Engineering Cultures: Better Problem Solving through Human and Global Perspectives?

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Abstract

The purpose of this paper is both to call attention to the need for a new focus on problem definition in engineering education and to outline one curricular approach to helping students learn to define and solve problems in the context of competing perspectives. The main goal in this approach, which draws its conceptual insights from the interdisciplinary field of Science and Technology Studies (STS), is to enable students to understand and reflect on their own problem-solving activities as perspectives that both could have been otherwise and must live amidst other perspectives. The principal means is to help students learn about engineering in different times and places sufficiently that they can recognize, understand, respect, and possibly even value perspectives other than their own. For students trained to understand problems as given and answers as either right or wrong, putting in historical and global perspective what they value in themselves is no easy task.

I. Introduction

Do engineering curricula adequately prepare graduates to work with people who define problems differently than they do? As undergraduates, engineering students learn to focus their attention wholly on the internal structure of problem solving. They are trained to value the repeated application of a stabilized method. The only thing that should vary from course to course and major to major is the type of problem and the appropriate mathematical tools for solving it.

Yet life on the job requires something that the mastery of mathematical problem solving does not provide, an ability to interact with and engage positively perspectives other than one's own. By focusing on discipline-based problem solving, for example, does a mechanical engineering curriculum prepare students adequately to interact with other types of engineers who define their problems differently? By defining problems in mathematical terms and problem solving as the appropriate application of equations, do engineering curricula prepare students adequately to work with people trained to understand their work in other ways? By celebrating the one skill of math-based problem solving, do engineering curricula in the United States adequately prepare students to work with engineers trained in distinct national traditions? How might engineering students be trained better to work in environments where the need for negotiation and compromise in the definition of problems is more the rule than the exception?

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II. Globalization as a problem for engineering education

Concerns about the relative inflexibility and low cross-cultural competency of engineering students have gained prominence among reformers in academia, industry, and government since the end of the Cold War. International organizations, national security think tanks, and academic and industry leaders argue that the global economy brings about the globalization of technological work, which in turn requires new ways to educate and train the future U.S. engineering workforce (United Nations 1990; RAND 1994; O'Hara-Devereaux and Johansen 1994; Kennedy 1993; Thurow 1996; Reich 1991; MIT Commission on Industrial Productivity 1989a, 1989b). According to this vision of globalization, a transformation in economic activity may be changing, perhaps to an unprecedented extent, our values towards the way we work, create knowledge, and interact with others. O'Hara-Deveraux and Johansen (1994), for example, claim that "the globalization of economic activity is perhaps the defining trend of our time. It is reshaping not only the grand, macro-level aspects of economic life but the personal aspects as well, including where, when, how, and with whom we perform our daily work."

Proponents of educational change argue that mapping the global terrain is not only one of the most pressing educational needs but it is the one skill that U.S. students lack the most. Some studies, for example, are documenting ways in which engineering education, research, and practice are extending beyond national borders, taking a transnational character, and having significant consequences for the U.S. (GUIRR 1992; NSF 1995). According to the Rand Corporation (1994), the significance for engineering education is clear: "[C]ross-cultural competence was considered by members of both the academic and corporate communities to be the most important new attribute for future effective performance in a global marketplace… However, it is what U.S. citizens are most lacking."

Many important responses are emerging within engineering institutions. The National Science Foundation (NSF) has funded systemic reforms in engineering education under the Engineering Education Coalitions, a multi-million program to develop new curricula aiming at creating 21st-century flexible engineers for global competition (NSF 1993; Peden et al 1995). Universities are creating programs to prepare engineers for a global environment such as the Global Engineering Education Exchange (GE3), the Global Innovation for Engineers program at Georgia Tech (Higgins 1998), the Eurotech program at University of Connecticut (Long and Einbeck 1998), and the Design for International Market Program at Calvin College (VanderLeest and Nielsen 1998).

A key, still open, question for all to ask concerns the extent to which these and other emerging innovations in engineering education will experience transient lives on the surface of engineering curricula or be successful in digging down deep into the heart of long-established courses, pedagogical strategies, and curricular structures. Largely stable at least since Sputnik, science-based engineering curricula in the United States have long resisted successfully reform movements for curricular change. A principal means has been to locate reforms and changes on or around the boundaries of existing material and courses. The boundaries shift somewhat while the core pedagogy of mathematical problem solving has remained largely unchallenged and, hence, untouched.

III. Reaching out to science and technology studies?

Meanwhile humanities and social science courses have remained in relatively stable positions on students' transcripts as voluntary electives, disconnected from the integrated network of engineering requirements and present largely to help "round out" engineering students as human beings.

As corporate reformers call for new forms engineering education for globalization (Boeing 1997; Conditt 1998; Globalization 1995; Honeywell 1998), some analysts have called on engineering departments and faculty to make more visible the contextual nature of their knowledge and practices (Wenks 1996; Florman 1993). Some recent proposals call for teaching engineering in ways that highlight their social, economic, and cultural dimensions (Wenks 1996; Kranzberg 1993; Johnston et al 1988). Indeed, the Accreditation Board for Engineering and Technology (ABET), for many years a conservative force in engineering education, has incorporated in its ABET 2000 criteria a call for "broad education necessary to understand the impact of engineering solutions in a global and societal context."

At the same time, undergraduate curricula in the humanities and social sciences generally do not privilege the educational needs of engineers. For example, Jonathan Cole, a prominent sociologist of science and provost of Columbia University, blames traditional humanities departments for the neglect of science and technology generally as subjects worth teaching. "[T]the gulf in understanding between scientists and nonscientists," Cole concludes, "may be traceable to an educational system that neglects the historical importance of scientific and technological developments." (Cole 1996. Not surprisingly, some of the most energetic critics of traditional humanities curricula come from engineering reformers who, wanting to call attention to globalization, worry that their undergraduates are not being prepared for cross-cultural work in a global economy (Bell 1996; Jones 1995). While championing instruction in critical thinking, humanities and social science courses generally position themselves more to introduce and socialize students into their fields than to intervene and participate critically in the learning activities of other curricula, e.g., engineering.

A key exception to this trend has been undergraduate courses drawing on the interdisciplinary field of Science and Technology Studies (STS). Sometimes referred to as science, technology, and society, this field includes work clustered around the central question: What is the relation between the technical (or knowledge or cognitive) dimensions and the non-technical (or social) dimensions of science and technology? Probably every undergraduate engineering institution

currently has one or more courses drawing from this field. Although STS interest in engineering and engineering education has a somewhat checkered history (Downey, Donovan, and Elliott 1989; Downey and Lucena 1994), such is now expanding rapidly (see Carporael 1998; Downey 1998b; Fricke 1998; Lucena 1997; Lynch 1998; Nieusma 1998; Saudek and Carlson 1998; Schumacher 1998)

Undergraduate STS courses for engineering students tend to help students recognize that technological problems have multiple dimensions and that solving technical problems involves paying attention to the non-technical dimensions as well. It is critically important for engineering students to understand that technological problems raise a variety of socio-political issues, only some of which engineers have been well-prepared to address. Sometimes, collaborative efforts between STS scholar/teachers and engineering faculty have integrated such considerations directly into engineering design courses (e.g., Arizona, Rensselaer, University of Virginia). In such cases, STS faculty helps guide students as they work to identify different dimensions and then solve both technical and non-technical problems at the same time.

A key problem for existing STS contributions to engineering education is that engineering students tend not to arrive prepared to understand themselves as working in worlds filled with distinct and, sometimes, competing perspectives. Addressing the political, social, or other value dimensions of a technological problem typically involves engaging groups who occupy political or social positions that differ from one's own, whether based in engineering or in other fields. The integrated structure of training in engineering problem solving prepares students to master, and hence value, a perspective specific to one's own discipline. An unintended consequence of such learning is that engineering education also trains students to devalue perspectives born and living in other fields and locations. If, for example, I define my own discipline-based work as the rational production of factual accounts, it is easy for me to reject other accounts as untrue, irrational, and, hence, unworthy of serious engagement.

IV. *Engineering Cultures* in the engineering curriculum?

Accordingly, we have concentrated our attention on enabling students to become better observers of their own experiences by developing a course that focuses on the relationship between engineering students and their own curricula. The syllabus for *Engineering Cultures* (www.cyber.vt.edu/hst/2054) describes its aim at helping students figure out how and where to locate engineering problem solving in their lives while also holding onto their dreams. In other words, it takes as its core mission helping students figure out what they are going through as they learn engineering problem solving and then to step back and analyze their experiences from a distance.

The course works to achieve this goal by improving students' abilities to understand and assess engineering problem solving in historical and global perspectives. An approach to achieving flexibility in engineering graduates that goes beyond simply producing flexible bodies (Martin 1994) may be to enable engineers to assess critically their current positions in relation to others and then to devise new strategies appropriate to changing contexts. Our desire is to participate in the challenge of globalization by helping define flexibility as sophisticated critical positioning. Kennedy (1993) argues that education for the 21st century "means more than technically 're-

tooling' the workforce, or even the encouragement of a manufacturing culture in the schools and colleges in order to preserve a productive base. It also implies a deep understanding of why our world is changing, of how other people and cultures feel about those changes, of what we have in common--as well as of what divides cultures, classes, and nations" (see also Thurow 1996; Reich 1991). *Engineering Cultures* takes a small step in this direction by striving to enable engineering students to understand themselves as holding perspectives by systematically challenging them to recognize and explore perspectives other than their own.

The course emerged from a research project sponsored by the Ethics and Values Studies program (now Societal Dimensions of Science and Technology) at the National Science Foundation. After completing undergraduate degrees in engineering, both authors went on to conduct ethnographic and historical work in the social studies of technology and engineering (e.g., Downey 1998a; Downey and Lucena 1994, 1998; Lucena 1996). With NSF support, we conducted a three-year ethnographic study of how engineering curricula challenge and shape engineering students as persons. Drawing on 4,000 pages of transcribed and coded data collected from year-long, bi-weekly interviews with 12 focus groups, 61 individual interviews, 13 undergraduate engineering courses, and assorted presentations and lectures, we are now completing the book manuscript Just Tell Me What the Problem Is: The Learning of Engineers.

During the project, we came to focus specifically on the content and implications of learning engineering problem solving. The manuscript traces the series of challenges to personal identity students experience as they move through various stages in the process, marked by the chapter titles, Discipline, Loss of Romance, Hacking It, Weed-Out, Eat-Sleep-Study, and Living a Grade Point Average. In collecting our data and interacting with students, we realized the need for and possible implications of a new type of course. We also found a way of linking conceptually the challenges students experienced in the classroom with the challenges posed by globalization.

V. Living with dominant cultural images

Engineering students fully understand that they do not all think alike. They encounter differences among themselves on a daily basis. However, U.S.-born engineering students have much more difficulty understanding that people in other cultures, e.g. Japanese people, do not all think alike. This problem is an unintended consequence of the concept of culture, which generally is used to refer to the totality of shared beliefs and values of a particular society. By focusing on shared beliefs and values, our concept of culture is good at highlighting differences between cultures but at the expense of hiding differences within cultures.

Engineering Cultures addresses this problem by describing and analyzing a culture as a set of dominant images. Rather than shared beliefs deeply imbedded inside people's bodies and lives, as something akin to linguistic grammars, this approach to culture locates it metaphorically outside and above people, as dominant images that challenge us. What people share is the challenge of an image rather than its effect as a belief. For example, individual engineers may believe all sorts of things about engineering problem solving but what all share is a challenge to do it properly.

Once culture is relocated from an interior state to an external challenge, many things become possible. Japanese culture, for example, becomes a set of dominant images that challenge all Japanese people. Such images are important for Americans to study because they mark crucial differences between America and Japan, but it does not follow that all Japanese are alike. In meeting Japanese engineers, then, the student who emerges from the *Engineering Cultures* course is predisposed to inquire what sorts of images have challenged such people, with an eye toward identifying differences, rather than to assume they are all alike. Likewise, students' understanding of Japanese-American shifts from viewing them as an anomaly, an unfortunate group of people who must deal with a unique form of cultural schizophrenia, to an interesting group of people who must deal with two different sets of dominant images at the same time.

Taking the identification and analysis of dominant cultural images as its core method, the course uses a series of readings, discussions, guest presentations, homework assignments, exams, formal essays, and final portfolio to help students make visible their own perspectives by demonstrating knowledge about many others. The idea is to help them see what they take as natural to be the product of historically and culturally specific processes. By the end of the course, students are more capable of describing distinct national traditions of engineering, mapping the history of engineering disciplines in the United States, identifying and describing current debates over engineering education in the United States, and mapping the world more generally through an enhanced understanding of colonial and post-colonial histories. By thus traveling the world to demonstrate that what counts as an engineer and engineering knowledge varies dramatically across time and from place to place, students learn to view their own curricula as offering one perspective among many. The course concludes by offering students a strategy for problem solving in an environment where people define problems differently from one another.

From this point of view, mathematical problem solving shifts from being the absolute foundation of all engineering practice to an immensely important component of good engineering practice. Also, the traditional idea of "trade-offs" in engineering design shifts from referring to trade-offs among alternative objectives by a given problem solving to trade-offs between individual or groups of problem solvers occupying different perspectives.

We teach the course as a series of modules, each self-contained but fitting the overall mission of the course as steps toward a more developed understanding of the dominant American approach to engineering problem solving amidst other approaches. The course's modules are the following:

Engineers and politics. Can engineering students learn to think about politics as an integral part of engineering problem solving? We begin by posing this question, knowing that students are not ready to answer and that will gain significance throughout the course. At present, the engineering curriculum trains students to understand engineering and politics as opposed concepts and practices. We use the life and experiences of John Sununu, MIT engineer and former Chief of Staff to President Reagan. Here students learn that defining a problem in one's own terms gives one possession of the problem. If different groups define problems differently, then an interaction between them is inherently a political one, for whoever wins the battle over definition gains power in relation to the other. Perhaps politics is part of the real-life problem solving of engineers.

The Western Emphasis on Individualism. The course turns to help students understand what's specific about the present. With the conclusion of the Cold War, a shift has taken place in the dominant image of the world, from a military-political competition between two philosophies to an economic competition among a collection of distinct nation-states. This shift during the 1980s led the United States to adopt a range of new strategies for acting as a single economic actor, linking the success of American corporations to the well-being of the nation as a whole. These included national commitments to automation, joint-ventures among government, industry, and academia, total-quality management, strong corporate cultures, and business process reengineering, as well as a new focus on productivity.

We show students how the cultural image of economic competitiveness has shaped engineering practice and education since the early 1980s. Most students take this relationship for granted because they were born in it. The image of economic competitiveness has led hi- tech corporations to find ways to make their engineers more productive and loyal in the midst of job-security uncertainty. We give students the opportunity to explore and critically reflect on the engineering of culture in a corporate environment and to see how other engineers deal with the ambiguity and tensions between self and corporate culture. Drawing on Kunda's (1993) Engineering Culture, we explore the corporate culture movement in order to help students understand the images they will confront on the job. In the process, the most important part is that they also learn about the importance of individualism in the U.S

Japan. In a kind of shock therapy, we help students experience a wholly distinct conception of the person by learning about Japan, a nation whose dominant images do not include the individual person, through the stories of US engineers working there. Students come to appreciate a perspective where group identity serves as the main means for defining persons. Students also learn how the cultural images of Zen Buddhism, Confucianism, and Shintoism have shaped technological development in Japan and how images of Japan have shaped U.S. engineering practice and education in the last two decades.

Soviet Union. Through a biographical account of Peter Palchinsky (Graham 1993), an engineer of the Stalin era, students learn how in Soviet engineers' technical work always had political content. Students also learn how the cultural images of both the USSR and the US shaped each other's technological development and engineering problem solving practices. For example, the existing American engineering curriculum, built on basic and engineering sciences as the foundational blocks of engineering knowledge, was a response to Soviet technoscientific developments, particularly Sputnik. The mutual shaping of Soviet and US engineering problem solving practices clearly illustrates the point that engineering is always political.

Engineering education reform. Through the history of the engineering pipeline, students learn how engineering education reform in the 1980s was a response to an image of Japan as an economic threat to the American nation. Students analyze how engineers in policy-making positions used engineering-problem solving methodology to respond to the threat and developed the engineering pipeline to demonstrate the need to educate thousands of engineers for economic competitiveness. Students come to realize that K-12 federal-sponsored programs in pre-engineering in the early 1990s, from which some of them graduated, were in place as a result of

the pipeline. Students also analyze more recent engineering education reforms such as systemic reform through the Engineering Education Coalitions. By making visible images of education reform that engineering faculty face, the main goal here is to help students understand disputes and struggles among their professors over education reform while helping students construct alternative pathways into their engineering careers.

20th century U.S. Through case-studies in 20th century history of engineering, we show students the origin of a key divide in contemporary engineering, between design and manufacturing. This is the best example in the U.S. of differing perspectives that cannot be either ignored or resolved. Here students also learn that doing good engineering work involves more than purely technical problem solving.

19th century. Through analysis of case studies in 19th century history of engineering, students historically locate U.S. engineering disciplines through descent lines from civil engineering and mechanical engineering and come to understand why engineers live inside of corporations rather than as doctors or lawyers. They also connect the origins of U.S. engineering to British and French engineering traditions.

European perspectives. Through case studies in the history of engineering in Britain, France, and Germany, students learn that what counts as engineering knowledge in Britain is craftsmanship, in France is mathematical theory, particularly directed towards the rational organizational of society and the State, and in Germany is emerging quality/reason. This is a key moment in the course because the contrasts in national perspectives are so clear.

Asian perspectives. Here students learn that engineering practice and knowledge in different Asian countries are shaped by "historical particularism," such as the constant threat of occupation that brings out "catalytic bitterness and anger" in South Korea or the cultural revolution in China. Students learn to tell Asian perspectives apart and then apply these insights into their lives.

Latin American perspectives. Students learn that engineering practice and knowledge are shaped by cultural histories of antagonism and collaboration with the U.S. in Mexico, by internal regional disputes and surges of nationalism against imperial nations in Colombia, and by servitude to the military, the church, and the aristocracy in Brazil. This is a second application of learning how to tell national perspectives apart.

Can engineers deal with politics? We pose this question again to students to reassert that politics is inherent part of engineering experiences and with the hope that students have reached the following conclusions: first, engineering problems mean different things in different cultural and historical perspectives; second, drawing a boundary around a problem has non-technical or political dimensions; third, engineering-problem solving, based on mathematics and engineering sciences, becomes only one resource among many for engineers to use yet remains a distinctive, crucially important resource.

VI. Past, present, and future of *Engineering Cultures*

We have taught the course a total of eight times since Fall 1995, six times at Virginia Tech and twice at Embry-Riddle. At Virginia Tech, enrollments rose rapidly. For Fall 1998, Dr. Downey originally scheduled a class for 95 students but pre-registration yielded over 250 requests. The division director of Engineering Fundamentals in the College of Engineering indicated his faculty would have recommended "many dozens" more freshmen were the course not closed. In Spring 1999 Dr. Downey opened the course to 100+ students at the request of deans, students, faculty, and the office of the President. In Fall 1999, Dr. Downey will teach the course to 300+ students. At ERAU, Dr. Lucena teaches the course in the summer for engineering seniors who stay to complete their senior design projects but the course is also open to students of Science, Technology, and Globalization (STG) and Aeronautical Sciences. Some of the case studies have been changed to incorporate aviation and aerospace industries, such as Boeing and Honeywell, where a significant number of ERAU graduates end up working.

Dr. Downey has proposed to accommodate large student demand for this course at Virginia Tech by developing an asynchronous, online version of *Engineering Cultures*. Dr. Downey wants to replicate as closely as possible the intensely personal experience students now gain in the classroom and web version of the course through a combination of CD/ROM, web support, and communication with graduate assistants. He also wants to expand the range of active learning by students in both the online and classroom versions of the course by using the high storage capacity of CD/ROM technology. Beginning Spring 2000, the Humanities, Science, and Technology program in the Center for Interdisciplinary Studies at Virginia Tech will offer the online version of the course every semester and at least one summer session each year. The main assessment indicators will be growth in enrollment by Virginia Tech students on-campus and off-campus, as well as quantitative and qualitative results from a web-based questionnaire. An additional indicator of success will be enrollments by engineering students at other universities through the emerging Virginia Commonwealth Electronic Campus.

Under a new grant, Dr. Lucena will be traveling throughout the United States, Europe, and Latin America to interview engineers in the aircraft and aerospace industries to explore how "globalization" means different things in different places. Dr. Lucena will contribute to *Engineering Cultures* CD/ROM project with transcribed interviews, audio clips, and possibly short video clips of interviews with international engineers. Through extensive reading, he will also contribute to a course-wide multimedia database of text and audio introductions/reviews of books, articles, reports, and government documents about engineering education. We believe this database may prove attractive to instructors at other institutions who may want to use the course.

We also plan to work with other STS colleagues to integrate *Engineering Cultures* in between generic introductory courses to STS-related issues and more focused STS in engineering design courses. This sequence of three STS courses for engineers would not only satisfy upcoming ABET 2000 accreditation criteria but further meet our goal to enable students to understand and reflect on their own problem-solving and design activities as perspectives that both could have been otherwise and must live amidst other perspectives.

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