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Societal Dimensions of Nanotechnology as a Trading Zone: Results from a Pilot Project

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Abstract: If nanotechnology is to represent social as well as technological progress, societal dimensions need to be incorporated from the outset. The best way to do this is to create interdisciplinary trading zones among scientists, engineers, ethicists and social scientists. This chapter describes a collaboration between a materials scientist and a psychologist, who jointly supervised a graduate student as she did cutting-edge scientific research directed towards a socially beneficial outcome.

> *Productive work on societal implications needs to be engaged with the research from the start. Ethicists need to go into the lab to understand what's possible. Scientists and engineers need to engage with humanists to start thinking about this aspect of their work. Only thus, working together in dialog, will we make genuine progress on the societal and ethical issues that nanotechnology poses.*
> (Davis Baird, in testimony before the Senate Committee on Commerce, Science and Transportation, May 1, 2003)

1. Models of Technology Development

There are probably as many models of technological development as there are authors that have tackled the topic (Hughes 1987, Pacey 1993), but for purposes of our discussion, three will illustrate the range of possibilities (see Figure 1).

The Technological Determinism model, or Chicago World's Fair motto, embodies the classic 'throw it over the wall to society' approach to engineering, immortalized in the Tom Lehrer song about Werner von Braun: "Once rockets are up, who cares where they come down? That's not my department, says Werner von Braun". During the GMO debate, the so-called Terminator trait was seen by the Rural Agricultural Foundation International as an example of this sort of technological determinism. Farmers would be forced to buy seeds that would be viable for only one generation; many, especially in the developing world, considered this a violation of their fundamental right to re-use seed they had purchased (Gorman *et al.* 2001).

The second model, Social Goals Drive Research, was suggested, but not necessarily endorsed, by Henry Etzkowitz as an alternative to Technological Determinism (Etzkowitz 2001). Here society dictates the direction of research. Advocates of GMOs thought they were following this strategy. What could be wrong with a suite of products that promised to feed the world's growing population while reducing the need for pesticides and herbicides (Magretta 1997)?

Although technological determinism and social goals appear to be very different approaches to directing scientific discovery, they share a common problem. In each model, one group or community is seeking to dictate to others, *e.g.* the engineers and scientists imposing their view of nanotechnology on the rest of society or a non-governmental organization like ETC (Erosion, Technology, Concentration) imposing a moratorium on scientists and engineers (Mnyusiwalla *et al.* 2003). The idea of forcing people to conform to any technology is clearly wrong; indeed, that is one of the problems experienced by companies like Monsanto that try to make a profit from GMOs. Studies have shown this to be a common trait – socio-technical networks dominated by a single group are better for control than innovation, and they are certainly not democratic (Gorman & Mehalik 2002, Gorman 2002, Scott 1998).

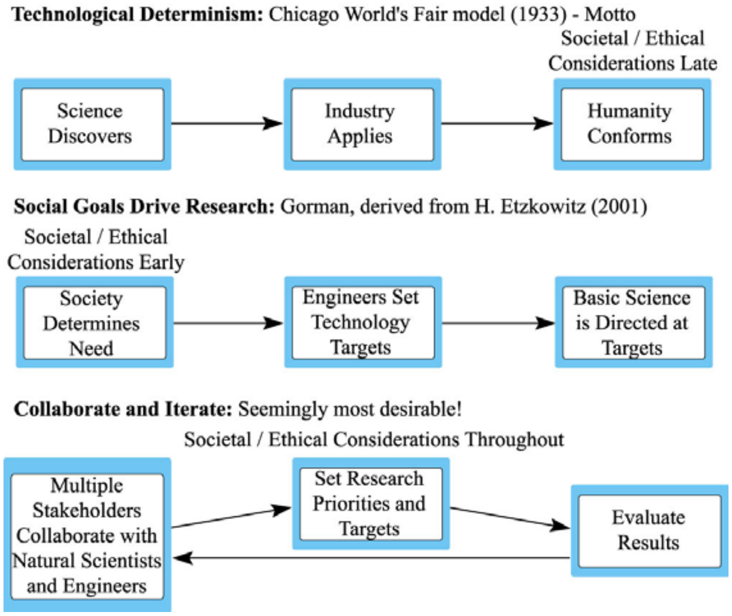

Figure 1: Three models for the development of new technologies.

In contrast, the pilot project described in this paper follows the ‘collaborate and iterate’ approach in which a social psychologist (Gorman) collaborates with a materials scientist (Groves), sharing a graduate student. This project is consistent with Davis Baird’s advice that a genuine dialog between scientists and humanists includes ‘ethicists going into the lab’, as Gorman is also on the board of the University of Virginia’s Institute for Practical Ethics.

Thomas Kuhn argued that normal science is conducted within paradigms, and that deep, meaningful communication across paradigms is nearly impossible – participants in these different research cultures literally talk past one another (Kuhn 1962). This problem of ‘incommensurability’, to use Kuhn’s terms, occurs *within* disciplines like physics.[1] Imagine how much larger it is *across* disciplines as diverse as psychology, ethics and materials science!

Peter Galison noted that physicists and engineers have collaborated on the creation of technological systems like radar and particle detectors (Galison 1997). To explain how they got around the problem of incommensurabilty, Galison invoked the metaphor of a *trading zone*. Cultures with radically different epistemologies can still trade by developing creoles, or reduced common languages.

Trading zones are not a mere metaphor. Jet Propulsion Laboratory (JPL) engineers have used the term “trade” to refer to negotiations over design options (Lambert & Shaw 2002). Because these trades involved exchanges of information and perspectives, they are not the same as trade-offs. For example, on the Mars Rover, engineers and scientists had to conduct a series of trades to arrive at a landing site that was both satisfactory from a scientific standpoint and feasible from an engineering one.

In order for developments in nanotechnology to represent social and scientific progress, engineers, natural scientists, social scientists, and ethicists will have to develop their own dialect, a kind of 'nanocajun'[2], that allows them to communicate effectively. Nanotechnology trading zones such as these can be multidisciplinary – in which there is a division of labor between the ethicists and scientists and the groups develop a specialized dialect, a creole, to coordinate activity, or they can be genuinely interdisciplinary – with all participants engaging in discussions of all aspects of the research and development activity.

The goal of trading zones is the sharing of expertise. Collins and Evans distinguish between three *levels of shared expertise* (Collins & Evans 2002):

1. *None* – This level is akin to Kuhn's incommensurability. Those in the old paradigm supposedly cannot communicate effectively with those in the new, even though they are working in the same field – because the world-views are incommensurable. The same kind of incommensurability could potentially occur between different disciplinary specialties and cultures.
2. *Interactional* – This level involves knowing less than an expert in another area, but enough to communicate. A good example is a problem that emerged early on in the application of magnetic resonant imaging (MRI). Between 1987 and 1990 "it became fashionable for physicians to reduce the rather long MR (magnetic resonance) imaging times by using anisotropically shaped (*i.e.*, non-square) imaging pixels in studies of the spine. As it turned out, this resulted in a prominent dark line appearing within the spinal cord. The dark line was a Gibbs ringing artifact. Unfortunately, clinicians, not aware of this kind of artifact – for not being conversant with the mathematics used to transform the instrument signal into an image – at times interpreted this artifact as a disease process: a fluid filled lesion known as a 'syrinx' requiring aggressive medical treatment" (Baird & Cohen 1999, p. 238). An interactional expert who bridged medicine and physics detected the problem and solved it.
3. *Contributing* – This level involves experts jointly contributing to an area of inquiry. An example is the way in which Walter Alvarez, a geologist, brought in his father Luis a physicist, and the two jointly made a significant contribution to paleontology: the asteroid explanation for the extinction of the dinosaurs (Alvarez 1997).

These three kinds of sharing potentially create three kinds of trading zones.

1. There is no sharing of expertise, so experts do not really trade; they just throw disciplinary solutions 'over the wall' to other participants across an incommensurable gulf.
2. Interactional expertise and the use of a creole partially circumvent incommensurability, leading to the kind of trading noted by Galison on radar, Lambert on the Mars rover, and Baird & Cohen on MRI.
3. Contributing expertise creates the possibility of a new paradigm, like the asteroid theory of dinosaur extinction. This kind of sharing indicates that incommensurability is partly an attitude. Experts who are working on a cutting-edge problem can share conceptual frameworks, if they are willing to see that their paradigm is a useful comprehensive framework that can be transcended, not a reality.

Every emerging technological system raises questions about values. What kind of future are we building with GMOs? Europeans, at least, have rejected a future in which they will have no choice – they will have to eat genetically-modified organisms. What kind of future are we building with nanotechnology? One in which a few countries – like the U.S. – will create a new generation of supersoldiers that will keep them ahead of the rest of the world? Or one in which nanotechnology will help solve enduring problems like the absence of clean water, safe food and security for much of the world?

If trading zones around nanotechnology are going to expand to include societal dimensions at a deep level, then social scientists, ethicists, scientists and engineers will have to jointly contribute to new research paradigms. This kind of interdisciplinary collaboration will require *moral imagination* (Werhane 1999). Kuhn discusses how paradigms are learned from textbook stories about how science is done. Similarly, moral imagination assumes our most important lessons come from stories which we turn into mental models for conduct (Johnson 1993). To practice moral imagination, each member of a truly interdisciplinary trading zone involving societal dimensions of nanotechnology will have to:

1. Become aware of her or his own mental models of the potential societal impacts of nanotechnology.
2. Learn about mental models of other members of the trading zone.
3. Imagine alternate directions for nanotechnology development, in light of these different views – evolving new mental models
4. Establish criteria and methods that can be used to evaluate the impact of these new alternatives.

Moral imagination creates the possibility of going from a multidisciplinary trading zone to a true interdisciplinary collaboration, in which relevant experts from ethics, social sciences, engineering and natural science understand enough of each others' disciplinary cultures to ensure that an emerging technology makes genuine social and technical progress (Gorman & Mehalik 2002). Other stakeholders need to be added to the trading zone as well. For example, Monsanto discovered that NGOs like Greenpeace and RAFI did not share the company's vision for GMOs, nor did European consumers. Could these stakeholders have been drawn into the trading zone, or are their views incommensurable with those of Monsanto? An attempt at mutual moral imagination might have failed, but would have been worth trying.

2. Pilot Research Activity

To see if these observations concerning trading zones, levels of expertise and moral imagination could be turned into reality, the authors obtained a grant from the National Science Foundation to set up a small trading zone, involving a social scientist (Gorman), a materials scientist (Groves), and a graduate student. Gorman and Groves co-advised the graduate student, and all members of the team were supposed to send reflective e-mails to an offsite cognitive scientist, Shrager, following a methodology he created for recording his own cognitive processes as he entered a new field (Shrager 2004). Shrager was not a part of the trading zone – he did not attend meetings nor contribute to the content of the discussion – but acted as an "unbiased" observer and recorder.

Team members tried to exercise moral imagination from the start, articulating and sharing their mental models. Figure 2 shows the process team members followed to find a specific research topic that would incorporate societal dimensions and allow the student to complete a degree in materials science. The funnel shape indicates the way the project starts with broad social concerns and ends up with a focused research project a Masters student could carry out. The line to the left of the funnel indicates continuous development of a creole. The line on the right indicates that the whole process is iterative – that work at a lower level could send the team back up to the top, re-opening discussion of project goals and motives.

The graduate student began by attempting to create a matrix that combined global problems with possible nano-engineered devices that could mitigate such ills. While mitigation of certain problems could involve development of a newly engineered sensor system (*e.g.* to detect a chemical, biological, or radiation hazard), other research might seek to develop systems for purification (*e.g.* of ground water for drinking, of manufacturing plant effluent, or of fluids used in medical treatments). Still other research might investigate newly engineered medications and delivery systems for improved human and biosphere health. In certain instances, it was unclear how nanotechnology might make a direct impact upon a recognized problem – for example, gender disparity in science. Here indirect impacts were considered, *e.g.*, making certain that nanotechnology education made a special effort to reach out to groups traditionally under-represented in science and engineering. It was our hope that linking nanotechnology to societal benefits might provoke students' concerned with society to consider careers in science and engineering.

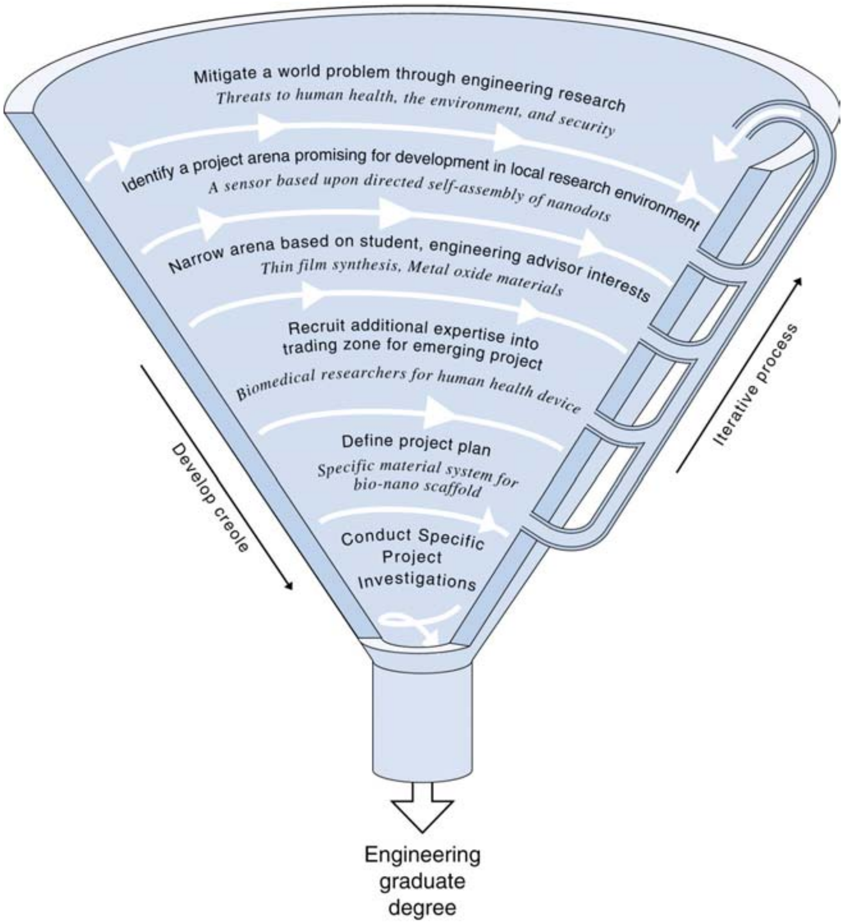

Figure 2: A process for developing graduate student thesis projects that incorporate societal and ethical considerations from the outset. The actual steps followed during the pilot project are included in italics beneath each step.

The student recognized that this matrix of global problems and possible links to nanotechnology could turn into a never-ending task. To constrain the task, the team considered expertise and resources available in the local research environment through the Center for Nanoscopic Materials Design, a National Science Foundation Materials Research Science and Engineering Center (MRSEC) established in 2000 to investigate the directed self-assembly of materials onto patterned surfaces. The members of this societal dimensions of nanotechnology project were already affiliated with the Center, and the Center's research, which focused faculty investigations on related aspects of the same scientific challenge, presented a naturally collaborative environment.

The Center for Nanoscopic Material Design studies directed self-assembly of nanodots, primarily in the silicon-germanium material system. Researchers have reported the formation of nanodots in semiconductor material systems in which a single crystal growth surface (*e.g.* a silicon substrate) and a depositing thin film (*e.g.* pure germanium) have the same crystal structure and a small lattice mismatch (Eaglesham & Cerullo 1990; Floro *et al.* 1990). The crystal structures of silicon and germanium (*i.e.* the arrangement of their atoms) are both diamond cubic, and pure Ge has a lattice constant (*i.e.* interatomic spacing) 4.1% greater than that of pure Si. Under carefully selected growth conditions, germanium will form small dots of material on the silicon surface, *i.e.* nanodots. However, if nature is left to perform the process on its own, the dots generally appear at random locations across the substrate, *e.g.* like water droplets on the hood of a car. The Center is performing fundamental studies of how the growth location of dots can be specified to enable applications that demand dot placement in specific areas (Kammler *et al.* 2003, Du *et al.* in press). Applications under consideration by faculty affiliated with the Center range from next-generation computer architectures to biological scaffolds built upon arrays of nanodots.

Having chosen to couple the materials science aspects of this project to mitigation of one or more global problems, and having chosen to couple the work to the Center, the team found it necessary to introduce a third constraint to the research problem space. They agreed to allow the particular physical science research expertise of the materials science faculty team member (Groves) and the interests of the graduate student to narrow the field of focus The team agreed to guide the research towards consideration of how the self-assembly of metal oxide nanodots might be directed (or guided) in a manner similar to the Center's work in the silicon-germanium system (Kammler *et al.*, 2003). Recent reports in the literature suggest that a number of metal oxide material systems demonstrate a nanodot self-assembly process similar to that observed in semiconductor systems (Y. Liang *et al.* 2001, Markworth *et al.* 2001). Export of the Kammler *et al.* results in Si-Ge to metal oxide systems through the efforts of this societal impact project could enable the creation of one or more engineered devices that can address global problems.

The student set a goal of identifying at least five global problems that could be linked to these metal oxide nanodots, then select one or two that could potentially be reduced to proof-of concept. The literature suggested that metal oxides might be useful as a foundation for a bio-nano scaffold (Michel *et al.* 2001), that could be used to mitigate global problems like terrorism, disease, and pollution.

The team took advantage of the fact that a biomedical engineer associated with the Center was interested in how endothelial cells lining the artery wall at the blood tissue interface adapt to fluid mechanical forces that vary with time and place (Helmke & Davies 2002). The mechanisms by which these cells translate mechanical stimuli into biochemical signals are not well understood. Breakthroughs in this area could lead to increased understanding of progression of arteriosclerosis in arteries, tumor cell invasion and potentially contribute to wound healing.

We added the bio-medical engineer to our trading zone, discussing what kind of bio-nano scaffold would be most useful in this research. The student and advisors decided to focus on finding a combination of metal oxides that could bind a single endothelial cell in several places, allowing its response to fluid forces to be studied at the nano level. Such a binding process could be useful in a wide range of other bio-medical applications.

This pilot project demonstrated that it was possible for a social scientist and a material scientist to share a graduate student who would explicitly consider societal dimensions as part of her research project. She had to present her project to the other graduate students, and they were both interested and puzzled by the emphasis on social impacts – her presentation generated a lot of questions, some of which occurred in one-on-one follow up conversations. Members of the Center's advisory board noted that this student was the only one who had an understanding of societal and ethical issues, and recommended that other students be given more exposure.

As a result, the nanotechnology graduate students organized an internal workshop on societal and ethical implications of nanotechnology. Clearly, this project had positive ripple effects on the Center of which it was a part.

3. Developing a Metaphorical Language

In order to trade, members of this small zone had to develop a creole. At one level, this creole was simply agreeing on shared meanings for common terms. Gorman had to learn what ‘directed self-assembly’ meant, and why isoelectric points and lattice structures were important. Groves had to learn what trading zones and moral imagination meant. Shared understanding of these terms evolved through frequent explanations, collaborative poster sessions, and publications.

Gorman’s understanding of a term like ‘directed self-assembly’ was never as deep, as replete with examples, as Groves’, and vice-versa with respect to the concept of a trading zone. The student was learning both of these concepts for the first time, so she benefited from her advisors’ efforts to explain concepts to each other.

The team also had to develop a metaphoric language to talk about its goals (see Figure 3).

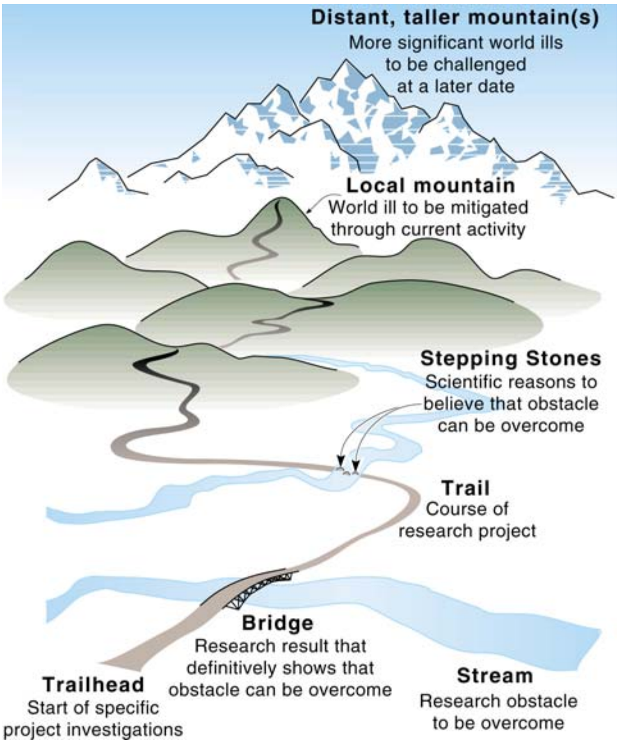

Figure 3: Metaphoric language used to related societal dimensions to project goals

All three participants in the trading zone liked hiking, which is why this seemed a natural set of metaphors. Groves took the lead in creating the language. Distant mountains are major global problems and opportunities, like human health, climate change, the prevalence of warfare, and so on. Surfaces patterned at the micro- and nano-scale with biomaterials could be useful for a host of new applications ranging from the field of medicine (*e.g.*, fundamental research into protein-surface and cell-surface adhesion; optimized cell-culture substrates for biotechnology applications in tissue engineering; cell-based compact diagnostic systems; functional biochip surfaces for high sensitivity, high-throughput DNA/RNA and protein detection; and nanoarrays of single molecules for the study of molecular interactions) to homeland security (*e.g.*, detection of biological, chemical, and radiological terror agents) and environmental assessment (*e.g.* detection of pollutants in air and liquids).

Closer foothills represented specific aspects of these problems, like providing more data on toxins introduced into the environment either as a form of biological warfare or as pollution. The graduate student needed to build a bridge that could be used by us or others to reach a range of local mountains, or foothills. This bridge would be part of a trail, but could also give access to other trails.

The bridge, in this case, corresponded to directing the deposition of one metal oxide on another in a way that would create positive or negative surface charge (determined by the oxide's inherent isoelectric point). When a biomolecule of opposite charge came into contact with the charged metal oxide surface, that biomolecule would adhere to the surface. Therefore, the foothills we were targeting involved gaining better understanding and control of cellular mechanisms – specifically, in our case, the flow of blood cells through an artery.

The existing methods for linking metal oxide surfaces with biomaterials require the use of slow and expensive methods to produce the biomaterial patterns. Photolithography and self-assembling monolayer (SAM) techniques require the creation of expensive masks and could be limited by the resolution of the photolithography equipment. These photolithographic and SAM techniques are also known, in some instances, to denature or degrade the previous biomaterial deposit. Microcontact printing requires the creation of stamps prior to pattern generation. Once created, these stamps can generally not be reconfigured. They are often difficult to align for large area printing, and they are known to transfer contaminants to the biosurface.

The students' bridge, therefore, provided an alternative to existing methods that might allow a bio-medical researcher to hold a single cell at several places, in order to study its function. This path could lead towards treatments for arteriosclerosis and other medical conditions.

4. Stages in the Acquisition of Shared Expertise

In order to participate in this trading zone, Gorman and Groves both found that they had to go through the three stages described by Collins and Evans (2002).

- None: Gorman began the project with a little general knowledge about nanotechnology, and no specific knowledge about the metal oxide domain. Similarly Groves did not recognize how to consider the project's activities within a trading zone that used a creole for effective communication.
- Interactional: After repeated conversations about research direction, and exchanges of e-mails, Gorman acquired a working knowledge of a few terms like directed self-assembly and a shakier knowledge of terms like isoelectric point and lattice mismatch. There was no hands-on experiential component to this knowledge; although Gorman observed the graduate student and others use equipment, he never actually used it himself. Groves soon became comfortable with the trading zone concept and the common reduced language of the group. Understanding of additional concepts like moral imagination continued to be somewhat superficial.
- Contributing: Gorman's goal was to acquire enough knowledge to participate in intelligent conversations about what experiment should be done next, and what results meant. Gorman's background in studies of scientific and technological thinking was helpful, here (Gorman 1992, Gorman *et al.* 2004). The other participants in the trading zone convinced Gorman to share in a patent application on the grounds that the project had taken a different direction because of his input. Groves sought to restructure his typical research process by including societal considerations at every step of the project. These considerations led to deep reflection upon issues such as patenting of the technology. If the goal of the technology development is societal benefit, how can this group best ensure that the technology developments of the project are put to

"good" use? The group finally decided that patenting provided them with greater control over the eventual end use of their discoveries.

5. Lessons Learned from this Experience

This pilot study indicated that a trading zone including a social scientist, a materials scientist and a materials science graduate student could be formed around nanotechnology and negotiate a scientific project that was explicitly aimed at what they thought of as a social goal: facilitating breakthroughs in the understanding and management of arteriosclerosis and related conditions. One problem with this pilot project is that there was no control group. It was impossible to run Groves and the student through a Masters project both with and without input from Gorman and see if there was a difference in terms of research approach and results. But it was obvious to Groves that there was a difference. No other project involved the explicit consideration of global problems, the metaphoric language and the persistent focus on the major research theme.

Additionally, the direction taken by the project was distinctly different because of the societal considerations. This unique direction led the group to confront scientific challenges and questions that otherwise would have remained unexplored. As Campbell notes, graduate research in the sciences is frequently opportunistic, with students pursuing multiple problems to see which ones will pan out (Campbell 2003). In this project, disappointing results were not used as excuses to abandon the project, because the bridge was so important we wanted to be certain that it could not be built before switching to another approach. The graduate student was never asked to achieve a positive result – that would constitute confirmation bias (Gorman 1992) – but was instead offered every opportunity and given every encouragement to thoroughly test whether specific metal oxides could be deposited in a way that produced the key differences in charge across the surface as needed for the bionano scaffold application.

In the end, the materials scientist felt that the result was better science. The social scientist learned more about the kinds of negotiations that go into achieving a Masters degree on the cutting edge of a new science, and also gained specific knowledge about a promising area of nanoscience. The graduate student at the very least caught a glimpse of how her thesis looked from social sciences and ethics perspectives, and this kind of perspective is important for any science student (Campbell 2003). But the student was necessarily focused more on the difficulties encountered in coursework and empirical work, and could only spend a limited amount of time doing research on global problems. Furthermore, she was immersed in a graduate science culture where no one else discussed these issues unless she brought them up.

A logical follow-up to this pilot study is one in which science students are paired with a social sciences or ethics student working with them on the same topic. If nothing else, such research and training experiences would help eliminate the problem of compartmentalization, in which scientists view their research activities, and engineers their design processes, as value-free (Gorman *et al.* 2000). Not every scientist and engineer needs to engage in a collaboration of this sort, but it is recommended for those working on the cutting edge in areas where society has provided significant funding in anticipation of social benefits.

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Notes

[1] Kuhn's work is controversial, and not everyone agrees on the extent of the problem of incommensurability, or on the nature of a paradigm. See Giere 1992, for a good overview of the issues, and examples from controversies like plate tectonics.

[2] The term nanocajun was suggested by an unknown member of the audience at a paper Gorman gave on converging technologies and trading zones at UCLA on February 6, 2003.

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