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CHAPTER

Nanotechnology in Society Education: Cultivating the Mental Habits of Social Engineers and Critical Citizens

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1 Introduction

Alvin Weinberg's now infamous article "Can technology replace social engineering?" [1] has had an enormous impact on our understanding of engineering and its role in society. In this article, Weinberg introduced the concept of a technological fix, a term that has become the bane of those of us in the engineering community who now are required to go to great lengths to persuade our students that technology is not necessarily the answer to every social problem. To be fair, Weinberg never suggested that the answer to his title question was an unequivocal "yes." Indeed, Weinberg argued in the article that so-called technological fixes would inevitably need to go hand-in-hand with social engineering, which Weinberg defined as the modification of human behavior and values, in efforts to solve most social problems. Even so, by crystallizing popular misconceptions of a clear dichotomy, among both engineers and the broader public, Weinberg helped to transform the way society thinks about social problems and applied engineering.

Today, we know that Weinberg's simple dichotomy is deeply misleading. To put it bluntly, there is no such thing as a "technical fix." We may not like the phrase "social engineering." Some of us who have been around for a few decades may even associate it with socialism, although, to be even-handed, democratic governments have not been entirely free of the dream of applying engineering to efforts to transform society (the Tennessee Valley Authority comes to mind; see David Lilienthal [2]). Nonetheless, the truth is that all engineering is social engineering. Inevitably, new and emerging technologies prompt us to reconsider our ideas, our values, or our behaviors as individuals and as communities. Technologies are integral elements of what Langdon Winner [3] has described as forms of life—social arrangements that we inhabit and that make us who and what we are. To alter our technological possibilities is, therefore, to alter our social possibilities as well.

In this regard, nanotechnology is no different than any other technology. In a recent class on international policy problems taught by one of the authors at the University of Wisconsin-Madison (UW-Madison), students examining the problem of airport security during an epidemic outbreak called for additional investment in an inexpensive, hand-held field sensor for the flu virus. Nanotechnology may soon provide them with the technology they want, and who, really, could object? It's not too hard to imagine, however, that airports may not be the primary market for such a technology. Office workers may find it handy to be able to screen their cubicles for viruses. Think of the litigation problems for a school that fails to protect children from exposure to a potentially deadly virus when such a simple screening device would help create a healthier educational environment. Businesses may screen employees to prevent them from exposing their colleagues and thus costing the company money, instead forcing employees that tested positive to take sick leave, regardless of how sick they felt. These examples reflect the social negotiations that surround the introduction of any new technology. Sometimes they are referred to as unintended or unanticipated side effects. The thing is, they're not too difficult to anticipate, if an engineer has the right habits of mind.

This, then, is the first objective of our chapter: to describe some of the habits of mind that we try to cultivate in social engineers in our classes at the University of Wisconsin-Madison. Engineering education, we suggest, should cultivate reflexive habits that enable engineers to anticipate a range of potential trajectories in the technological forms of life they design. It should teach engineers to recognize the heterogeneous elements of social engineering: the social, economic, political, and cultural elements that go into the fashioning of forms of life. And it should mentor them, as they learn technological design, in reaching out to and engaging with people whose lives will be impacted by social engineering. (These ideas have a long history among humanists, scientists, and engineers; see, for example, the works of Lewis Mumford, C. P. Snow, and Samuel Florman [4–6] in the bibliography). Our second objective is to do the same for what we will term "critical citizens." Social engineering ultimately must be a collective process—it cannot be solely the province of engineers. But for collective design work to succeed, citizens must acquire the habits of mind to become active partners with engineers. They must learn both to be constructive contributors to the design process and also critical inquirers into and assessors of life in a technological world. We end with a few thoughts toward a third objective: what a new engineering education might look like if nanotechnology in society education took seriously the cultivation of the mental habits of the social engineer and the critical citizen.

2 Core Concepts in Nanotechnology in Society Education

At the University of Wisconsin-Madison, we are engaged like many other universities in building new programs in nanotechnology education, ranging from K-12 through undergraduate and graduate education. Although much of the focus of these programs is on teaching the science and engineering of nanotechnology, our programs have also made an important commitment to teaching a subject that we call "nanotechnology in society" (also see chapters by Jaszczak and Seely; Toumey and Baird; and Zenner and Crone in this volume). The key focus of nanotechnology in society education, as we conceptualize it, is to help students to think critically about what happens as nanotechnology moves out of the research and development process—out of the laboratory, if you will—and into society. This is a crucial phase of technological development, in which social forces are brought to bear on all new technologies, shaping their use, bringing changes to their design, sometimes embroiling them in controversies, and even resulting in their occasional rejection. We believe it is an important subject not only for citizens, who increasingly live in landscapes, literal and figurative, that are defined primarily by the technological choices they and previous generations of people have made, but also for engineers, whose designs, prototypes, and products will be moving into society and helping to create the landscapes of the future. Yet, somewhat surprisingly, it is a subject that has at best a marginal position throughout the educational system, whether we are talking about K-12, liberal arts, or engineering curricula.

Our programs in nanotechnology and society education are built around a small number of core concepts. One of the most important is that of technological forms of life, introduced previously, which highlights that human lives are intimately wrapped up in the technologies they choose to design, build, buy, and make use of in their day-to-day activities. Closely related is the concept of interpretive and design flexibility, which emphasizes that technologies are not fixed entities; their social meanings often vary across parts of society and, as a consequence, the criteria used to evaluate competing designs may vary as well. The potential for multiple meanings and design criteria can occasionally also give rise to technological controversies and regulation, such as those that have surrounded nuclear power, genetically modified food crops, and stem cell research. Finally, all of these ideas contribute to the notion that technologies are socially imagined and constructed. We don't mean this in the naïve sense that they are simply products of our imagination, that is, fanciful flights from reality, but rather that they result from the productive power of human imagination. Before there could be an Internet, someone had to imagine its possibility. Engineers design technologies. Businesses invest in them. Consumers buy them. Social activists march for and against them. Governments regulate them. Ultimately, there is very little if anything at all about technologies not subject to myriad human imaginings and choices, and many of those imaginings and choices are made in the context not only of the laboratory but also of society.

Perhaps the most important of these ideas is that of technological forms of life. Imagine a technology: nuclear weapons, automobiles, electricity, e-mail, cellular phones, mp3 players ... in living with these and other technologies, humans live technological forms of life. Day-to-day actions and choices are made in the context of technological possibilities. Technologies allow for the creation and maintenance of social relationships, through frequent communication over long distances and lengthy periods of separation, and through the possibility of transportation. They challenge moral and ethical frameworks, as advances in science and technology prompt reconsideration of questions such as in what contexts it is acceptable to use a cellular phone, or what new reproductive technologies or forms of genetic manipulation will be permitted. They become key elements of psychological and social profiles, as people display their most recent technological acquisitions, as they declare loyalty to Macs or PCs, and sometimes, even, as they become caught up in new virtual realities, where they mold self-images and self-representations in online communities. People give technologies meaning and, as a consequence, those technologies come to contribute to the shaping of social and political order.

As nanotechnologies join mainstream society, they, too, will become central to human lives and dramas. Indeed, they already are. It is important not to be careless in interpreting the meaning of this logic. It is not that technology drives history or acts as a force independent of human agency. Nothing could be further from the truth. Rather, people make choices to design technologies, they attribute meaning to technologies, and they make use of them in pursuit of their own objectives and visions. Technological change happens as a result of human inventiveness, organization, and deliberation, in turn offering people new opportunities to alter their own lives and those of their fellow citizens. Visions of nanotechnology already haunt the shelves of bookstores, the boardrooms of corporate finance, and the halls of Congress. The U.S. *21st Century Nanotechnology Research & Development Act* established nanotechnology as the next major arena of technological and economic innovation following genetics and biotechnology. Morgan Stanley announced a "Nanotechnology Index" to measure the economic progress of the small but growing sector of the economy dependent on nanoscale science and engineering. The ETC Group, a prominent critic of agricultural biotechnologies, declared that nanotechnology required careful attention from social watchdog groups, while major environmental groups, the U.S. Environmental Protection Agency, and key corporate leaders have begun to seek ways to ensure that nanotechnology develops in a manner that minimizes risks to human health and ecological systems. Even before the hardware of nanotechnology has become a reality, already social forces are at work to shape its future meaning and evolution. Their focus is that of answering a single key question: what kind of lives will we live in a nanotechnological future? (Also see chapter by Berne in this volume.)

Not surprisingly, when what is at stake in new technologies is the kinds of lives we will live in the future, people do not always agree on what a technology means or what criteria should be applied to its design and evaluation. A famous case study focuses on the history of the bicycle, illustrating how people who wanted to go fast and demonstrate a great deal of skill demanded very different bicycle designs than people who wanted a stable means of everyday transportation. Ultimately, the latter won out, and bicycle designs stabilized around two evenly sized wheels. Nanotechnology is no different. Already, chemists and engineers disagree over its meaning. Engineers, who are pressing to design systems at ever-smaller scales, see it as a highly novel domain. Chemists, on the other hand, see the manipulation of atoms and molecules as nothing really new. In society, this difference of opinion is already creating challenges. Sunscreen manufacturers have come under scrutiny as the size of dissolved titanium dioxide particles in their sunscreen decreases from micro- to nanoscales. The latter is transparent, instead of white, which apparently appeals to beachgoers. Regulators at the U.S. Food and Drug Administration face controversy over their decision not to subject the new nano-enabled sunscreens to greater regulatory oversight. Yes, critics charge, the chemical agent is still titanium dioxide, but it is engineered differently. Compounding their concerns is the claim, frequently made by nanotechnology boosters, that materials exhibit distinct properties when engineered at nanoscales. If so, critics ask, should we not examine carefully whether these novel properties pose novel risks?

Underpinning all of these arenas is the question of how communities and societies will make decisions regarding the future of nanotechnology, and the lives we live in and around it. Engineers will obviously be an important part of the process. Engineers sit at the center of the research and development process, and their skills and expertise are critical for innovation. Yet, engineers must also be partners with numerous others in making decisions about new technologies. Financiers, business managers, salespeople, and consumers all shape the marketability of new technologies. At the same time, citizens, social activists, legislators, and regulators are all also integral to the future shape and success of nanotechnological systems. There is growing sentiment that society needs to pay careful attention not only to considerations such as safety and health, but also to the forms of life created around new technologies. Although the U.S. Congress dismantled the Office of Technology Assessment in 1995, it did so for budgetary reasons and not because of a rejection of the need for close analysis of technologies in society. In its place, both President Clinton and President Bush have subsequently established ethical advisory boards to evaluate the social implications of biotechnology.

For nanotechnology, Congress has called for, and the National Science Foundation has established, a new networked multi-university Center for Nanotechnology in Society. The Center's mission is both to conduct research that can inform public decision-making about nanotechnology, and also to prototype new approaches to more reflexive, socially oriented decision-making in the laboratory. As part of this new Center, our efforts at developing new approaches to nanotechnology in society education are intended to help engineers learn how to think critically about the social forces that are coming to bear on their work, and how to work closely with non-engineers—who will be the future users of their technologies—to help shape the design process. We offer courses that explore the kinds of issues described previously and their application to emerging nanotechnologies. We also help engineers develop communications and networking skills for engaging effectively with nonengineers in the process of designing and evaluating technologies. At the same time, we also are teaching courses designed to introduce similar topics for citizens. At the center of both efforts is a sense that what is most important is a set of *habits of mind* that will allow engineers and citizens to collectively pursue social engineering.

3 The Mental Habits of Social Engineers

Engineers are instrumental in creating not only technologies but also technological forms of life; hence, our argument that all engineering is social engineering. Engineers are hardly alone in this regard, however. They build new forms of life with partners in the marketplace, in government, and in society at large. These two facts are at the core of our efforts to rethink the training of social engineers around a new set of mental habits that we see as essential components of engineering education. We should point out, however, that our ideas are not radical in content. The U.S. Accreditation Board for Engineering and Technology (ABET; www.abet.org) lists many of these habits and skills in its new criteria for engineering accreditation. We have simply gathered together here the range of "non-technical" criteria and given them content and meaning in a fashion that integrates these criteria and highlights their integral value for engineering work.

Perhaps the most obvious mental habits for social engineers must be (1) to recognize that engineering work is a form of social engineering and (2) to develop a commitment to systematically inquire into the broad (read social, economic, political, or ethical) impact and import of their engineering work. Further, because the second is often a particularly complex and challenging task, we encourage engineering students (3) to regularly seek out opportunities to learn new skills with regard to successfully pursuing such inquiries. Engineers should not make the mistake, however, of assuming that these tasks can be accomplished individually or even necessarily by teams of engineers. A key aspect of social engineering is (4) to recognize the obligation of engineers to work in partnership with those who will inhabit the technological worlds the engineers design and build. Almost universally, today, good engineering design practice emphasizes close consultation with the future users of technologies or with clients throughout the design process. This is a valuable element of the partnerships we encourage forging, but clients and users are not the only ones who inhabit technological forms of life. In Boston, local residents revolted when they realized that bridges built for commuters by the "Big Dig Project" would end in their neighborhoods, disrupting community life. Early cell phone use created disruptions to meetings and contributed to automobile accidents, both impacting non-cell phone users. Incorporating relevant voices in the design process is often illuminating in many ways, helping to avoid obvious problems and sometimes giving rise to unique or innovative engineering solutions, by adding new perspectives to the design dialogue.

Once multiple, distinct social voices become a frequent element of the design process, an important characteristic of the construction of technological forms of life is likely to become quickly apparent: namely, that social interests and views are frequently at odds over various aspects of how technologies should be designed and implemented. We see it as important, therefore, for engineers to develop the habit (5) of recognizing that all design decisions involve the need to balance, choose, and evaluate interests, views, and perspectives and (6) of looking for ways of making those choices explicit and an integral part of the dialogue that surrounds design

1. To recognize engineering work as a form of social engineering
2. To develop a commitment to systematically inquire into the broad impact and import of engineering work
3. To regularly seek out opportunities to learn new skills to successfully pursue such inquiries
4. To recognize the obligation of engineers to work in partnership with those who will inhabit the technological worlds the engineers design and build
5. To recognize that all design decisions involve the need to balance, choose, and evaluate interests, views, and perspectives
6. To look for ways to make those choices an explicit and integral part of the dialogue that surrounds design decisions
7. To develop a tolerance and appreciation for dissention, debate, and dialogue
8. To involve the public more actively as participants in deliberations about the public good as embedded in technological systems

Table 1: Habits of mind of social engineers.

decisions. This is likely to make design processes more complex and contentious—not an outcome that many engineers are likely to appreciate. It is hard to see, however, how the design process can be made more reflexively attuned to ensuring that the views of future inhabitants of technological forms of life are appropriately taken into account in design choices without opening up the process of making those choices to more disparate ideas and perspectives. Developing [7] a tolerance and even appreciation for dissension, debate, and dialogue, is thus also likely to be important.

Debates about the future organization and implementation of technological forms of life, that is, debates about design and construction of technological systems, are inevitably debates about what constitutes the public good. Although not often actively contemplated in engineering schools today, the history of the engineering profession is closely wrapped up with notions of the public good. Indeed, the idea of a profession—and of professional ethics—began with the notion that individuals with special skills and expertise also encumbered special obligations with respect to using those skills to pursue public good. Although contemporary debates about public good frequently devolve to debates about the value of privatizing decisions, few engineers have difficulty recognizing that leaving technological decision-making solely to producer and consumer choices in the marketplace will not always result in publicly optimal decisions about what kinds of technological designs to pursue (or not to pursue). If we are to revitalize such debates, however, engineers must develop new habits that (8) involve them more actively as participants in deliberations about the public good, among themselves and with others in society, especially as their own knowledge, skills, and expertise give them a unique perspective on how technologies fit into broader social, economic, and political arrangements in society.

4 The Mental Habits of Critical Citizens

That the elaboration of new technological worlds, that is,new ideas, behaviors, relationships, institutions, and communities centered on technology, evolves in partnership between engineers and citizens (in which category we subsume, for the purposes of this discussion, consumers, businesses, regulators, activists, and citizens) should, by now be relatively obvious. It would be wrong, however, to assume that only engineers need new mental habits to pursue this partnership. Citizens, too, must acquire new ways of thinking about technology and engineering to adjust to the realities of social engineering. To be sure, the idea that citizens are out of touch with contemporary technological realities is not a new one. Too often, however, this idea is tainted by what a number of people have called the 'deficit model' of public understanding of science. Put simply, this model suggests that the problem is that the public is deficient in its understanding of technology and ignorant of its true realities; therefore, the deficit model presumes, it should defer more to engineering authority.

We could not disagree more. We believe that public trust in engineering must be earned (and frequently re-earned, again and again) and that citizens have a great

1. To consistently apply critical thinking to emerging and changing technological forms of life
2. To ask hard questions about technological developments
3. To work to create networks of people that span technical and non-technical communities and so strengthen the flow of ideas and insights back and forth

Table 2: Habits of mind of critical citizens.

deal of knowledge and insights to contribute to the engineering design process, precisely because they know what it is like to live with technologies. Engineering authority will be strongest, we believe, when it is confronted with skeptical viewpoints and critical perspectives and works through these challenges to develop persuasive accounts of how future technological systems should be designed and constructed. If this process is to work effectively, however, citizens must become much more effectively re-engaged with the technological systems they inhabit. Sadly, one of the consequences of seeing engineering work as exclusively technical work has been to isolate citizens from the design process and to marginalize their potential contributions, thus contributing to broader processes of disengagement and alienation in which citizens feel as if they are not in control of key aspects of their own lives in technological societies. This disengagement and alienation must be overcome through new approaches to engineering education that reach out to nonengineers.

One of the most important habits citizens must reacquire, therefore, is (1) to consistently apply critical thinking to emerging and changing technological forms of life. Citizens must begin, once again, (2) to ask hard questions about technological developments. By learning to apply critical thinking skills and to read the socio-technical landscapes and contours of contemporary societies, citizens will learn how to ask appropriate questions and to evaluate the answers they get to these questions, accepting explanations that make sense while probing further when they receive answers that do not comport with what they know about living in technological worlds. It is important to note that such engagement doesn't need to create conflict. Although social mobilization around technologies such as nuclear power and genetically modified food crops has occurred, it has done so not because of a failure of dialogue, but rather because avenues for dialogue were not available during the design process. Engaged citizens saw little alternative, therefore, but to express their concerns in more adversarial contexts.

If dialogue and deliberation are to replace mobilization and protest, then citizens must not only challenge engineers to more actively involve them earlier in the design process but also get into the habit of (3) working to create networks of people that span technical and non-technical communities and so strengthen the flow of ideas and insights back and forth. Here in Madison, we have been lucky to work closely with a group of citizens who participated in a citizens' consensus conference on nanotechnology in April 2005. During the three weeks of the conference, this citizens' group became convinced of the need for much closer and more frequent interaction between citizens and nanoengineers, and they have begun to seek mechanisms to foster such interaction on a regular basis through a series of Science Cafés. These meetings invite nano-engineers to come to speak with groups of 30 to 50 citizens in a local eating establishment to discuss their work and its social import and implications. These discussions often range widely, challenging the participants' knowledge and understanding (also see chapter by Toumey & Baird in this volume).

5 Approaches to Nanotechnology in Society Education

Very few, if any, of the mental habits we have described for social engineers and critical citizens are unique to nanotechnology. Nonetheless, nanotechnology in society education has offered us an opportunity to pilot some of these ideas, as has teaching the introductory design course for engineering freshmen at the University of Wisconsin-Madison. In this final section, we briefly describe three educational programs that we have developed that make use of the ideas presented in this chapter. We make no claims to have identified unique or even especially effective approaches to inculcating the habits described above in our own efforts to teach engineering design and nanotechnology in society. They are simply one example of how the teaching of engineering in society and nanotechnology in society might proceed.

The course "Where Science Meets Society" serves as the introductory course for the University of Wisconsin's Holtz Center for Science & Technology Studies and is explicitly designed to address many of the educational objectives discussed above. The course mixes students from across campus and provides a semester-long focus on what happens as science and technology are integrated into society. The course begins with a brief theoretical introduction to the key concepts in science and society discussed above, and then adopts a problem-centered approach that examines key arenas of scientific and technological change and their place in society; in past years, these have included nanotechnology, computing, genetics, reproductive technologies, nuclear power, and others. The course asks science and engineering students to confront the social implications and import of their work, while simultaneously challenging students from other parts of campus to become more critically engaged in understanding the emergence and elaboration of scientific and technological forms of life. Taught in a discussion-heavy format, the course also encourages students to develop the skills necessary to communicate effectively across disciplinary boundaries in deliberating about particular technologies.

Frequent writing assignments in the course seek to develop students' ability to understand and apply important conceptual frameworks to new and emerging technologies, as well as to foster a broader ability to think critically about the meaning of technology in society. A common assignment is to provide students with a "top 10" list of breakthrough technologies of the future and ask them to analyze potential social controversies that may emerge. A variant of this assignment asks students to analyze the potential effectiveness of various strategies for either preventing or resolving social conflict with respect to new technologies. Another common assignment is to challenge students to question whether or not there are areas of science and engineering that it might be advisable, necessary, or desirable for human society to forego. Students must grapple with questions such as intellectual freedom, democratic governance of science and technology, the conditions or contexts under which society might want to opt to forego knowledge, and the validity of arguments for and against placing restrictions on science and technology.

In 2004, we received a National Science Foundation-funded Nanotechnology Undergraduate Education (NUE) award to pilot a new program in nanotechnology in society education, "Nanotechnology in Society." This program entails two components. First, the program offers a teaching seminar taught jointly by faculty from nanoscale science and engineering and by faculty who study the interactions between science, technology, and society. In the training seminar, graduate students in fields of chemistry, physics, engineering, history, and sociology learn skills useful in teaching science in society topics, share insights that their own fields offer for teaching nanotechnology in society, and work together to create syllabi for first-year undergraduate seminars. Participants in the training seminar also benefit from hands-on teaching mentorships that provide short-term exposure to designing course materials, creating teaching plans, and teaching in a range of courses that range from large science and engineering lectures to small social science and humanities seminars (also see chapter by Zenner and Crone in this volume).

Second, graduate students who have participated in the teaching seminar are given an opportunity to teach a first-year undergraduate seminar on the topic of nanotechnology in society, based on the syllabi they have designed in the training seminar. At time of writing, five students have taught these seminars to a total of more than 100 undergraduates. Students in the first-year seminars come from a wide range of disciplinary backgrounds, with about two-thirds from science and engineering fields and one-third from social science and humanities. As these first-year seminars are taught as sections of "Where Science Meets Society," they often pursue similar strategies in writing assignments and discussions as those described previously. Key themes that permeate these discussions include comparative analyses of nanotechnology, genetic engineering, and nuclear power; nanotechnology and democracy; human performance enhancement and other nano-biotechnologies; privacy; law and regulation; utopian and dystopian visions of nanotechnology; environmental and health impacts; media and public representations of nanotechnology; and the military, security, and new and emerging nanotechnologies.

For example, a course section offered in early 2006 focused on issues of nanotechnology and democracy, and was taught as a comparison of nanotechnology and biotechnology. The course asked students to understand how democratic governance and politics are playing out in the context of new and emerging technologies. For example, what kinds of social movements are emerging around these technologies? How are regulatory agencies assessing and managing technological risks in each case, and what role are citizens playing in that process? How are genetics and nanotechnology contributing to new concerns about surveillance, privacy, and social control, whether in the domain of health or more broadly?

Another course section offered in early 2006 focused on the history of public fears of nanotechnology. It explored early writings about nanotechnology, including both non-fiction and fictional accounts, and asked why these have contributed to public concern. The course then tracked the public and scientific debate over the so-called "gray goo" phenomenon, and examined recent public opinion surveys to get a better sense of what the public understanding of nanotechnology actually is. Finally, the course attempted to situate the story of nanotechnology in the larger historical context of public fears of older technologies.

A decade ago, a small group of faculty in the College of Engineering piloted a class, "Introduction to Engineering Design," as a way to engage first-year engineering students with the college. Traditionally, these students had been sent off to spend a year or more taking the requisite calculus, chemistry, and physics classes before being admitted to departments; as a result, they had little idea as to the true nature of this field they were choosing to enter. Today, all students in the college are required to take an introduction to engineering course in their first year, and this intro class remains the most popular option, with more than 300 students—roughly half the incoming class—enrolling each year.

The course consists of twice-weekly lectures on engineering design, broadly conceived, plus a 3-h lab each week, in which students complete a design project for a client in the community, typically from a non-profit or community service organization. Among the half-dozen goals for the course lies one that, at first, strikes the students as puzzling: "preliminary development of the habits of mind that engineering study and practice require." The syllabus for the course provides some examples of how students might demonstrate these "habits of mind":

- Do the lab notebook and in-class performance of this student indicate an ability to organize and document the design process?
- Is the student timely in attending class and submitting assignments?
- Has the student put forth a level of effort consistent with the demands of the project?
- Are the student's interactions with peers, instructors, and clients professional?

As the semester goes along, students (and new instructors in the course) begin to see that we mean for them to develop more sophisticated habits than simply keeping neat and detailed notes. Through our presentations on risk assessment, engineering ethics, communication, societal implications, safety, decision-making, and more, students repeatedly get the message that good engineering goes far beyond excelling at the application of technical ideas. It is through their hands-on work with their clients, however, that students develop an intuitive understanding of what we mean by these habits of mind. For their projects to be successful, for their clients to be satisfied, and for their instructors to be pleased requires that students do more than bury their heads in the technical minutiae of their designs. One group's project, for example, involved building retractable ramps to provide access for wheelchairs (and strollers and walkers) to businesses along Madison's popular pedestrian mall, State Street, whose front doors are often one awkward step up from the sloping sidewalk. The design itself was relatively straightforward, but the students also spent the semester documenting access issues, attending city council meetings, consulting with shoppers and business owners, trying wheelchairs for themselves, and grappling with the requirements of accommodation laws and building codes. By semester's end, these students had a deep understanding that engineering habits of mind are as much about "how you know" as what you know. The stage has been set for them to continue their education with a broad conception of engineering practice and their responsibilities in it.

6 Final Thoughts

There can be little doubt that nanotechnologies are going to contribute to the construction and elaboration of new kinds of human societies, new social relationships, new identities, and new values as they become part of the worlds we inhabit. In this process of social engineering, both engineers and citizens will inevitably play key roles, whether they choose to or not, whether they know it or not. We believe it is possible, however, for engineers and citizens to pursue this social engineering in a more reflective partnership that acknowledges, recognizes, and even celebrates the fact that engineering is never simply a technical task, and that technologies are integral elements of virtually any meaningful idea, act, or relationship in contemporary societies. For this to happen, we must envision a new kind of university curriculum that finds ways to integrate engineering and the liberal arts, such that engineers become critical thinkers, and humanists become attuned to the human dimensions of technological choices. Without this kind of transformation, we will bumble through the nanotechnological transformations of the next century, but there is little chance that we will do so in a fashion that mitigates the human costs and consequences of technological change, and that makes reasoned decisions about how to apply nanotechnologies to achieving greater public good.

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