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When Worlds Collide: Engineering Students Encounter Social Aspects of Production

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ABSTRACT: *To design effective and socially sensitive systems, engineers must be able to integrate a technology-based approach to engineering problems with concerns for social impact and the context of use. The conventional approach to engineering education is largely technology-based, and even when additional courses with a social orientation are added, engineering graduates are often not well prepared to design user- and context-sensitive systems. Using data from interviews with three engineering students who had significant exposure to a socially-oriented perspective on production systems design, this paper argues that engineering students may have difficulty integrating in their own practice the technology-based and the socially-oriented perspectives on production. To enhance engineering students' ability to create systems that integrate both perspectives, and to relieve the intense cognitive and emotional pain that can be experienced by students exposed to both perspectives but unable to reconcile them, this paper reinforces the importance of teaching students the meta skill,* design. *A design perspective can help students integrate varied, sometimes conflicting, perspectives, and reach beyond customer-defined constraints to consider workplace and social impact.*

To create effective, sustainable production systems that are sensitive to their impact on the workplace and on society, engineers must be able to integrate technology-based concerns with other, more socially-oriented demands. Engineering education can play an important role in laying the groundwork for the integration of these two diverse perspectives, by teaching engineers how to respond to heterogeneous constraints and opportunities. Conventional technology-based engineering education, however, does not necessarily produce engineers who are capable of this integration, even in cases where additional courses with a more social focus are offered.

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In the pages that follow, interviews with three engineering students reveal that integrating a socially sensitive approach to production with a conventional technology-based engineering approach is, for these students, an insurmountable challenge. Not only does the technology-focused curriculum in most US engineering schools today not prepare students to integrate the social and the technical, it is sometimes deeply in conflict with a socially sensitive approach to production. This paper focuses on the nature of this conflict and its effects on engineering students, and on how an alternative approach to engineering education might help to educate a generation of engineers more capable of integrating a technology-based approach with other, more socially-oriented considerations, and thus form a firmer foundation for ethical practice.

Social Aspects of Production

In the conventional technology-based engineering curriculum there is a marked absence of human agency, and little or no discussion of the workplace and social impacts of the design of production systems. A 1992 survey of over two hundred equipment design and engineering textbooks found that only 42 made any mention of human workers or human activity. Those that did usually presented the "role of people in production as subordinate if not marginal... The potential for deliberate operator action to promote systems performance rarely ranked as even a [minor] theme" (page 69 [1]).* When production workers were discussed, they were generally treated as a source of error and disruption. Specific recommendations, while few, tended to focus on safety and ergonomic concerns, especially after the mid-1960s. The textbooks made no attempt to encourage students to think about the impact on workers' skill and autonomy, or about the broader social effects—such as unemployment, alienation, and passivity—of production systems.

Consider the following examples in which engineering products have a distinct social impact:

- At an automobile assembly plant, a new computer-integrated manufacturing system, with just-in-time inventory control, placed enormous new pressures on assembly, repair, and supervisory workers. The pace of work could no longer be controlled by an individual worker, and the economic consequences of breakdown anywhere in the system were so high that production, maintenance, and supervisory employees all reported greatly increased levels of stress and stress-related illnesses, which also affected their families.[2]
- In agriculture, the "shorthoe"—a hoe with a two-foot handle—allowed supervisors to more easily see from a distance who was working and who was not, because workers had to lean over to use the hoe. Anyone standing upright was not being productive. While making supervision easier, the shorthoe added to the physical strain of agricultural work.

* See also Bucciarelli and Kuhn,[3] for a discussion of some of the issues raised by the absence of human agency from most engineering education.

- At an optics manufacturer, an assembly line designed for fully automatic operation still required extensive operator intervention twenty-one months after installation. To keep the line functioning even at 40 percent of planned capacity, operators had to override a number of safety features and insert their fingers into the machinery, putting them at frequent risk of injury.[1]
- The bridges spanning the parkways of Long Island, New York, were deliberately designed with unusually low clearance. The result is that only those with private cars have access to Jones Beach and other Long Island attractions, while people dependent on bus transportation are excluded.[4]

To be able better to anticipate and to evaluate the social and workplace impacts of their designs, engineering students need to learn to integrate the technical and the social. Only in so doing will they be able to design systems that are socially sensitive as well as technically robust.

In many curricula, engineering students are exposed to social issues in separate General Education courses that introduce them to the social sciences and humanities. They may also take business courses, and even a "technology and society" course. While these courses surely serve to broaden students' horizons, it is not clear how much these freestanding courses influence their professional practice. Particularly when engineering curricula present production systems as largely technical systems, with human agency and impact substantially absent, students may have difficulty integrating—or may not even attempt to integrate—the technical and the social.

Extended interviews with three engineering students reveal the intense difficulty that students can have when they attempt to integrate a critical, socially-oriented view of production with the technical view that predominates in engineering courses. All three students had taken courses or worked on projects (or done both) which exposed them to social and political perspectives on production systems. All three described substantial cognitive and personal distress as they attempted to integrate the socially-oriented perspective they had acquired with their technically-oriented engineering education.

The Students Tell Their Stories

Troy and Lisa were graduate students and Paul was an undergraduate in Industrial Technology* in the School of Engineering at a public university in North America during the academic year 1990-1991, when these interviews took place. They were chosen for interview because, of all the students in the School of Engineering, they had

* Like other accredited engineering programs in the United States, this university distinguishes "technology" programs, which are more applied, from more theoretically oriented engineering programs. Students in the Industrial Technology program should have an *easier* time integrating their classroom education with the ideas of skill-based automation because of the comparatively applied nature of their program. The fact that even these students had such difficulty suggests that students in the more theoretical engineering programs might have as much or more trouble. At the time of these interviews, relatively little teaching of design was being done in the engineering program proper.

shown the most interest in, and had the most thorough exposure to, a socially-oriented perspective on production.*

The students' introduction: Troy remembers that from his earliest days he wanted to be an engineer. In high school and college, Troy worked at blue collar jobs, including as a machinist, in order to support his education. His first academic introduction to a social and political perspective on production systems was in a course in which he read material such as Robert Howard's *Brave New Workplace*[6] and case studies of workplace automation, and listened to discussions and critiques of workplace applications of technology. He had no idea what the course was about when he enrolled, and says that it was well into the semester when "it just hit me... I think there was probably a defense mechanism in there that took a while to overcome." Unlike some of the students, on whom the course made no significant visible impact, Troy wrestled with the ideas of the course and said "it made me start thinking." Two years later he taught a course on Labor and Technology with the Teaching Assistant (TA) of the course he had taken, and collaborated with him on a project the purpose of which was to critique the features of Computer-Aided Manufacturing (CAM) software from a skilled machinist's point of view.

Lisa, from a blue-collar family, attended a vocational high school and majored in drafting. After two years working as a drafter, she enrolled in an electromechanical engineering program at a community college, working on the side as a child care worker for special needs children in order to support herself. After two years she transferred to the Mechanical Engineering program at the university. At the end of the first semester, Lisa says, she was missing the kids she had cared for and was questioning whether she was "cut out for engineering." She changed her major to psychology, but quickly decided that

> ...that seemed too far removed from engineering. Mechanical engineering seemed too far removed from things that are human and tangible in that regard, but then the psychology was too far removed from my design interests and things that are mechanical.

One of Lisa's professors was in the Industrial Technology [IT] department, and she recalls that he would talk about things like appropriate technology and energy issues. This appealed to her because it seemed like "engineering with a particular focus on improving life in some way." She decided to enter the IT program. It was there that she first heard the term "human factors engineering" and thought that it might be an opportunity to integrate her two interests. When Lisa mentioned her interest in human

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* These interviews, conducted by me, lasted one to two hours and were audio taped and fully transcribed. The quotations are taken verbatim, with minor editing for flow, from the transcripts. The students were informed before the interview of the purpose of the research in which they were participating, were shown copies of the interview transcripts, and approved a final draft of the article in which these data first appeared.[5] Two have also seen drafts of this article. At the time of the interviews, none of the students was enrolled in a course taught by me or by any of the faculty or staff mentioned in this article. The students' names are pseudonyms.

factors to the director of one of the university's research centers, he suggested she speak to the professor who had taught the course that was Troy's introduction to a socially-oriented view of production.

The professor, the TA, and others were beginning work on a case study of technological change at a large aerospace manufacturing facility (the "MFG" case). Lisa joined the project team, conducted interviews and read documents, and worked closely with other project members. Work of this sort "was not my view of human factors engineering at the time," but she found her experience working on the case engrossing and formative.

Paul came to the university with an Associate's degree in microcomputer technology from a technical school and three or four years of work experience. What spurred him to go back to school for a Bachelor's degree was his experience working in manufacturing support and later in field service for a computer-related company. He said that in these roles he "seemed to be getting dumped on a lot" by people with Bachelors degrees, so he decided to get more education himself. In the IT program at the university, Paul worked for Troy in the CAD/CAM Laboratory. When Troy taught the Labor and Technology course with the TA, Paul took it.

Responses to their exposure: One of Troy's early reactions to the class material was to see it as an additional burden: "We've got enough to worry about [as engineers] and now we've got to worry about this." As an engineering student "you're not concerned with it because you are more worried about getting through general dynamics and things of that nature...and then to all of a sudden see this other side of the coin ... presents a whole new light on things that should be addressed but aren't." Confronting the "other side of the coin" was important, Troy felt, but it caused him deep feelings of ambivalence and distress. He felt he was being criticized as an engineer and called on to operate in a much "wider channel."

> It's not that we're taught to do these things without thinking about the impact... I guess it could be characterized as a realization that I never thought about the long term or the wide impact, and what large impact a little decision, or what seemingly was a little decision, could make. And the more you see this humanistic side of things, the tougher and tougher it gets just to make a decision period, or to make a statement, or to throw out some of the data...

Troy's ability to identify with the experience of blue collar workers seems to have been an important ingredient of his ability to see "the other side." His work experience during high school and college must have contributed to this ability. He also pointed out that engineers are vulnerable to unemployment, too, and that this can be a basis for identification.

Troy talked repeatedly about the experience of "seeing the other side". Before the course he had been on "the engineering side," as the course progressed he came to see what he called the "human" or "humanistic" side.

> It is difficult to see the other side, and it's probably even more difficult to see them both at the same time, which is the trick, I guess...I would have to think long and hard for an example of where I saw both at the same time.

His ability to see both sides of the coin put him "on the edge", which was confusing and frustrating, but also challenged him and made him think differently about the world. Troy did some consulting work with the TA, in which they advised a local company to make the transition to a skill-based or worker-centered approach to automation. Troy noted that managers and engineers at the company couldn't see why the consultants advocated such changes. Troy's experiences had given him the ability to take a broader view.

> [The people at the company should] look at the bottom line—the overall bottom line [which takes social impact into account]... I guess it all boils down to this coin. Being able to see the other side, being able to be on the other side...you flip back and forth. The ability to flatten that coin out and spread across both sides... I don't know if that's been done... [It's tough to get off the edge] because you don't know which way to go...and I guess [you] fear going the wrong way.

Troy believes there are few examples in industry of companies whose production process has taken "the human side" into account. Although he used the Volvo plant at Udevalla as an example in the course he taught, Troy believes that even this may not have been a stable or "pure" solution.* He says that

> ...arriving at a solution to something that...would encompass both is, I think, extremely difficult...Can this exist or can this methodology exist in a capitalist state? Can there ever be one that purely satisfies both? I don't know that. It may not.

Lisa recalls that the TA said to her on several occasions that technology is designed as a way of controlling the workforce. "I had a major knee-jerk reaction to those sorts of comments...I really didn't believe what he was saying and...I didn't understand his context for saying [it]...It didn't seem like from where I was coming from at the time that there was a context in which that could be true... [It] used to tie me up in knots..."

Although she reports having had "a strong negative resistance" to his view, she also remembers that in the course of the MFG project

> ...he said that in America we have this democracy, and then you walk through the front gates of your work place and it's no longer a democracy, and when I heard that...it sort of clicked with me... [T]hinking back, that was a way for me to be able to tie [the TA's] world and my world of engineering together. I think that helped me to make the bridge.

Her experience working intensively on the MFG project was transformative for Lisa, and also acutely painful and difficult. After a time she gained some understanding of her collaborator's view of technology as a mechanism of control, but she still found herself looking at things as an engineer, too, she felt.

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* Indeed, not long after his interview, Volvo announced plans to close the Udevalla plant.

> ...there was some sort of change that had occurred in me that enabled me to see where [the TA] was coming from, and that change did not come easily. It was actually a painful change... About the time that the MFG case was getting wrapped up... I was questioning a lot of things... I was trying to make sense of my world... And I remember one day in particular I just found myself at home, my husband had gone off to work, and I was in the shower and I was thinking about the case and I found myself crying. Just, not your ordinary crying. It was a lot of stuff that had been building up. A[n] ... acute awareness of these social forces influencing this decision about technological change and what the impact was going to be on the work force...I think the MFG case represented that point in time when I was trying to sort of, I don't know if transcend is the word. but go through this change in sort of my view of the world and how engineering gets played out.

Lisa had an experience while working on the case which disturbed her but also reinforced her emerging awareness that the design and implementation of technology were highly charged political, not simply technical, processes. At the end of a day of research at the public library near the plant, Lisa got into her car and started the drive home. Her car started to make a noise which grew progressively louder. At length she pulled into a service station and discovered that the lug nuts on her right front tire had been loosened. "It really scared me because at that point there were several people in the company who knew I was doing this case study, and I really got concerned that [there] is someone who doesn't want this case study to be done."

Lisa recalls that when she discovered the field of human factors, she intended to go on for a Masters degree in human factors engineering. As a result of her experience on the MFG case and her subsequent work in this area, she became instead a graduate student in ergonomics. Lisa says that she now sees the world in a very different way than she did when she was an IT student interested in human factors.

> I find that when I talk with some of my friends who are now working as engineers, you know, I know their language, I can identify with their points of view... [B]ecause I'm not really aware of, or I'm not able to see the process that I went through in changing my view of the world, it's hard for me to describe to people how my thinking is different. It's this process that's really mysterious...it's like looking through a window. You can't really see the change, how the change occurred...

For Lisa, then, although the process of transformation took place over a period of time, she experiences her present view as discontinuous from the way in which she used to see the world.

Reflecting on his exposure to a social and political perspective on production, Paul remembers one of the first exercises in the Labor and Technology course, in which fictitious telephone operators were to be given small electric shocks if they fell behind a set pace handling calls. The students in the course were to comment on the system and, if they were critical of it, propose an alternative. Paul says:

> I didn't think the electric shock was, like, appropriate, a little bit too severe, but I redeveloped the system using something else other than electric shock, something that wouldn't hurt them, but it would be like something that they would be aware of. And I felt really good about that solution. And then [it was explained to us]...how many calls an operator really takes all the time, the rates that they're expected to perform...it was like, wow, they expect these people to do a lot. Maybe we should sacrifice a few lost calls... So that was kind of like the first eye opener.

When Paul realized what working conditions were like for operators, he became able to identify with them to an extent he had not before. He made the connection between his own work experience and the lack of respect with which he was treated, and the experiences of the telephone operators. Paul drew two main lessons from the course. First, he learned to question the standard approach and ask whether there might be an alternative.

> If I hadn't taken the course, I wouldn't even question it. I would have thought, right now, because my background is in computers and [because of] my faith in the strength of what they could do... I wouldn't even have thought that there could be a better system. I guess I wouldn't have even considered the other side of the coin because I'm not on the other side of the coin.*

The second effect the course had on Paul was that at his job supporting office users of computers he was more apt to talk to a user about the problems they were experiencing than to simply fix a problem without understanding how the user experienced it. "I make it a point now to try to understand...and answer their questions and look at it from their point of view and if they don't understand then I'll try and work with them so they understand what's going on, and it works well." Because he had, through a combination of his own work experience and the course work, come to identify with users and shop floor workers, he treated their experiences and opinions as valuable.

Although Paul changed the way in which he practiced engineering, acting on his increased sense of identification with users and blue collar workers, he did not experience the sense of conflict expressed by Troy and Lisa. Paul did not grasp or internalize the aspects of a socially-oriented and critical perspective which are not simply an extension of engineering practice, but may in fact be in conflict with it, and he treated the conflict as personal rather than systemic. Paul understood that this aspect of the course was still beyond his reach.

Lasting effects on the students: Each of the students found his or her own way of coping with or accommodating to the sense of split and conflict. When Troy got his degree and left the university, he went to work for a small local company that develops and sells computer software to engineers—a position which he held at the time of his interview. His colleagues at the company were all engineers, and so were his clients.

* The "other side of the coin" expression used here is borrowed explicitly from Troy; Paul did not come up with this expression independently.

Troy provided customer training and support, and could also be hired on a consulting basis to design parts. Troy felt removed from the social dimensions of automation because of the homogeneity of his environment and because he was engaged in product design, not process design.

> This approach...it's all numbers, and the only qualitative decisions that could be placed in there is how, if I did change this piece of geometry, it would be easier to make, cost more to make, something along those lines. The other side of the equation, I guess, never really comes into bearing. I'm not sure that it would in this environment. My environment is the design of mechanical parts. Does this desk handle look square or round? Not much of a place for what we are talking about there...I'm not put in this position where I need to make a choice...I don't know that I've made a decision, I don't know that I could see both sides at one time now, but I do know I don't really need to. I mean there's no wall there that I have to turn left or right or decide to climb up....

In the course he took that introduced him to a socially-oriented view, Troy says he wrote on the final exam, "My life was great until I met you." Now, on his job and away from daily reminders about "the other side of the world," Troy says, "I'm happier. To be totally honest with you, I'm happier now than I was then."

Lisa describes herself as more at home in the occupational health field than she would be, holding the views she now has, back in engineering. Occupational health, she says, allows for more diversity in points of view.

> ...it's a lot easier for me in this field of ergonomics than if I was to have stayed in, say, manufacturing engineering or done industrial engineering, because there are people in the occupational health field who...focus on technical aspects and then there are other people who do some of the technical but also recognize some of the political stuff. So in the occupational health field it's easier to have some social awareness and to do your work in that context. That's not the case in engineering. I recognize that I would...possibly be more effective as an ergonomist...if I got a job as a manufacturing engineer...[but then] people are going to expect me to be concerned foremost with productivity... I'm still possibly receptive to doing something like that, but it does feel like a role conflict...to do manufacturing or industrial engineering...and to not be so focused on productivity. I mean I don't know who would hire me.

Just as Lisa recognizes that there are two different views of the world, the engineering view that she held as an IT student and the occupational health view that recognizes the social dimension of the workplace, she also sees that there are two different workplace roles—the manufacturing engineer and the occupational health specialist. She is not optimistic about the ability to play both roles at once, observing that the demands on the two are very different and to some extent in conflict. Troy was grappling with a similar issue when he asked "can this methodology exist in a capitalist state?" Both Lisa and Troy see a socially-oriented view as incompatible with the "engineering view" as it is normally taught and practiced. They see engineers as under pressure for productivity, with occupational health and other social concerns as at best a costly extension of the engineer's mandate. Lisa describes engineering, as she learned it, as a field inhospitable to the concerns which are now central to her.

> ...my engineering education didn't give me really a political context, and it sort of denied a political context by denoting that everything was objective and quantifiable and could be sort of foreseen. And if it couldn't be foreseen, we didn't measure it and we didn't take account of it.... Having this core of engineers without a political context, it seems to me [they] quickly buy into a management ideology....

Like Troy and Lisa, Paul also wonders about the feasibility of incorporating a socially-oriented view into engineering curriculum and practice. He suggests that it may be a futile effort since it is such a minority view, and it is in conflict with so much prevailing practice.

> ...the traditional model that you see with engineering and white collar/blue collar...it's pretty much entrenched and...from a long point of view, an extended point of view, I just kind of get this image of, like, Don Quixote out there tilting at windmills. [If] there's not a total buy-in from everybody, then it's pretty much you're a champion for the underdog. In most corporate organizations I don't think the champions of the little guy are really getting too much....

Understanding the Conflict

How might we characterize the conflict that the students describe? For Paul, the socially-oriented view he acquired is an extension of his engineering education. For Lisa, there is a fundamental conflict between what she learned in engineering class and the perspective she encountered during her work on the MFG case. Troy fluctuates in his description—sometimes, like Paul, he sees the new information as a simple broadening of scope; at other times, like Lisa, he is very aware of the existence of a conflict he cannot resolve. In shorthand, I will refer to the students' sense that the socially-oriented view is an *extension* of what they have learned as the problem of ***More***. The sense that there is a *fundamental conflict* I will call the problem of ***Other***.

Both the problem of *More* and the problem of *Other* are genuine problems, and both constitute potential barriers to engineers' participation in the design of socially sensitive systems. I will discuss both problems below, giving the second more weight than the first because it is the greatest source of cognitive and emotional pain for the students, and because it is the more difficult problem for educators and practitioners to resolve.

The Problems of *More*

Because of his developing identification with workers, which was stimulated by the Labor and Technology course, Paul changed his practices as an engineer and computer consultant. He came to ask users about their problems, treating them both as an important source of diagnostic information and as human beings who have wants and needs in the workplace. Paul did not see this as a fundamental challenge to his work as an engineer, but as a supplement to it. Even so, he wondered whether this user-oriented work would be valued in the workplace; for him, this kind of work made him a "champion for the underdog", and he was skeptical that his efforts on behalf of the underdog would ever be valued or rewarded by an employer.

Troy used a variety of metaphors to describe the relationship between his engineering training and a socially-oriented approach. He saw the socially-oriented view as one more thing he had to worry about as an engineer, when he already had plenty to concern himself with. In the interview he talked about having to operate in a much "wider channel." Although overall he seemed to suggest that the fundamental problem was the problem of *Other*, even the notion of a broadening of scope posed for him a difficult challenge.

The Problems of *Other*

Both Troy and Lisa gave compelling descriptions of the conflict between the engineering perspective and a socially-oriented perspective on production. Troy described what he called "two sides" or "two sides of a coin," the "engineering side" and the "human" or "humanistic side." He saw himself as "on the edge" and having to choose sides. Sometimes he described "two channels," one representing the "traditional engineering view" and the other a socially-oriented view. As Lisa told the story of her college career, she portrayed it as a search to integrate her interest in technical, design activities and her interest in people. The experience of the MFG case occasioned "a painful change" that had Lisa struggling "to make sense of my world." She could still describe–and recognize in her friends–the view of the world that she had before, but said she felt and thought differently than she did then. She went through a "mysterious" process, she said, and looking back was like "looking through a window."

Reinforcing the sense of discontinuity is the fact that both Troy and Lisa spoke of a moment when "it just hit me" (Troy) and "it sort of clicked with me" (Lisa). This suggests that there was at least one moment in time when each of them felt a sudden insight into the socially-oriented view. Their accounts suggest that from that time on they had a foothold—even though a precarious one—in the new world to which they were being introduced.* Before that moment, they could make no sense of what their teachers or project leaders were telling them—after that moment they had at least some conceptual basis for exploring a social perspective on production design.

* Shahaf Gal's article, "Footholds for Design,"[7] introduced me to rock climbing as a metaphor for the design process. His use of it differs somewhat from mine, since in this context I am stressing the importance of an initial conceptual foothold as a basis for further understanding of a new area.

Implications for Teaching

The ability to integrate technical aspects of engineering with concern for the workplace and social impacts of production is an important component of ethical engineering practice, and essential to the creation of production technologies that enhance, rather than harm, workers and their communities. Seeing the pain expressed by these students as they try to reconcile the technical and the social, moves us to ask to what extent we can relieve their suffering while improving, or at least not compromising, their education. How much of this distress, which is chiefly caused by the problems of *Other*, is unavoidable if students are to learn to work across disciplines, within organizational roles and institutional structures? If the problems of *Other* are unavoidable, are there tools we can offer students which will help them to integrate conflicting perspectives more effectively?

This article makes some fairly strong claims based on the experiences of three students, but it does not claim that all students do or will inevitably experience, given similar stimuli, the conflict and dissonance that these three students did. The data cannot support a claim of this sort, though they also cannot prove the contrary. Why should we give any weight to the experiences of only three students at a single institution? First, these were intelligent and capable students, who took seriously both their engineering work and the social issues to which they were exposed. Individual circumstances may have precipitated in them especially strong reactions, but both Troy and Lisa are sufficiently detailed and articulate in their descriptions of the cognitive conflict they felt, that it is difficult to dismiss their accounts. Second, the world of engineering work and education is often segmented in exactly the way the students describe. The absence of human agency in textbooks, noted by Salzman, and the role divisions between, for example, design engineers and human factors professionals, are features of the world to which these students are responding. Finally, the fact that even a minority of students find this integration so challenging, even if others do not, is significant.

One of the lessons these students' experiences teach us is that it is not enough to offer students an exposure to an alternative perspective. Indeed, it is potentially painful and unproductive to provide an alternative view without also giving students tools for coping with the dissonance created, and with the conflicts and paradoxes of which they will become acutely aware. Both Lisa and Troy grasped enough of the essentials of a socially-oriented view to make them aware of the challenge that it represented to their engineering training. Yet their exposure left them immobilized, painfully "on the edge", without ways to take action except by "choosing sides". In answer to the question "what should I do, given the new perspective I have learned?" they are unable to find a solution that represents a significant integration of their engineering education with a socially-oriented view. This suggests that freestanding courses, especially those taught by faculty without an engineering background, face steep challenges in trying to influence the work practices of engineering students.

The resolutions found by Troy, Lisa, and Paul represent an opportunity lost. In order to be able to act in the world, Troy and Lisa had to abandon, and Paul had to deny, the fundamental problem of *Other*: the deep challenge that the technology-based engineering view and the socially-oriented view represent to each other. They had come to know an alternative point of view about production, but rather than leading them to new and better informed action as engineers, their knowledge led them to immobility. Is there a better way? Can we, without doing violence to the important technical aspects of engineering, or to the genuine challenge that a socially-oriented perspective represents to the engineering *status quo*, teach students to integrate the two views in a productive way?*

Finding a way to help students integrate the technical and the social is important not only because the products and processes designed by engineers should be socially sensitive; it is also important because engineering practice itself has a very important social component. The popular press tends to portray engineering as a technical, science-based, often de-contextualized activity. Engineering textbooks create and perpetuate this view, as I discussed above. Studies of engineering practice reveal, however, that the world of working engineers is far different. Louis L. Bucciarelli discusses what he calls the "object world" of engineering practice, which most closely conforms to the popular stereotype, but he also asserts the existence of another, social world of discussion, negotiation, and cross-disciplinary collaboration in engineering design practice. Indeed, he even goes so far as to assert that engineering is fundamentally a social process.[10]** Michael Davis reports that decision making by consensus is the norm when engineers and managers find themselves at odds: typically disputes are resolved by discussion, negotiation, and by further information gathering, which may result in clarifying and redefining the initial problem statement.[11] In other words, engineers are often faced in practice with the need to reconcile two or more conflicting views of a situation. The ability to explore conflicting views, to gather new information, and to generate and evaluate solutions, selecting the better ones (or perhaps the less bad), is a critical professional skill.

"Ethics as Design"

How can we help students to integrate their technical capabilities with a socially sensitive perspective? One promising approach builds on what is already a growing trend in engineering education: teaching students the meta-skill ***design***. In learning how to design, students learn to reconcile or integrate conflicting disciplinary

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* I use the word "integrate" in this article, to indicate the goal of students and practitioners who want to do justice to apparently conflicting perspectives. It is possible that another term, or a metaphor, might better represent the relationship that the two views come to hold to each other after the engineer has engaged in the process I describe as "design". In "Blurring, Cracking, and Crossing: Permeation and the Fracturing of Discipline",[8] Klein uses an ecological metaphor to describe the relationship among disciplines. Thus, following Dogan and Parhe,[9] she refers to as "hybrid" what is commonly called "interdisciplinary." Klein's title offers yet another set of metaphors. Depending on what one's view of the character of relationship between disciplines is, "synthesis" may also be the right term.

** A briefer discussion of the two worlds of engineering work, which also examines the implications for engineering education, can be found in Bucciarelli and Kuhn.[3]

perspectives. While the focus is often on the integration of different engineering disciplines, it can be broadened to encompass social and political concerns as well.

Caroline Whitbeck leads us to this insight by drawing our attention to the shortcomings of forced-choice problems in the teaching of ethics. Ethical puzzles which require students to choose between two options, neither of which is really satisfactory, may develop students' intellectual agility and their ability to make certain kinds of judgments, but do little to teach them how to be active moral agents in a real world that rarely offers only two immutable courses of action. Whitbeck notes, following Hampshire, that in order to act in the world as a moral agent, one must not just "be able to evaluate well-defined actions, motives, etc., because actual moral problems are not multiple-choice problems. One must be able to *devise* possible courses of action as well as to evaluate them." (emphasis in the original.)[12] Noting that most of contemporary ethics has little to say about *devising*, Whitbeck looks for inspiration to engineering practice, to which the activity of design is central.

It is not a great leap to see the situation in which Troy and Lisa find themselves as analogous to that of students confronted with a forced-choice ethics problem. They experience the two views—the engineering view and a socially-oriented view—as both incompatible and immutable. Selecting one view at the expense of the other seems unacceptable, but they are unable to see another possible solution. Their education, which has exposed them to these two views, has not given them the tools they need to interrogate the views and to devise a course of action superior to either of the two choices initially presented to them. They see themselves as having only two options: on the one hand, to refuse to choose, and thus to remain painfully "on the edge", marginal in both worlds, or on the other hand, to choose one of the options, even though they know each to be flawed. In neither case do they learn to integrate the two perspectives and create a new approach which in some way addresses both.

The elements of good design practice include the ability to define, rather than accept as given, a problem. The designer clarifies and develops the problem definition by examining and interrogating its context, by investigating the context of use and the needs of users, and by being alert to and actively exploring ambiguities. Defining the problem is a crucial skill, and one which is left undeveloped when students confront multiple choice problems in engineering and ethics classes. Brainstorming and evaluating possible design responses (or courses of action) and being alert and responsive to the dynamism of design situations are also important elements of design practice. Whitbeck discusses these characteristics of engineering design and shows how useful they are to students (and practitioners) who must act as moral agents, not just as judges of problems whose definitions are fixed and given.*

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* Although I am focusing on addressing the challenges of *Other*, design as a meta tool is also useful for managing the challenges posed by *More*. Design skills can help students to define problems better even as their scope widens, and to mediate between competing demands. Without the perspective and overview that design skills can bring, even the multiplicity of heterogeneous considerations in a fairly conventional project can seem overwhelming; as we widen the scope of work, design skills become essential to effective engineering practice.

Beyond the Customer: The boundaries of design

Because defining the problem is central to the design process, one of the important skills that students studying engineering design must learn is to question and clarify the needs of the customer. What are the customer's real requirements? Does the customer really want what they think they want? Seeking this clarification is one of the most challenging aspects of design. But in order to consider the social impact of the product or process the engineer is designing, the designer must go beyond the customer's requirements. What is best for the customer—for example, when the customer is a manufacturer purchasing production machinery—is not necessarily best for the customer's employees. In agriculture, the shorthoe makes supervision easier but increases the work strain for farm workers. The customer—the grower—adopts this technology because it benefits him or her, and because the costs are not borne by the customer. In automobile production, the perceived advantages of computer integrated manufacturing outweigh the costs to the automaker—in lost production time, in disability claims, in workforce attrition.

Sometimes the interests of the customer are congruent with those of the workforce and the community, and an engineer who is sensitive to potential workplace and social impacts can create a design that will satisfy the customer and the community at the same time. In other cases, there is a conflict that the engineer cannot resolve within the existing economic and social context. Lisa, now working as an ergonomist who consults to manufacturers, tells a typical story from her consulting practice: she received a call from an industrial engineer who was trying to cost justify an expensive piece of manufacturing equipment that would dramatically reduce production workers' exposure to operations that tended to cause repetitive strain injuries (RSI's), and which had already caused at least one case of carpal tunnel syndrome. Without substantial data on such things as the cost of lost work time because of injury, he could not justify the equipment. This is typical, says Lisa, of the employers with whom she works: an injurious situation is not likely to be eliminated unless the monetary benefits outweigh the costs. To the extent that the negative costs are not borne by the employer, they are unlikely to be eliminated. Thus, for the engineer, taking social impact (social costs) into account may require going beyond what the customer wants—perhaps even doing something that is not directly in the customers' interest.

Conclusion

Although most engineering education today remains technology-based in its assumptions, educating engineers who are capable of integrating other, more socially-oriented, views is critical. One roadblock to the creation of socially sensitive systems is the inability of engineering students to integrate a socially-oriented perspective into their practice, even when they are exposed to it. The stories of Troy, Lisa, and Paul illustrate the cognitive and emotional conflict that students may experience when they grasp but are unable to integrate the technology-based and the socially-oriented perspectives.

To address this conflict, and to allow students better to integrate with other perspectives the technology-based knowledge they acquire, *design* is an effective meta tool. Engineering practice, particularly in the more socially-oriented world of engineering described by Bucciarelli, involves negotiating and problem definition across disciplinary and occupational perspectives. As Whitbeck shows us, a design stance encourages a student or practitioner to define (or redefine) the problem, and to propose and evaluate courses of action in a dynamic, context-sensitive way. Design is already a staple of engineering practice, and increasingly of engineering education. It can be in an educational context, as it is in practice, a vehicle for integrating technology-based material in an engineering curriculum with other, more socially-oriented perspectives. Because of its focus on defining the problem, a design approach is also a vehicle which can help an engineer to go beyond the problem definition developed with the client, to consider broader workplace and social impact as well.

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