10 Embedding the Humanities in Engineering: Art, Dialogue, and a Laboratory

Erik Fisher and Roop L. Mahajan

Introduction

In this chapter, we discuss the development and pursuit of two interdisciplinary trading zones in which the authors participated: (1) an initial year in which we developed the notion of "humanistic engineering" in the University of Colorado at Boulder's College of Engineering and Applied Science, and (2) a thirty-three-month period in which Fisher functioned as an "embedded humanist" in Mahajan's Thermal and Nanotechnology Laboratory. In both cases, we sought to integrate the divergent perspectives of engineering and the humanities in order to enhance the ability of engineers—in undergraduate, graduate, and ultimately professional contexts—to engage in productive, self-critical inquiry.

After describing areas of overlap between our various backgrounds and perspectives, we describe our collaborative undertakings, including the genesis and employment of several locutions and metaphors that framed and facilitated our efforts. We reflect on these collaborations in relation to a combined framework of trading zones and interactional expertise (Collins, Evans, and Gorman 2007). We outline the linguistic terms and metaphors we employed during our endeavors in order to reconstruct the coevolution of our thinking during the development and structuring of our interactions. Further, we consider the role played by cognitive activity in our account of these interdisciplinary collaborations. As will be evident, our collaborations were at times propelled by similar goals and assumptions, and at times hampered or shaped by differing ones. In addition, cognition appears to have played a role when the embedded humanist participated in a change in the direction of the laboratory research.

Part I: Humanistic Engineering in an Engineering College

An Engineering Art Gallery

From 1998 to 2003, as the humanities advisor of the College of Engineering and Applied Science, Fisher ran an array of interdisciplinary programs, both curricular and extracurricular, including curating a small art gallery. The 500-square-foot Connections Gallery was situated just inside the main entrance of the college, whose imposing brutalist architecture loomed on the east side of Boulder's otherwise Spanish-tile-and-flagstone-bedecked campus. With its mission to "connect art, engineering, and society," the gallery symbolized the notable interest of a handful of engineering administrators to open up the college and its curriculum to an infusion of humanistic ideas. Artistic installations, in the words of one associate dean, were intended to introduce engineering students to "a different way of thinking."

In 2002, Fisher and Mahajan, the newly appointed dean of the College of Engineering and Applied Science, met for the first time when they got together to discuss the gallery. Mahajan, then a professor of mechanical engineering and a former AT&T Bell Labs Fellow, had just accepted the appointment as interim dean. He was pleased to learn not only that the college was showcasing its newly constructed art gallery, but that someone without an engineering background was behind the endeavor. His assumption had been that the college's commitment to liberal and creative arts had been minimal and that the humanities advisor had not made any meaningful efforts to integrate the humanities and social sciences into the engineering curriculum. He was determined to establish a clear line of communication and to ensure that the image the gallery was projecting was in keeping with his intentions for the college as a whole.

After an initial and somewhat tense exchange, the two of us quickly overcame our various apprehensions. Our conversation turned more generally to the gallery's purpose and the role of the humanities in engineering education. We agreed that the humanities could serve as a means for self-development, for posing critical questions, and for broadening technical education in worthwhile ways. After our initial encounter, we began to explore these ideas in relation to the visual arts. The gallery hosted exhibitions in a variety of media that explored social, cultural, and conceptual dimensions of engineering.

One installation, sponsored by Ball Aerospace and entitled "Imaging the Invisible," began with the technological capability to render visual images of what is otherwise undetected by the human eye—for example, landscapes covered with dense jungle canopies, subterranean geological formations, stunning interstellar phenomena, and the activity of criminal underworlds and private life. The process of representing these previously imperceptible worlds to the probing eye was not, according to the exhibit, solely the product of satellite and aerospace engineering know-how. Rather, this process entailed other forms of invisibility: the role that visual artists, graphic designers, technical writers, and other actors play not only in supporting engineering work but in animating its outputs with focus, shape, and vigor. Nor were decisions to gather certain data or issues of its availability entirely separate from those who launched the mechanical birds. Exhibits such as this one were meant to reveal to the inhabitants of the college ways in which the aesthetic, societal, and ethical realms subtly and yet powerfully permeate and are permeated by the technical.

Our interactions around this and other gallery activities gave way in due time to new forums of exchange. We were soon engaged in conversations—with deans from other colleges, department chairs, and federal agency funding officers—about giving the arts, humanities, and social sciences broader roles within the college. These discussions were shaped in large part by Mahajan's vision for the college institution as a whole, in which he sought to establish a group of synergistic research and education initiatives—including microtechnology, nanotechnology, biotechnology, and earth systems engineering—and aimed to distinguish the college intellectually and culturally in order to continue to attract both talent and resources to the Rocky Mountain region.

Congruent Mental Models

Upon reflection, we had each separately hit upon the notion that interdisciplinary activities, both cognitive and social, could enhance practical scientific undertakings—whether by grasping and relating concepts or by creating new research pathways. This common perspective can be characterized as a shared mental model (Gorman 2005). In Mahajan's case, his vision for the college was informed by values rooted in his professional and personal experiences. At Bell Labs, he had developed the conviction that interdisciplinary interaction facilitated a "creative reprieve" in which the intermingling of ideas and perspectives provided relief from the tedium of technical details, a relief that in turn allowed insights for new endeavors to emerge. There, he had employed the phrase, "the buds bloom at the borders," to suggest that different outlooks, experiences, and even disciplinary training can give rise to worthwhile exchanges. Meanwhile, Fisher, whose experience at St. John's College had steeped him in original scientific and philosophical Western texts, had been experimenting with courses that conjoined such subjects as philosophy and mathematics, science and literature, and engineering design and writing composition. In the process he had discovered that open-ended and conceptual inquiry in technical settings, in addition to being a pleasurable end in itself, could lend value to engineering education in unanticipated ways. Classroom discussions took on new relevance for his students, some of whom regularly reported going about their engineering coursework more successfully as a result of grasping and comparing fundamental mathematical and philosophical concepts.

We also shared concerns about the unintended consequences, emergent effects, and increasing roles of technology in society. Mahajan had a keen sense that recent advances in technology had been buoyed and advanced by expectations and promises that were not readily forthcoming. Increased leisure time, for instance, had been one expectation behind the ever faster and cheaper computing machines made possible by the invention of the transistor; in reality, the trend toward higher productivity makes it hard to see how our technological advances liberate rather than enslave users. This observation had long ago sparked Mahajan's sense that engineers—like a collective magician's apprentice—had played a role in giving rise to "unfettered technology." Fisher's background in classical political philosophy in turn led him to question the prudent governance of modern knowledge production. He found discomfiting correlations between the lack of distinctions his engineering students made among the concepts of information, knowledge, and practical wisdom and the institutional arrangements for allocating knowledge resources and social responsibility.

In short, we each enjoyed cultivating the practical utility of higher pursuits such as learning, and yet cast a critical eye upon the unreflective employment of knowledge.

Humanistic Engineering

Over time, we envisioned a vibrant and successful engineering education program that combined solid scientific foundations, hands-on design and research experience, and lively humanistic inquiry—that was, at the same time, sensitive to the practical, unintended consequences of its exuberance. Our efforts were focused on the undergraduate curriculum, and we aimed to build upon existing programs that Fisher had created which emphasized the development of a self-critical capacity in relation to technical modes of thought. To fulfill our goal of "techno-humanistic" integration in the engineering curriculum, we sought to include liberal arts components in the technical curriculum and to make a more compelling case to students for their inclusion (Fisher and Mahajan 2003).

We used the term "humanistic engineering" to describe our new program and the skills and ideals that characterized it. Besides suggesting a critical and reflective quality that we believed engineers had to possess in order to better grasp the ethical, human, and social dimensions of their work, the phrase also implied a creativity and sharpness of mind that we felt would increase the practical value of their work in the process. We imagined future engineers who could draw from and supplement existing paradigms in engineering and the humanities to develop more context sensitive solutions; as we wrote: "Humanistic Engineers ... are able to initiate and engage in effective dialogue with non-technical audiences regarding socio-humanistic critiques of engineering processes and products and ... perform their own socio-humanistic critiques in the absence of such dialogue" (Fisher and Mahajan 2003). This statement tasks engineers and technical practitioners—and not only regulators, members of the public, and experts in fields other than engineering—with the job of initiating integrative efforts and of generating critical insights into their work. From our perspective, engineers would need to be able to think through and address the social and ethical dimensions of their work, regardless of whether others helped them in this task, so as to frame problems and generate solutions in new ways. It is not that we failed to see a role for civil society, professional groups, and other disciplinary practitioners; rather, we held that it often would not be feasible to bring together such actors with engineering researchers, designers, and decision makers at key times in order to produce more informed and efficacious critiques. For, while there are pressing reasons to focus on the broader social worlds, groups, and discourses that surround technology in society, our experience and professional commitments as engineering educators had led us to take a different tack: to address the intellectual activities that already animated the earliest institutionalized processes of technology in the making.

The term "humanistic engineering" was an attempt to fuse, on the one hand, the sense of critical insight and discovery that can proceed from the practice of open-ended inquiry associated with the humanities; and on the other, the employment of this in the service of engineering innovation that is optimally directed at socially relevant needs, but in a context-sensitive manner. Despite our shared terminology, our conceptions of the humanities and of engineering were not identical. We had different understandings of the nature of both fields, and thus envisioned directing their employment toward subtly different ends. Mahajan, who had studied philosophy as an undergraduate, placed tremendous value on the activities of humanistic reflection, and saw the place of the humanities in engineering—at least initially—as providing a creative stimulus for new ideas to emerge. Fisher, on the other hand, was committed to the view that humanistic inquiry, as an attempt to grasp wholes and reveal foundations, could actually lead more directly to fundamental insight and self-discovery.

Dialogues between Two Cultures

A central forum in which we and others explored the intellectual and cultural groundwork of humanistic engineering was Fisher's faculty seminar project, Dialogues between Two Cultures, supported by the National Endowment for the Humanities.[1] The yearlong seminar and lecture series brought together a core group of engineering, natural sciences, humanities, and social science faculty. The group met twice monthly to discuss core readings with invited interdisciplinary scholars. Monthly themes (and visitors) included art and technology (Natalie Jeremijenko), science and religion (Arthur Zajonc), and social networks and trading zones (Michael Gorman), among others. The project allowed participants to engage in regular, sustained, and focused conversations among people who held radically different disciplinary perspectives. Several participants went on to design and teach collaborative interdisciplinary courses or to pursue interdisciplinary research proposals.

One of the functions of the seminar series was to explore potential areas of convergence between the humanities and social sciences with their disciplinary counterparts, as well as clear divergences. In a seminar on the so-called "science wars," Mahajan articulated a role for the cognitive dimensions of science and engineering: "Among scientists and technologists or engineers, many of the discoveries and innovations are intuitive, and then we present evidence later on. ... That is a wonderful process. Now that intuitive thing is not so much evidence-based, it is not so much experiments-based." Not every seminar participant shared this view, and at least one felt it adhered to an outdated distinction in the philosophy of science between discovery and justification.[2] That said, Mahajan's emphasis on inductive insight over deductive ratiocination, on intuition as a creative principle, ostensibly opens the heart of scientific discovery and engineering design (and hence education) to a particular form of empirically based humanistic inquiry. His distinction—reminiscent of the "reprieve" that gives rise to creative activity—between "intuitive" content and "rational" structures was commensurate with Fisher's interest in cognitive and social processes—writing composition, product design, decision making—in which an indeterminate path is taken by actors through otherwise discrete steps, stages, or categories (Fisher and Benassi 2003). In short, we were each sensitive to the role of ideation in stimulating innovative pathways within formal structures, both conceptual and institutional.

The prospect of facilitating fruitful exchanges between the critical cultures of the social sciences and humanities and the productive cultures of science and engineering ran throughout the Dialogues project. In the same seminar session, possible connections between modes of thought and the larger workings of science can be seen in the following separate remarks, by Mark Winokur (Department of English):

At its best for me, interpretation creates—recreates—the student as a kind of paranoiac. Questioning everything about the world, not just literature, not just interpreting literature but, the hope is, beyond literature, the student will be asking questions about the way the world works including, hopefully, the way that science works, the way that every discipline works, the way in which one perceives the universe to work, and certainly one's own self.

And by Clayton Lewis (Department of Computer Engineering):

My sense is that the best scientists ... are the ones that are in fact skeptical of themselves, of what they do. Here again, I was most impressed by those articles [in Labinger and Collins 2001] in which there's a kind of assumption that really the greatest and most acute criticism comes from within the community, not from without.

Despite the different conceptions of skepticism and of the self that these two statements suggest, they both link the cognitive aspects of interpretation and criticism to a more robust understanding of the "working" and "doing" of science. Lewis's emphasis on scientific self-criticism suggests a form of scientific autonomy that would include an ability to take into account and productively benefit from internally generated critiques. Winokur, on the other hand, emphasizes a form of training in mental habits—in this case that of literary interpretation—that suggests a skill consonant with Lewis's picture, but nonetheless originating from outside of scientific practice per se. These two conceptions, of critical capacity that rests within versus outside of science and engineering, emerged in different guises throughout the Dialogues series. We return to these ideas below, where we reflect on the notion of humanistic engineering and explore different forms of interdisciplinary trading zones.

Conversations such as the two-hour Dialogues seminars, partly nested within the larger institutional context of an engineering college, foreshadowed our further collaborations. As a humanist formally embedded within an engineering college, Fisher had created a space for sustained social and intellectual interactions among various disciplinary cultures—a workshop of sorts, which constituted a type of laboratory of its own. Soon, Fisher's interest in interdisciplinary inquiry conducted in small groups and Mahajan's interest in institutional transformation came to provide additional opportunities for our collaborative interactions that would eventually find their way into an engineering research laboratory. For the next phase of our undertaking was an attempt to bring humanistic engineering to the level of graduate engineering education and research.

Part II: An Embedded Humanist in an Engineering Laboratory

An Embedded Humanist

In September 2003, Fisher accepted the invitation to formally join Mahajan's Thermal and Nanotechnology Laboratory in the Department of Mechanical Engineering. Shortly thereafter, he began referring to himself as an "embedded humanist." He coined the term in a somewhat lighthearted attempt to explain to his colleagues what a scholar like him was doing in a laboratory. Mahajan soon also began using the term to explain his objectives in reconfiguring his lab to other laboratory directors, some of whom resisted the term because they associated it with "embedded journalist." However, unlike an embedded journalist, who reports to an audience outside the environment that he or she has joined, Fisher's audience was inside the environment he had entered. During the thirty-three-month experience, Fisher interacted with numerous researchers and laboratory personnel, followed a variety of laboratory projects, and conducted several studies. As a member of the research group, he had desk space; attended weekly meetings; participated in equipment training sessions, events, and professional conferences; and interacted informally with the researchers through his regular presence in the lab, its offices, and its connected Nanoscale Fabrication and Characterization Laboratory. As a working member of the laboratory, he also made regular presentations to the rest of the group on his research progress. Over time, Fisher gained a wealth of interactional abilities, which formed some of the basis for what later became tangible contributions to laboratory research practices.

Integration Policy

In December of 2003, just a few months after Fisher joined Mahajan's laboratory, the Twenty-first Century Nanotechnology Research and Development Act of 2003 (NRDA), which required "societal concerns ... [to be] considered during the development of nanotechnology" by "insofar as possible, integrating research on societal, ethical, and environmental concerns with nanotechnology research and development," became public law (U.S. Congress 2003). The legislation placed repeated emphasis on interdisciplinarity and administrative coordination, two aspects that can logically be applied to the sociotechnical integration it called for (Fisher and Mahajan 2006a). The act was also largely unprecedented and went beyond traditional policy models (Bennett and Sarewitz 2006; Fisher and Mahajan 2006a; Macnaghten, Kearnes, and Wynne 2005). Policies that bring societal considerations to bear on technological trajectories tend to occur on one side (*upstream*) of research and development activities, in the form of research policies, or on the other (*downstream*), in the form of regulations.

One of the things that made the NRDA unique as a science policy prescription was its inclusion of *midstream* research and development activities as a legitimate site for interdisciplinary interaction aimed at the responsible development of science and technology (Barben et al. 2008; Fisher, Mahajan, and Mitcham 2006).

Given the work on nanotechnology that had recently begun in Mahajan's lab, and our interest in ultimately developing humanistic engineering within a context of engineering practice, we chose to frame our lab-based collaborations in terms of this larger policy development. For Mahajan, the NRDA validated the need to lay the foundations for a graduate engineering program in humanistic engineering; for Fisher, it was an opportunity to conduct empirical studies into central intellectual and policy challenges facing modern industrial societies—such as the negotiation of human values and material practices—in the unique setting of laboratory knowledge production.

Sociotechnical Integration

The terms "sociotechnical integration" and "integration of science and society" served us sometimes as a means and sometimes as an end. While we both had been using the term "integration" for several years (e.g., Neeley et al. 2002), although in differing contexts and meanings, the word gained prominence after it appeared in the NRDA. The NRDA coincided with our shift from using the concept of "techno-humanistic integration," which was closely linked to our interest in the cognitive aspects of interdisciplinarity discussed above, to using "sociotechnical integration" (Fisher and Mahajan 2006a), which was oriented toward broader social goals and institutional contexts and thus took sociological findings (e.g., Bijker 1995) more explicitly into account.

Notably, the legislation's language called for integrating research, not necessarily researchers. Certainly, there is a place for researchers to perform this work and hence for interdisciplinary interactions to embody much of the integration. Our interest, if not the goal of the NRDA, in exploring the integration of disciplinary approaches in the laboratory was less for the sake of finding new social arrangements in themselves, however, than for understanding and pioneering new knowledge generation techniques, safeguards, and outcomes. New forms of social epistemology, and not merely enlightened engineers, may indeed be necessary to bring these about—but we were interested in how much could be asked of engineers in the absence of such new social arrangements.

Seamless Integration

In 1989, Mahajan had received a Bell Labs Fellow Award in recognition of his work on the seamless integration of fundamental and applied research. Accordingly, we attempted to build on our interdisciplinary perspectives as well as the confluence of theory and practice in order to get as close as possible to new forms of knowledge production. The term "seamless integration of science and society" came to symbolize our attempts to build upon past research accomplishments and to probe the limits of a new practice that might hold similar utility. "Seamless integration" implied that the elements to be integrated were not treated separately but were coupled frequently and at key junctures, so that the elements influenced one another and so that the coupling occurred at every stage of an engineering project. Seamless integration also served as a baseline posited to assess how far we could actually come and to assist similar attempts in the future.

We eventually abandoned the idea of seamlessly integrating sociohumanistic and technical considerations at every conceivable stage of an engineering research project. The decision was due in part to time constraints and in part to a study by Fisher that revealed differing stages of laboratory research projects—which implied differing possibilities for and constraints upon integration. The shift also occurred in conjunction with a more explicit focus on processes. As we wrote,

> Ideally, seamless integration would introduce broader considerations at every stage of a research project and make more explicit the extent to which such considerations are already implicitly present. It would require a tendency to remain open to questions and concerns and a willingness to revisit them at later stages. Due to practical constraints of engineering research, however, integration will usually be limited to opportunities for subtle modulation of ongoing processes. (Fisher and Mahajan 2006b)

Seamless integration thus set the stage for the more modest but demonstrably potent approach of midstream modulation.

Midstream Modulation

Mahajan desired a replicable methodology and encouraged Fisher to develop a "protocol." Although sympathetic, Fisher had reservations about the limitations of an overly reductive and deterministic approach. After initial attempts to formulate the basis for a prescriptive process, his doubts were soon intensified by the resistance of several laboratory colleagues. When he modified his initial efforts, it became clear that we did not have the same understanding of the implementation tool for sociotechnical integration. This can be indicated by our different understandings of the term "protocol": while Mahajan's reference point was from medical research, and involved a normative flow chart to address ethical harms and risks, Fisher preferred to associate the term with an interview schedule such as that used in sociological and ethnographic research. The differences in our conceptions were not clear at first, which caused confusion. When they did become clear, Mahajan's desire for an instrument that would facilitate normative prescription contrasted with Fisher's desire for a richly descriptive basis for integrative laboratory research practice that was in accordance with his ethnomethodological observations. For instance, Fisher had come to appreciate that the integration of societal and technical considerations was in fact already occurring, and that the problem to be worked on was that researchers were largely unaware of their own role in such de facto integration.

It is worth noting that our collaboration could have taken any of a number of different forms at this point. In short, we were encountering the problem of incommensurability. Despite a number of overlapping values and synergistic ideas, we had different expectations and assumptions about the nature and role of ethical questions in lab research and about what kind of social and cognitive actions would constitute a productive response to these questions. The differences were no doubt due in some part to the different research paradigms we employed and had observed others employ. Fortunately, we were able to find a way to sidestep, if not surmount, this initial incommensurability.

As a result of our diverging expectations, and still keeping in mind the NRDA language, Fisher developed a framework for midstream modulation that would satisfy our competing goals. It consisted of a three-stage dialectical process that modeled sociotechnical integration and change. The process factored in both descriptions of existing material practices (*de facto* modulation) and an awareness of them (*reflexive* modulation) as a cognitive precondition for acting upon normative prescriptions (*deliberate* modulation). Using this framework and Fisher's observations of laboratory decision making, the laboratory researchers held group and individual meetings to further develop a descriptive model that could apply generically to any laboratory research decision. The research group thus negotiated in various iterations with Fisher to develop the instrument that was meant to capture opportunities for integration and modulation. The output of this process has elsewhere been termed an "ethnographic invention" (Fisher 2007). Here, we note that the negotiations that gave rise to it are reminiscent of those in trading zones designed to either work around or overcome paradigmatic differences. The new protocol thus converted what was a top-down directive into a bottom-up cultural artifact that served as the basis for a new interview schedule. Moreover, the new interview process itself could now take into account—if not facilitate—intentionality and normative goals.

In the spring of 2006, toward the end of the thirty-three-month laboratory experience, Fisher conducted a twelve-week field study in which he interacted with graduate researchers to assess the feasibility of sociotechnical integration in a laboratory context. The results suggested that midstream modulation activities were able to enhance if not stimulate graduate engineering researchers' awareness of cognitive, social, and material research-conditioning factors (Fisher and Mahajan 2006b). Moreover, in a few cases, where there had been a high level of interdisciplinary engagement, this awareness correlated to specific and concrete changes in research decisions, thus influencing the direction of engineering research (ibid.). As stated elsewhere, "While the protocol rendered elements of [one engineering researcher's] decision making more visible to [the embedded humanist], it also made them more visible to [the engineer, who demonstrated a] reflexive capacity to identify and align 'social' considerations with 'technical' alternatives in order to solve a complex problem" (Fisher 2007). Moreover, the research practices themselves underwent several changes that were correlated to the engagement, and specifically to social and environmental concerns that were articulated during the interactions. These changes in research practice—which included altering the disposal method and chemical synthesis techniques for carbon nanotubes—were considerably more benign in terms of their environmental and human health dimensions.

Meanwhile, the midstream modulation experiment did not disrupt laboratory conduct or compromise its outputs. If anything, it aided the research—as illustrated, for example, by one researcher who noted on several occasions that discussing his research with Fisher helped to clarify his own thinking about his work. As a proof of concept, then, the collaborative engagement indicated that the goals of humanistic engineering are reasonable and worthwhile. Not only are such interactive methods consonant with academic engineering research practices, it appears that they could be applied to other engineering activities, such as design, and to other forms of lab-based science. The techniques and concepts used in the experiment, which were primarily aimed at asking questions, thus had dual value both for enhancing the creativity and productivity of research and in integrating social and ethical considerations into the research.[3]

Part III: Reflections on Trading Zones and Interactional Expertise

Collins, Evans, and Gorman (2007) produced a framework to relate different types of trading zones (Galison 1997) and to chart their evolution, and which incorporates Collins and Evans's (2002) notion of interactional expertise. The framework's calculus of characterizing a trading zone by means of its end state can be instructively applied to the above two-part account in several respects.

Degree of Integration in Trading Zones

The fourfold characterization of trading zones derives from a two-by-two matrix that identifies zones in terms of their placement along two axes: one axis represents the degree of coercion or collaboration involved in the interaction; the other, the degree of heterogeneity or homogeneity of the end state of collaboration (see figure 2.2). If we consider this latter axis, we find there are indeed differing degrees of homogeneity and heterogeneity in our conceptions of humanistic engineering and in our attempts to enact it—particularly in the case of embedding a humanist in an engineering laboratory.

Applied to our ideas about and work on humanistic engineering, this model suggests that we actually envisioned a pair of sequential trading zones: while the first one comprises the educational environment and training ground for humanistic engineering, the second one denotes its practice. Humanistic engineering education is made up of an interdisciplinary combination of pedagogical goals and approaches, and consists of a relatively heterogeneous state in which the disciplinary cultures involved have a high degree of collaboration and yet remain distinct and distinguishable. This stage of interdisciplinary collaboration, which Collins, Evans, and Gorman term a "fractionated trading zone," can be likened to both the provocative situating of an art gallery within an engineering college and the educational goal of producing humanistic engineers.

In Mark Winokur's example during the Dialogues project of a highly skeptical and inquisitive literary critic who is able to turn her attention to the workings of science qua science (as opposed to science qua literature), the requisite skill set and training in literary criticism would most likely occur in a classroom environment in which the disciplinary profile of English, comparative literature, classics, etc., is highly visible—even if it has integrated elements of, say, civil or mechanical engineering. The same would be true for most analytical mathematic and scientific skills—even if they included elements of philosophy, sociology, psychology, and political science. One imagines that linguistic innovations would indeed occur as the pedagogy of this envisioned program developed and matured, but the traditional quantitative and qualitative reasoning skills associated with engineering and the humanities, respectively, would likely remain as distinctly characteristic as the separation between the quadrivium and the trivium in long-standing conceptions of the liberal arts—as would the identity of their primary classroom instructors and other facilitators, as a designation like "humanities advisor" suggests.

Humanistic engineering practice, on the other hand, consists of a synthesis of culturally segregated skills, competencies, and habits of thought that, while they can be decomposed into humanistic and engineering approaches, have become largely indistinguishable from one another. This "interlanguage trading zone" represents a homogeneous end state that is in keeping with Clayton Lewis's notion of criticism emerging from "within the [scientific] community." It is also clear in the description of humanistic engineers who are able to "perform their own socio-humanistic critiques" (Fisher and Mahajan 2003) in the absence of dialogical relations with practitioners or decision makers in fields other than engineering or with lay citizens. While an interdisciplinary basis would in theory allow the humanistic engineer to tap different disciplinary techniques and modes of thought, the modes of thought themselves are sewn up in the identity and mental habits of the practitioner.

We also note that during our first year of collaboration our own interactions revolved largely around shared terms and ideas, several of which we had generated relatively early on. We became conversant in each other's languages and cultural contexts and began to develop our own shared terms or "jargon." We also tried to downplay and, in some cases, to transcend disciplinary and cultural distinctions, which nevertheless are evident in hindsight.

The phrase "humanistic engineering," for instance, symbolized both the creativity that Mahajan was interested in and the self-critical inquiry Fisher was focused on. Because our interests overlapped in this way, we were friendly to reflection and to the time it takes to engage in it—a crucial factor that helped protect our unorthodox collaborations from mainstream skeptical reactions. In particular, the phrase served to establish an interactive niche between Mahajan, who tended to emphasize the human and cultural development of the engineer, and Fisher, who was more animated by philosophical questions and the political implications of sociomaterial productions. While the word "engineering" in this phrase served to identify the shared topical site of action and observation, the word "humanistic" afforded a fruitful ambiguity, in that it at once signified two anticipated outcomes of reflective inquiry by technological actors: the informed development of the self, and the construction of the sociotechnical world tempered by humility (cf. Jasanoff 2007). At any rate, the phrase exemplifies the notion of a fractionated trading zone in which language allows productive interchange even when the meaning of terms can be multiple.

Evolution of Trading Zones

The heterogeneity of a trading zone, which can in our case be thought of in terms of external versus internal critique, not only represents two different forms of interdisciplinarity but describes a general process of evolution—for instance, from education and training to practice. In our case, however, as our collaboration coalesced around a specific challenge and our attempts to implement humanistic engineering moved from undergraduate to graduate engineering education, our conceptions of what we were doing appear to have taken heterogeneity more into account as time went on—even as we sought to blur disciplinary distinctions.

While the humanistic engineer embodies a state of disciplinary homogeneity, the embedded humanist calls attention to heterogeneity. Arguably, the notion of embeddedness contains the notion of an "other," regardless of how successfully the other has been incorporated within a new culture; for it remains nonnative, a transfer, a foreigner. Thus, as we sought to implement our program of humanistic engineering within the context of laboratory practice, we moved from the guiding motif of a highly integrated form of interdisciplinarity to the more heterogeneous state of an outsider within the highly bounded space of an academic laboratory. The shift to a more pronounced fractionated trading zone was perhaps in part due to the different contextual demands and the shift from program development to research formulation and conduct.

We have noted the association of our concept to the embedded journalists deployed by the U.S. armed forces during the 2003 invasion of Iraq. As we suggested earlier, there are key differences: embedded journalists are intended to relay information to those outside of a unit, without affecting its internal operations; an embedded humanist, on the other hand, seeks to learn *through intervening* to what extent the internal routines of the laboratory may undergo and tolerate change as a result of self-critical activities. The term "embedded humanist" was also meant to stress the novelty of the enterprise in light of more traditional participant observation: ours was an attempt to interact and collaborate in order to issue policy recommendations on engineering education that were inspired from outside of engineering education and yet that would be grounded in firsthand experience with it. Unlike the self-sufficient and enlightened engineer that we had formerly conjured up, the work of the embedded humanist requires a synergistic dependence of dissimilar practitioners on one another. In that this work involves sustained engagement of laboratory practitioners, the embedded humanist is in a position to become part of the convergence of goals, strategies, and sociomaterial configurations. Yet, despite the fusing of practice and the intermingling of knowledge, the collaboration retained its interdisciplinary heterogeneity and the volitional autonomy of its members. We find little evidence of cooptation of either the embedded humanist's research or that of the laboratory practitioners, and we note that some of the key decisions made by both sides of the various collaborative partnerships were independent of the understanding and expectation of the other.

The shift from disciplinary integration to differentiation can also be seen in our own roles. As the embedded humanist forged greater relationships with those who occupied the laboratory on a daily and hourly basis, he identified more closely than before with their bench science and came to better understand their perspective of working under the institutional figure of the laboratory director.

From Coercion to Collaboration

The evolution of our collaborations in this first year went from a somewhat enforced meeting in which we embodied distinct formal and institutional roles, to a collaborative set of ideas and activities in which we generated, responded to, and attempted to align broader visions and strategies, existing opportunities and resources, and local means and venues—a highly collaborative trading zone in which we merged language, practice and to some extent identity. While the institutional structures that defined our roles initially exerted a coercive influence, our interest in redefining these structures and our ability to do so helped us open up additional possibilities for others to then engage in unconventional interactions that were nested within the broader and changing institutional structure of the College of Engineering and Applied Science.

The development of a protocol for midstream modulation was also born of coercion, albeit of a more gentle kind. Mahajan's interest in a protocol that would extend the notion of seamless integration from that of basic-applied to that of sociotechnical integration was modeled on medical research protocols in which primarily expert-determined and quantifiable risks were at play. But in the case of emerging technologies such as nanotechnology—and the early stages of innovation in general—where risks are more obviously characterized by high degrees of uncertainty, ambivalence, and potential contestation, Fisher resisted bounding research practices by clear markers and prescriptive norms. And yet we were both normatively inspired to introduce broader reflection into these practices. The close and ongoing observation of laboratory decisions that the midstream modulation decision protocol allowed, coupled with the more modest interventionist notion that comes with the notion of modulation (Rip 1998), enabled us to bring about not only a process but productive outcomes that satisfied both Fisher's critical and Mahajan's pragmatic objectives. Without Mahajan's insistence on the normative applicability of the protocol, and Fisher's insistence on its empirical validity and sensitivity to context—including the laboratory researchers' acceptance of our ideas—we might not have come up with an instrument with potential value from multiple perspectives.

Cultural Subversion?

It is valid to ask whether cultural subversion, in which "one party's language overwhelms that of the other" (Collins, Evans, and Gorman 2007), occurred in the experience of the embedded humanist. Although we find limited evidence of an enforced trading zone, it might appear that the embedded humanist lost his identity in the technical language, institutional arrangements, or material practices of the laboratory (not to mention the steady uptake of the social sciences into the mix). Two observations caution against overly hasty conclusions that such forms of cultural subversion did occur here, however. First, the negotiated decision protocol served as a template that framed many of the collaborative interactions, especially when they became so intensive as to require constant study and attention to scientific and technical details. This conversational and analytical frame thus provided the embedded humanist with a method for maintaining if not retrieving an observational distance and analytical standpoint. Second, the role of the humanist was essentially to practice humanistic inquiry—something no one in the laboratory did in a structured or ongoing way—which resembles the kind of attitude and attention one might adopt in the case of textual analysis. In other words, the laboratory became a topical site for humanistic inquiry.

Ironically, Fisher had to repeatedly resist various efforts to cast him as the humanist spokesperson for "ethics" or to be the moral "conscience" of the group. Despite encouragements for him to identify ethical concerns and to advocate ways to address them, Fisher sought to tactically avoid taking outright prescriptive stances. Instead, although he did not in most cases promote specific ethical or societal concerns—or specific technical or scientific responses—he sought to enhance if not stimulate reflexive awareness. Also ironically, Fisher made no conscious attempt to alter research practices—which in itself may have been what allowed for practices to in fact change.

The Role of the Embedded Humanist

In the final phase of the embedded humanist's experience in the laboratory, what began as observation of engineering research and researchers in the making shifted to participation, and finally to collaboration. Fisher had to acquire what Collins and Evans (2002) call interactional expertise if he was to understand and critically inquire into the work that went on in the laboratory. He had to learn the language of Mahajan's research and the specific projects of a number of researchers he interviewed and interacted with intensively. In fact, he managed to develop sufficient interactional expertise to be mistaken for an engineer in a number of venues—including by a project manager at a prominent national laboratory. Moreover, as time progressed, the engineering researchers learned and adapted some of the language he employed. And yet his interactions with the researchers were not limited to discursive ones: as a result of these interactions, engineering research material practices underwent significant changes, suggesting that Fisher had achieved a measure of contributory expertise.

Although the embedded humanist had a role in stimulating these changes in research practice—changes that seem consonant with both Mahajan's and Fisher's shared perspectives on the practical value of cognitive activity—Fisher did not dictate the goals of the deliberate modulations, nor did he lobby for the alternatives that would lead to their pursuit. By asking questions and "holding out" in them (Heidegger 1977), his role was to maintain cognitive tension and social space for negotiations to emerge that otherwise might never have been opened up and amplified. Fisher contributed to the project, then, in an indirect way, rather than through suggesting new ideas or mediating the suggestions of others. Rather, he contributed through attempting to understand and articulate key social, material, and cognitive elements at work in the system within which he was embedded. This is perhaps similar to the interpretive work that Winokur described during the Dialogues project, in which questions are posed and the tensions they evoke are kept alive in an attempt to conceptually grasp a broader whole (in his provocative term, through paranoia). This activity thus added value to the engineering research both by promoting the advance of the research as such and by modestly controlling the undesirable effects of the research. As an interactional expert, the embedded humanist had the role of constructing fractionated trading zones.

A Suspended Trading Zone

One of the four types of trading zone that Collins, Evans, and Gorman identify is characterized by high degrees of both collaboration and heterogeneity. They call this a "fractionated trading zone" and identify two forms: "boundary object trading zones, which are mediated by material culture largely in the absence of linguistic interchange, and interactional expertise trading zones, which are mediated by language largely in the absence of the material."

An implication of their framework is that, if the trading zone is characterized by both linguistic interchange and material practices, it is likely that the zone has developed into an interlanguage trading zone, one with high degrees of collaboration and homogeneity. Yet there is also another possibility: a trading zone with high degrees of collaboration and heterogeneity might continue to exist in that state without producing a new culture, language, or science. We suggest that the lab-based interactions of the embedded humanist unified an otherwise fractionated trading zone through the shared jargon of the modulation protocol, the altered research decisions, and the subsequent material configurations that developed. The embedded humanist thus became part of the convergence of rituals, values, strategies, and material practices, but retained important elements of heterogeneity. In occupying both sides of the fractionated trading zone, then, which did not collapse into a homogeneous state, a new type of collaboration can be identified. We describe this as a "suspended trading zone."

Cognitive Dimensions of Interdisciplinarity

The cognitive dimensions of interdisciplinary collaborations may be a worthwhile element for understanding and characterizing suspended trading zones. In our case, discovering shared mental models that linked reflection, innovation, and social responsibility early in our collaboration and continuing to develop them over time provided a strong basis for our interactions. This connection made it possible for us to envision an intimate role for the humanities in both engineering education and in engineering practice. Moreover, it likely played a role in the embedded humanist's involvement in laboratory research, which resulted in equipment redesign, a new disposal method, and a new experimental technique. We attribute such altered research decisions to the enhanced reflexive awareness of the engineering researcher, which we see as a result of the midstream modulation activities. In short, the embedded humanist was able to facilitate responsible development through simultaneous reflection on ethical values and on alternative material pathways, precisely because he did not advocate for either one. The change in engineering research, he explains,

> was instrumentally triggered not by the interjection of mandates or prescriptions, but by [the engineer's] own cognitive work of reflection, association, and invention. Rather than introduce social or ethical considerations, the protocol instead allowed [the engineer's] latent concerns to surface. As an intervention, this engagement of research capacity was productive because of the work of the subject—the engagement may have influenced practice, but to do so it required the practitioner's desire to remedy a perceived deficiency. [The engineer's] recognition was, in turn, enabled by [the humanist's] ongoing attentiveness to his unfolding account of social processes and material properties. (Fisher 2007)

The embedded humanist's work thus consisted of observation, reflecting observations back into the research context, and sparking inquiry about potential value-material relations that emerged as a result. The central role of cognition in this interdisciplinary collaboration may help explain how both sides of the suspended trading zone were able to function without producing a new homogeneous state.

Arguably, there was some form of a shared mental model between the humanist and the engineers in this case, in that they both employed the same analytical decision categories during their conversations and, it appears, in their cogitations. There was also something of a shared goal of research, at least at certain moments, when both humanist and engineer seemed focused on the question of to what extent sociotechnical integration was possible. Beyond this, it is difficult to specify whether there was much, if any, shared cognitive content. The surfactant that maintained the collaborative enterprise was, in our view, rooted in a learning process—that of semistructured, ongoing, shared reflection and inquiry into evolving human practices (Rabinow and Bennett 2009).

Conclusion

This chapter describes our attempts to embed the humanities into engineering in two main venues: the physical, institutional, and intellectual spaces of an engineering college and of an engineering research laboratory. We used the combined metaphors of trading zones and interactional expertise to analyze these attempts. Our analysis highlights a tension between two types of trading zone implicit in our conception of humanistic engineering: a relatively homogeneous state of interdisciplinarity that we initially desired and that Collins, Evans, and Gorman term an "interlanguage trading zone," and a relatively heterogeneous state of interdisciplinarity that we came to rely on and that they call a "fractionated trading zone." This tension shows up both in the case of humanistic engineering and in that of the embedded humanist. The analysis also suggests that creative forms of collaboration can emerge out of initially coercive conditions. Finally, we argue that there are other, nonlinguistic aspects to the interdisciplinary collaborations we were involved in that are also not fully attributable to material boundary objects. We suggest that cognitive dimensions may be an underutilized factor in theorizing interdisciplinary collaborations, and that they may be useful in accounting for what we term the "suspended" trading zone.

Notes

This material is based upon work supported by the National Science Foundation under Grants No. 0531194 and 0849101 and the National Endowment for the Humanities under Award No. ED-22408-02. The views, findings, conclusions, or recommendations expressed in this chapter do not necessarily reflect those of the NSF or the NEH.

1. The project is documented at http://www.colorado.edu/engineering/dialogues/.

2. Alan Franklin (Department of Physics), for instance, responded: "I think this is a very old-fashioned view in philosophy of science, namely the context of discovery and justification. In the old days the context of discovery was regarded as the subject for psychology. ... For example, take the old myth—it doesn't really matter where Kekule got his idea for the benzene ring because he dreamed about snakes swallowing their tails. God knows what a Freudian would do with that, but what matters is what evidence was then provided to argue that benzene had a ring structure."

3. The experiment came to serve as pilot study for the Socio-Technical Integration Research (STIR) project, which embeds social and human scientists in twenty laboratories of numerous kinds in ten countries on three continents (http://cns.asu.edu/stir/).

References

Barben, Daniel, Erik Fisher, Cynthia Selin, and David H. Guston. 2008. Anticipatory Governance of Nanotechnology: Foresight, Engagement, and Integration. In *The Handbook of Science and Technology Studies*, 3rd ed., ed. Edward J. Hackett, Olga Amsterdamska, Michael Lynch, and Judy Wajcman, 979–1000. Cambridge, MA: MIT Press.

Bennett, I., and D. Sarewitz. 2006. Too Little, Too Late? Research Policies on the Societal Implications of Nanotechnology in the United States. *Science as Culture* 15 (4):309–325.

Bijker, W. E. 1995. *Of Bicycles, Bakelites, and Bulbs: Toward a Theory of Sociotechnical Change.* Cambridge, MA: MIT Press.

Collins, H., and R. Evans. 2002. The Third Wave of Science Studies: Studies of Expertise and Experience. *Social Studies of Science* 32 (2):235–296.

Collins, H., R. Evans, and M. Gorman. 2007. Trading Zones and Interactional Expertise. *Studies in History and Philosophy of Science* 39 (1):657–666.

Fisher, E. 2007. Ethnographic Invention: Probing the Capacity of Laboratory Decisions. *NanoEthics* 1 (2):155–165.

Fisher, E., and M. Benassi. 2003. Writing as Design: Integrating Composition and Product Design in the Undergraduate Engineering Curriculum. American Society of Engineering Education Annual Conference Proceedings, Nashville, Tennessee.

Fisher, E., and R. L. Mahajan. 2003. Humanistic Enhancement of Engineering: Liberalizing the Technical Curriculum. International Conference on Engineering Education Proceedings, Valencia, Spain.

Fisher, E., and R. L. Mahajan. 2006a. Contradictory Intent? U.S. Federal Legislation on Integrating Societal Concerns into Nanotechnology Research and Development. *Science and Public Policy* 33 (1):5–16.

Fisher, E., and R. L. Mahajan. 2006b. Midstream Modulation of Nanotechnology Research in an Academic Laboratory. Proceedings of International Mechanical Engineering Congress and Exposition 2006, Chicago, Paper no. IMECE2006-14790, 189–195.

Fisher, E., R. L. Mahajan, and C. Mitcham. 2006. Midstream Modulation of Technology: Governance from Within. *Bulletin of Science, Technology and Society* 26 (6):485–496.

Galison, P. 1997. *Image and Logic: A Material Culture of Microphysics*. Chicago: University of Chicago Press.

Gorman, M. E. 2005. Levels of Expertise and Trading Zones: Combining Cognitive and Social Approaches to Technology Studies. In *Scientific and Technological Thinking*, ed. M. E. Gorman et al., 287–302. Mahwah, NJ: Lawrence Erlbaum Associates.

Heidegger, M. 1977. Modern Science, Metaphysics, and Mathematics. In Heidegger, *Basic Writings*, 267–305. New York: Harper and Row.

Jasanoff, S. 2007. Technologies of Humility. *Nature* 450:33.

Labinger, Jay A., and Harry Collins, eds. 2001. *The One Culture? A Conversation about Science.* Chicago: University of Chicago Press.

Macnaghten, P., M. Kearnes, and B. Wynne. 2005. Nanotechnology, Governance, and Public Deliberation: What Role for the Social Sciences? *Science Communication* 27 (2):1–24.

Neeley, K., E. Fisher, E. Maslen, M. Piket-May, J. Prados, M. Cherno, J. K. Brown, M. Schoultz, and R. Spizer. 2002. Integration as a Means to Excellence in Engineering Education and Practice. Conference Reports, Liberal Studies and the Integrated Engineering Education of ABET 2000, Charlottesville, Virginia.

Rabinow, P., and G. Bennett. 2009. Human Practices: Interfacing Three Modes of Collaboration. In *The Ethics of Protocells: Moral and Social Implications of Creating Life in the Laboratory*, ed. M. A. Bedau and E. C. Parke, 263–290. Cambridge, MA: MIT Press.

Rip, A. 1998. The Dancer and the Dance: Steering in/of Science and Technology. In *Steering and Effectiveness in a Developing Knowledge Society*, ed. A. Rip. Utrecht: Uitgeverij Lemma BV, 27–50.

U.S. Congress. 2003. Twenty-first Century Nanotechnology Research and Development Act of 2003, Pub. L. 108-153, § 2, Dec. 3, 2003, 117 Stat. 1923.