these fundamental ethical responsibilities?

A widely recognized fundamental ethical responsibility of medical doctors is to "do no harm" to their patients, whether by commission or omission. Scientists and engineers have a similar fundamental ethical responsibility: to not harm *their* "patients," i.e., their fellow workers, employers, clients, users and consumers of their products, and, most generally, all who are or might be affected by their work and its products.[15] As with the medical doctor's basic ethical responsibility, the fundamental ethical responsibility of scientists and engineers to not harm their patients can be unpacked into three *Fundamental Ethical Responsibilities of Scientists and Engineers (FERSEs):*

FERSE #1: to not do anything in one's work that one knows (or should know) will *cause* harm (or create an unreasonable risk[16] of causing harm) to others or to public welfare;

FERSE #2: to try to *prevent* any parties affected or likely to be affected by one's work (or by work about which one is knowledgeable) from being harmed (or subjected to an unreasonable risk of being harmed) by that work.

FERSE #3: to try to *alert* well before the fact any parties put at significant risk of being harmed by one's work (or by work about which one is knowledgeable) that they are at risk of being harmed.[17]

A fourth fundamental ethical responsibility applies to scientists and engineers employed by an organization or engaged by a client:

FERSE #4: to do the best they can in their work to *serve the legitimate interests* of their employers or clients.[18]

In contemporary societies, many researchers have their work funded, directly or indirectly, by government grants. In such cases, it makes sense to say that the researcher's "background client," whose legitimate interests must always be kept carefully in mind and respected, is *society at large*.[19]

We now turn to the task of elaborating specific ethical responsibilities of NT researchers. To do so, we shall apply the four FERSEs just elaborated to the specific conditions that confront researchers in the nanotechnology field.

Ethical Responsibilities of NT Researchers

Three Domains

Ethical responsibilities of NT researchers arise in 3 domains: the micro-, meso-, and macro-social domains.

1. Micro-social

[15] Some believe that because the relationship between doctor and patient is typically more *direct* than that between engineer or scientist and those affected by her/his work, engineers and scientists do not have the same fundamental ethical responsibility as doctors, viz., to do no harm to their patients. However, the fact that the relationship between the engineer or scientist and parties affected downsteam by her/his work products is typically more indirect does not by itself exempt the engineer or scientist from the fundamental ethical responsibility to do no harm to their "patients" (in the broader sense specified above). Harm indirectly caused is still harm caused.

[16] What makes a risk of causing harm "unreasonable" will vary from situation to situation, depending on various factors.

[17] This responsibility applies even if the alerting party is not the cause of the risky situation and not able to prevent it.

[18] This is intended to be a more defensible version of the vague loyalty-to-employer canons found in many codes of engineering ethics. For example, the code of ethics of the National Society of Professional Engineers (NSPE) states that engineers, in the performance of their professional duties, shall "act for each employer or client as faithful agents or trustees." See [6], Fundamental Canon # 4.

[19] Many codes of engineering ethics state categorically that engineers, in the performance of their professional duties, shall "hold paramount" the legitimate interests of society at large ("the health, safety, and welfare of the public.") See, e.g., the NSPE code of ethics [6], Fundamental Canon # 1.

The micro-social domain is the realm of NT R&D labs and production facilities. The most important ethical issue in this domain is, of course, *safety*. Since jeopardizing safety, in either a R&D lab or a production facility, may cause harm or create an unreasonable risk of causing harm to personnel, it follows from FERSE #1 that...

ER1: NT researchers have an ethical responsibility to not do anything that they know or suspect (or *should* know or suspect) will undermine or pose a non-trivial risk to safety in the NT lab or production facility.

This fairly broad ethical responsibility of NT researchers applies by implication to any more specific kind of action that would or might jeopardize lab safety. Consider, for example, actions related to the use of new nano-materials and that deviate from established laboratory procedures.

a. new nano-materials

Regarding new nano-materials, NT researchers must always bear in mind a salient fact: *there is no guarantee that an element known to be safe at the macro- and/or micro-scales will also be safe at the nano-scale*. This is because the properties of nano-materials often differ substantially from those of the same materials at larger scale. Two factors explain this remarkable phenomenon. First, nano-materials have relatively high percentages of their constituent atoms at the surface (rather than being within their volumes) compared to the percentages at the surface in bulk materials. This can lead to phenomena like increased chemical reactivity and affect the strength of such materials. Properties and phenomena attributable to the fact that nano-materials have much greater surface area to volume ratios than do bulk materials are called "surface effects." Second, at the nano scale, a material's intra- and inter-atomic relationships can affect its properties, giving rise to novel electrical, optical, magnetic and chemical characteristics and phenomena, often called "quantum effects."[20] Some of the novel, surprising, and dramatically different properties exhibited by nano-materials may pose a threat to safety unless appropriate precautions are taken. Therefore,

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ER2: NT researchers have an ethical responsibility to *always* take suitable precautions when working with elements at the nano-scale.

Similarly, product designers have a derivative ethical responsibility to confirm that any nano-material that they contemplate using in a commercial product is safe, both individually and in combination with other materials.

b. established NT lab procedures

In order to save time or money, be more productive, or reach an important objective before a competitor, a NT researcher may be tempted to depart from established laboratory procedures and take a *prohibited shortcut* in her/his work. Regardless of motive, NT researchers have an ethical responsibility to avoid taking prohibited shortcuts, because departing from established, time-tested laboratory procedures could jeopardize safety. Harm could result to people, machinery, or the laboratory's reputation; indeed, harm to the latter could jeopardize its fund-raising ability or license to operate. Such possible harmful outcomes should be kept in mind by NT researchers tempted to take prohibited shortcuts for reasons of personal convenience. In short,

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ER3: NT researchers have an ethical responsibility to not take prohibited shortcuts in their laboratory work.

Suppose a NT researcher becomes aware that a fellow lab member is taking prohibited shortcuts in her/his work. Does the researcher have an ethical responsibility in such a situation? Yes, s/he should act in a way that s/he believes will deter or stop the individual in question from further prohibited short-cutting, e.g., by attempting to persuade her/him to stop, bringing up the occurrence of shortcutting for group discussion in the lab, or reporting the individual to management. Given how critical safety is for NT facilities, reporting the shortcutting party to lab management may become more than ethically permissible. If less coercive deterrent actions fail to stop the shortcutting, reporting the individual to management becomes the researcher's ethical *responsibility*. If a NT researcher takes no action and the shortcutting

[20] See, for example, [7].

persists, then s/he is not acting in accordance with FERSE #2's injunction to prevent harm or the unreasonable risk of harm. In short,

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ER4: if less coercive measures do not succeed in stopping prohibited shortcutting, NT researchers have an ethical responsibility to report such behavior to laboratory managers.

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c. laboratory culture

The ethically disturbing phenomenon of prohibited shortcutting raises the important and neglected subject of *the culture of a NT laboratory*. To understand what this means, imagine two NT laboratories, L1 and L2.

Suppose that in L1 there is a widely shared expectation that researchers always put safety first, and that signs are prominently posted heralding the lab's excellent safety record and encouraging researchers to keep the record intact. Suppose further that top management consistently emphasizes safety, that researchers who have acted so as to jeopardize lab safety are quickly summoned before an in-house safety committee for scrutiny, that researchers found to have jeopardized lab safety are seriously penalized, and that most researchers care personally about preserving L1's reputation for safety, to the point of actively intervening if necessary. Let us say that L1 and labs like it have "safety cultures."

In contrast, suppose that in L2 there is a casual attitude toward safety, that talk of safety is widely regarded among researchers as empty rhetoric, that management gives no indication of taking safety seriously, and that the only signs posted in the lab read "Do your own thing!" and "Only results matter!" Suppose further that unsafe actions and risky practices are handled casually and *ad hoc*, that violations of safety rules are typically "winked at" or penalized with a "slap on the wrist," and that individual researchers do not care about how other researchers conduct themselves as long as they are left alone to work as they want to. Let us say that L2 and labs like it have "laissez-faire cultures."

L1 and L2 clearly have radically different, indeed polar opposite, cultures: a safety culture vs. a *laissez-faire* culture. The key point here is that *the culture of a NT laboratory can make it easier or harder for a researcher to act irresponsibly*, by fostering a climate that erects lower or higher barriers to problematic behavior. This is why the culture of a laboratory is an important factor in lab safety, even though it is an intangible presence that influences researcher behavior from 'behind the curtain.'

Because of their ability to shape behavioral norms, top managers have an ethical responsibility regarding the culture in their NT lab:

ER5: top managers in a NT lab have an ethical responsibility to actively promote a safety culture in their facility.[21]

For their part, practicing NT researchers have at least two complementary ethical responsibilities regarding the culture in their laboratory:

ER6: researchers in NT labs have an ethical responsibility to help train and encourage newcomer researchers to do things in ways consistent with maintaining a strong safety culture in the lab.

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and

ER7: NT researchers have an ethical responsibility to combat in their labs any manifestations of a *laissez-faire* culture in the actions and practices of their fellow researchers, whether newcomers or veterans.

A strong safety culture in a NT lab is an important counterweight to any temptation, due to researchers being subject to various kinds of pressure, to 'cut corners' in their work, thereby possibly putting lab safety at risk.

In 2010, NT research is burgeoning in many of the more developed countries (MDCs) of the West, as well as in China, India, and Japan. In coming decades, such research is likely to be launched in a number of less developed countries (LDCs). This will give rise to the transfer of NT equipment and knowledge from individuals and organizations in MDCs to counterparts in LDCs. Such transfers will give rise in turn to an important, closely related ethical responsibility for

[21] In the aforementioned survey, given a scenario in which "the top managers of a nanotechnology laboratory do not actively promote a culture of safety in their facility," 50.1% of the responding NT researchers deemed that failure on the part of top managers "completely unethical"; another 31.5% deemed it "somewhat unethical."

MDC NT researchers and research managers involved in such transfer processes:

ER8: NT researchers and lab managers from MDCs who are involved in the transfer of NT equipment and knowledge to LDCs have an ethical responsibility to explain in detail and to stress to LDC researchers and managers in charge of new NT facilities the importance of establishing and maintaining a strong safety culture.

In this connection, in December 2008, under the auspices of the NNIN and the Indian Institute of Technology (Kanpur), about a dozen U.S. and Indian faculty members taught an intensive 'short course' on NT to a group of 20 U.S. and Indian graduate students at the IIT (Kanpur). In line with ER8, along with imparting state-of-the-art NT technical knowledge and offering students experience working with NT equipment, substantial attention was given to ethical issues and responsibilities related to NT, including discussion of laboratory culture and its relationship to NT lab safety.

d. other kinds of ethical issues

Besides safety, other kinds of ethical issues can and do arise in NT (and non-NT) labs. Among them are intellectual property disputes—e.g., who is entitled to what degree of credit for a particular idea, discovery, or innovation?—and disputes over the integrity of data cited to justify technical claims. Such ethical issues are addressed in the scholarly literature on "research ethics."[22] The key point here is that such disputes can be evaluated in terms of *ethics*, for they are usually linkable, albeit indirectly, to harm and/or justice. For example, fraudulent data can result in serious physical or financial harm to competitors, institutions, or users of materials or devices whose design properties depend on that data. Similarly, giving too little (or too much) credit in a publication to colleagues, graduate students, or scholars whose ideas contributed to one's research work raises ethical issues of justice and intellectual property rights. While such ethical issues are not unique to NT R&D, the large stakes that often hinge on staking claims to prior achievement in this burgeoning area make general issues of research ethics highly relevant to contemporary NT research activity.[23]

2. Meso-social

The meso-social domain is the intermediary realm of interactions between laboratory researchers and production facility managers on the one hand and individuals from institutions representing or affecting society at large on the other. Two kinds of such interactions deserve attention: those involved in *public funding of research* and *media coverage*.

a. hype

A noteworthy ethical issue sometimes involved in public funding is *hype*[24]—deliberately exaggerated claims intended to serve the exaggerator's interests. In research, hype can exist at two levels. At the level of *a particular research area* as a whole, hype would occur if, in testimony before a key government funding agency, NT researchers touted the NT as the source of "the next Industrial Revolution" and asserted that it will "transform life as we know it." At the level of *an individual research proposal*, hype would occur if, in order to gain funding, a NT researcher exaggerated her/his project's feasibility, likely results, or significance. While hype may seem essential to researchers given the highly competitive nature of the research funding game, and while the line between genuine enthusiasm and deliberate exaggeration is sometimes unclear, engaging in hype *is* ethically irresponsible.

Hyping is ethically irresponsible for two reasons. Good science could go unfunded if a hyped field or project is funded or overfunded, and hype, in the form of exaggerated claims about research payoffs to the public, could erode the public's willingness, through its elected representatives, to continue or increase funding for science and engineering, especially in the hyped field, when exaggerated benefits fail to materialize.

Hyping one's application for funding might seem ethically worse than hyping one's field of specialization in hopes of gaining increased funding for it. However, *both* sorts of intentional exaggeration are

[22] See, for example, [3].

[23] Such stakes include patent ownership, promotion, realization of royalties, and recovery of initial investment.

[24] Instead of "hype," lawyers often use the expression "non-actionable puffery." I owe this phrase to Douglas Kysar.

wrong. If successful in serving the hyping party's interests, each kind of statement carries *significant opportunity costs*: potentially fruitful research on other projects or in another field may go unfunded because a hyped project is funded or a hyped field is overfunded. Such an outcome may effectively sustain harms that would have been diminished or overcome had the unfunded research been funded and succeeded. Just because hyping one's research field only *indirectly* benefits the person doing the hyping does not make such hype ethically permissible. In short,

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ER9: NT researchers have an ethical responsibility to avoid engaging in hype, at both the personal level and at the level of the NT field.[25]

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b. distortion

A noteworthy ethical issue involved in much media coverage of new science and engineering is *distortion*. For the sake of gaining market share, mass media coverage of new technologies often incorporates a "gee whiz" approach.[26] Impressive visual effects and exciting predictions are emphasized. Since carefully qualified, balanced, or complex views do not attract viewers, views of boosters and opponents dominate and are transmitted superficially and uncritically. Electronic and print media accounts of new technologies often give short shrift to problems, hurdles, risks, cost overruns, and time frames for accomplishment. Such coverage can contribute to raising unrealistic public expectations of major payoffs or to fueling irrational public fears about new technologies. Further, such coverage is not conducive to making good decisions about allocating public resources to and within science and engineering. Over time, researcher participation in or endorsement of media coverage of scientific or engineering developments that turns out to be distorted can dilute public trust and foster public misunderstanding of science and engineering. That each such harmful effect would be the aggregate result of many individual acts of participation or endorsement, each seemingly harmless by itself, does not make each individual act ethically neutral. In short,

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ER10: NT researchers have an ethical responsibility to avoid legitimizing distorted mass media coverage of scientific or engineering developments by participating in or endorsing such coverage without exercising due diligence about its accuracy.

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3. Macro-social

The "macro-social" domain refers to society at large.

The dominant view in the scientific research community has long been that researchers' major ethical responsibilities concern three things: laboratory safety, data integrity, and publication proprieties, issues that arise in the micro- and meso-social domains. But do researchers have any ethical responsibilities for the social consequences of research? A traditional view, popular in the research community, has been that while the fruits of research are neutral in themselves, they can be put to beneficial or harmful uses by those who apply them. Since, according to this view, researchers do not select the end goals that their work products are used to achieve, they cannot reasonably be held ethically responsible for any negative consequences that result from realizing those goals. Nobel laureate and physicist Leon Lederman expressed this traditional view thus:

> Our lame but perhaps time-honored response is that scientific knowledge is not good or evil; it is enabling. Modern science, however abstract, is never safe. It can be used to raise mankind to new heights or literally to destroy the planet. As democratic government spreads, it is the people and their representatives who must use the power provided by science. We give you a powerful engine. You steer the ship.[27]

In this view, then, society at large, *not* the individual researcher, is ethically responsible for what is done with the knowledge s/he produces. Nevertheless, if society at large played a role in enabling a research project, e.g., by funding it, some tradition-

[25] The same responsibility applies *vis-à-vis* hype at the level of any NT sub-area.

[26] In U.S. electronic media coverage of science and engineering, the long-running Public Broadcasting Service program, "NOVA," devoted to improving public understanding of science, technology, and engineering, is a notable exception to the rule.

[27] See [4].

alists would acknowledge that the researcher does have at least one responsibility to society at large:

ER11: NT researchers whose work is publicly funded have an ethical responsibility to society at large to do the best work they can to generate reliable new scientific and engineering knowledge, materials, devices, and systems.

For in so doing, they contribute indirectly to societal progress that allegedly results from individual contributions to technical progress. Such a responsibility, related to FERSE #4, is owed to society at large, the "background client" that makes the researcher's work possible.

While society, including private firms, public institutions, and their respective decision makers, clearly bears considerable responsibility for what is done with researchers' work products, contemporary researchers in NT and other technical fields do as well. They cannot always plausibly plead ignorance of the risks posed by the 'powerful engines' they make available to society. Researchers realize—or at least *should* realize—that the 'ships' these 'engines' may be used to power will be piloted by dominant social groups with track records, and will be given green lights by regulators and policy makers influenced by powerful forces with vested interests in proceeding apace. Contemporary researchers develop and facilitate the diffusion of their creations in *societies and social contexts of known character.* While it is clearly not always foreseeable that particular fruits of research will be turned into ethically troubling applications, in *some* cases it will be, e.g., when there are substantial military or economic advantages to be gained even if ethically problematic effects are foreseeable as a by-product. Hence, under FERSE #2,

ER12: if a NT researcher has reason to believe that her or his work will be applied to society so as to create a risk of significant harm to humans, he or she has an ethical responsibility to alert appropriate authorities about the potential danger.[28]

Whether a particular researcher has "reason to believe" on a particular occasion will, of course, often be a judgment call. But it is implausible to claim that a researcher can *never* have such reason to believe, regardless of the character of the society in which, or firm for which, s/he works.[29]

Two Application Areas

Some specific ethical responsibilities of NT researchers arise from the fact that NT R & D products pertain to particular societal application areas. We limit our discussion here to brief comments on two such areas: the environment and medicine.

1. environment

Developments in NT offer hope for *restoring* some kinds of degraded environments. For example, water filtration membranes based on nanometric-sized materials of oxy-aluminum hydroxide or iron oxide are being developed. "These common and inexpensive materials and the use of synthetic processes that avoid organic solvents and polymers could be an ideal solution for certain southern countries where water is often unfit for consumption."[30] Given the potential such membranes would have for overcoming water quality problems in LDCs, these NT products could significantly advance the cause of global distributive justice.[31] NT practitioners in MDCs who are positioned to influence MDC decision-making re funding and priorities for NT R&D, arguably have an ethical

[28] The above-referenced survey of NNIN researchers yielded a remarkable (and encouraging) finding: the vast majority (76.3%) of respondents "strongly agreed" that such a researcher would have the stated ethical responsibility under the specified condition. See McGinn, *loc. cit.*, p. 114.

[29] For example, a researcher who knows the historical record or economic and political condition of the company or government for which s/he works, is aware of some harm-risking uses that her/his work could be made to serve, recognizes that doing so could powerfully further her/his firm's or government's important political-economic interests, and has evidence suggesting company or government intent to pursue one or more such uses, might well be said to have "reason to believe" that would engender ER12.

[30] See [8].

[31] Access to water that does not pose a significant risk of harm to human health is arguably something to which all citizens have a moral right, derivable from the universal human right to life. Affordable nanometric water filtration membranes could foster a more equitable distribution of this good across the countries and peoples of the world than is currently the case.

responsibility (under FERSE #2) to attempt to have basic LDC environmental needs taken into consideration in that decision-making.[32]

Regarding pollution *prevention*, nano-particles of platinum and palladium increase the reactivity of catalysts, something that when used in automobile mufflers could better transform pollutants like CO, NO_x, and unburned hydrocarbons into normally benign molecules like CO_2, molecular nitrogen, and water vapor. Work is underway to determine the best metal or alloy at nano-scale and the combination of nanometric parameters that yields the most efficient catalyst.[33] Such work, if successful, would contribute to significant harm prevention, not because a researcher spoke out to prevent pending harm (FERSE #2), but rather because s/he did the best work s/he could to serve a legitimate interest of the background societal client (FERSE #4): protection or improvement of societal health. Suitably positioned practitioners who contribute to such technical progress would be fulfilling an ethical responsibility to the societal client that supports it.

It remains to be seen how rigorously government agencies regulate the environmental effects of nano-particles and nano-material-treated products. Will released nano-particles from the use of bacteria-killing nano-silver ions in a growing range of consumer products, from rain runoff across solar panel cells coated with nano-films or nano-inks, or from waste discharged by factories manufacturing nano-products, prove harmful to the environment? One would think that extremely unlikely. After all, most MDCs have environmental protection agencies.

But that is not always sufficient. For example, to date, U.S. regulatory agencies have been extremely reluctant to enact new regulations for new nano-materials.[34] With large mounts of money being invested in NT product development, political-economic pressure for quick environmental regulatory approval of new nano-products is likely to be intense. The potential for decision-making in government regulatory agencies, charged with protecting public health and safety, to be determined by *political-economic* considerations instead of by *scientific* evidence is troubling from an ethical point of view.

However, NT-related regulatory decisions regarding the environment that are made on non-scientific grounds cannot and should not be blamed on NT *per se*. Rather they should be attributed to shortcomings in the procedures and processes that governments use to decide under what circumstances new materials and products are released into society at large. Nevertheless, since they are subject to FERSE #2, knowledgeable NT researchers should be alert to the possible influence of politics and economics on regulatory decision-making regarding the manufacture and use of nano-materials in relation to the environment.

ER13: if a NT researcher is in a position to make the public aware that regulatory decision-making regarding nano-materials and the environment has been made on non-scientific grounds, and if doing so might help prevent harm to the public, then s/he has an ethical responsibility to bring that decision-making, as well as the most credible account of the benefits, costs, and risks of the situation, to public attention.[35]

2. medicine

   a. nano-medications

The first nano-medications are likely to be introduced in the not-too-distant future. Nano-capsules are

[32] It might be thought that while this would be a good thing to have happen, it cannot plausibly be viewed as an ethical responsibility of the MDC NT practitioner, no matter how well positioned. But when one considers the priority of fulfilling basic needs over non-need-based preferences, the international provenance of the NT knowledge base, and the appalling historical record of MDC-LDC relationships, the case for speaking of an ethical responsibility here, under FERSE #2 becomes compelling.

[33] Nano on All Fronts," *loc. cit*.

[34] At a meeting of the U.S. House Science Committee in September 2006, Dr. Andrew Maynard, Chief Science Advisor for the Project on Emerging Nanotechnologies, stated, "The evidence before us strongly suggests that current federal research efforts are not adequate to address concerns arising about the environmental, health and safety impacts of nanotechnology. There are clear gaps in the research portfolio in determining potential hazard, evaluating exposure, controlling releases of nanomaterials, determining potential impact and managing risk." See [9].

[35] The same ethical responsibility would apply if what a knowledgeable NT researcher became aware of was non-scientific regulatory decision-making regarding the use of nano-materials in food or personal care products, such as cosmetics.

being developed that, administered through the blood stream, would deliver therapeutic, active molecules right to targeted cells with greater efficacy and diminished side effects. Fatal hepatic diseases, such as cancer, are possible early targets of nano-medications.[36] The potential benefits of nano-medications are exciting, and researchers developing them deserve ethical commendation for work that may prevent, cure, or lessen serious health problems.

b. nano-devices

A more controversial category of projected medicine-related NT advances is that of human implantable nano-devices (HINDs). HINDs may eventually offer the ability to monitor and wirelessly communicate the conditions or states of internal body organs or systems, e.g., body temperature, pulse, blood sugar, blood glucose, and heart activity [2; p. 402]. The medical benefits of such innovations could prove enormous. HINDs are also being developed with the goal of restoring vision and correcting hearing dysfunctions.[37]

"NBIC" stands for "nano-bio-info-cogno," and "NBIC convergence" refers to the projected convergence of streams of research in four fields: *n*anotechnology, *b*iotechnology, *i*nformation science, and *c*ognitive science. One expected result is a new type of HIND, one able to transmit and receive information about brain-related conditions and processes. The head of a neurological institute wrote this about NBIC work being pursued in his lab:

> We have already begun...to create new nano-tools to explore critical issues in synapse assembly, myelin formation, neuron outgrowth, and brain tumor cell migration. We are developing nanodevices that we can manipulate to positions within neurons, or on nerve fiber surfaces, or within the myelinating cell, to monitor cellular events under very precisely controlled conditions. The nanodevice can be engineered to report back to our scientists in a variety of ways; for example, by light emission that may be detected by the highly sophisticated imaging microscopes...We thus will have an unprecedented window into the inner workings of neural cells [1].

[36] Staff, "Nanos on All Fronts," *loc. cit.*

[37] [2].

c. ethical issues and responsibilities

While the potential medical benefits of nano-medications and nano-devices are substantial and impressive, they are also likely to raise significant ethical issues that deserve early and ongoing ethical reflection, including by NT researchers involved in achieving these advances.

i. informed consent

For example, new nano-medications and nano-devices will be tested experimentally on humans. The push to bring such products to market quickly could collide with the ethical responsibility of involved technical professionals to insure that human subjects give their informed consent to being tested. In light of FERSE #2, as such testing draws near, knowledgeable NT researchers will have an ethical responsibility to oppose any plans to administer any nano-medications or implant experimental nano-devices in patients without their knowledge, even for the patients' benefit.[38]

ii. enhancement

Early NBIC technologies are likely be therapeutic in intent, e.g., aimed at addressing problems in brain functioning. However, they could eventually be developed for purposes of cognitive *enhancement*. Since the human mind and human autonomy are extremely sensitive ethical concerns, it is not surprising that the U.S. public and NT researchers are deeply split about the ethical acceptability of cognitive enhancement.[39] As with embryonic stem cell researchers, researchers working on NBIC HINDs for cognitive enhancement would do well to be sensitive to and learn to discuss thoughtfully the issue of the ethical acceptability of such work, in light of both its likely consequences in

[38] In the aforementioned survey, nanotechnology researchers were asked to assess the following scenario: "in the future, unknown to a group of human patients, experimental nano-devices will be implanted in them for their own benefit." 76% of the respondents deemed that practice "completely unethical" and 11.75% "somewhat ethical," whereas only 2.2% deemed it "somewhat ethical" and 3.6% "completely ethical."

[39] In the aforementioned survey of nanotechnology researchers, 18% of respondents deemed "future NT R&D projects to increase human mental abilities" "not at all" morally acceptable and 20.1% found such projects only "slightly" morally acceptable. (The response options were "not at all," "slightly," "moderately," "quite," and "very much.")

societies in which the fruits of such work become available and the opportunity costs of prohibiting such research.[40, 41] Not only is doing so in their own self-interest; they may have an ethical responsibility to do so. For if they do not, the fate of such work and of the beneficial innovations it might spawn would likely depend on the positions of politicians, corporate representatives, and clerics. Such individuals have strong political-economic interests and ideological commitments, concerns that tend to trump available empirical evidence and incline those under their sway toward one or another rigid, uncritical, and parochial point of view.

Conclusion

As scientists and engineers probe new areas of inquiry that promise major social benefits but are also socially controversial, society needs and is beginning to demand researchers with a hybrid competence: state-of-the-art technical knowledge coupled with a sensitive ethical compass. To paraphrase Samuel Johnson, "while [ethical] integrity without [technical] knowledge is weak and useless, [technical] knowledge without [ethical] integrity is dangerous and dreadful."[42]

Ethically responsible NT researchers must remember that the legitimate interests of the ever-present 'background client,' i.e., society at large, are paramount. They must prevail over pressing personal and organizational interests when giving priority to the latter would jeopardize public health, safety, or welfare. As Albert Einstein said to students at Cal Tech in 1931:

> "It is not enough that you should understand about applied science in order that your work may increase man's blessings. Concern for man himself must always be our goal, concern for the great unsolved problems of the distribution of goods and the division of labor, that the creations of your mind may be a blessing, and not a curse, to mankind. *Never forget this in the midst of your diagrams and equations.*"[43]

While there do not appear to be any ethical responsibilities unique to NT, study of the ethical dimension of NT, including the specific ethical responsibilities elaborated in this guide, should become an integral part of the formal education of all NT researchers.[44]

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[40] The aforementioned survey revealed that a strong majority of respondents were somewhat, quite, or very willing to "spend some time learning about ethical issues related to nanotechnology." (The percentages were 4.6% "not at all," 17.1% "slightly," 34.3% "somewhat," 29.3% "quite," and 13.7% "very" willing). See McGinn, *loc. cit.*, p. 116.

[41] Among the likely consequences of such work are blurring the line between interventions for therapeutic purposes and for purposes of enhancement by parties with economic interests in doing so, and access to enhancement-related HINDS being effectively limited to those able to pay the going market price or afford insurance policies that cover treatment with such devices.

[42] From Samuel Johnson's moral fable, *Rasselas*, 1759, Chapter 41 (bracketed words added), http://andromeda.rutgers.edu/~jlynch/Texts/rasselas.html.

[43] Albert Einstein, "Address Before Student Body," California Institute of Technology, February 16, 1931, http://www.hss.caltech.edu/~kcb/Ec121/EinsteinSpeech.html.

[44] In 2004, the U.K.'s Royal Society and Royal Academy of Engineering recommended "that the consideration of ethical and social implications of advanced technologies (such as nanotechnologies) should form part of the formal training of all research students and staff working in these areas and, specifically, that this type of formal training should be listed in the Joint Statement of the Research Councils'/AHRB's Skills Training Requirements for Research Students." See "Nanoscience and Nanotechnologies: Opportunities and Uncertainties," RS Policy Document 19/04, 29 July 2004, p. 87. See also http://www.royalsoc.ac.uk and http://www.raeng.org.uk.