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THE ENGINEERING CULTURES SYLLABUS AS FORMATION NARRATIVE: CRITICAL PARTICIPATION IN ENGINEERING EDUCATION THROUGH PROBLEM DEFINITION

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It doesn't matter what your major is. You have all learned the fundamental engineering method, the method of solving engineering problems.[1]

Engineers were designed to serve.[2]

Education . . . is not something you have. It is something you are.[3]

Engineering students should ask three questions: How are *they* located? What do *they* know? What do *they* want? The course syllabus in Engineering Cultures contests the image of the "engineering method" that first scaled up to dominance in engineering curricula across the United States during the late 1950s, when Americans watched Sputnik fly overhead and then accepted the view that their country needed to improve its capabilities in science. While celebrating the demonstrated efficacy and enormous power of the engineering sciences as essential resources in quality engineering work, this elective course calls attention to ways in which accepting and enacting practical strategies for bounding and solving engineering problems could have the unintended consequence of limiting the professional judgment of engineering practitioners. Drawing on prior ethnographic work examining how the application of engineering knowledge in practical problem solving generates unique problems of personhood for engineers,[4] the course queries the implications of learning to keep aspects of the self "invisible" in practices of problem solving. Also, by asking students to grapple with the three questions above while mapping differences in, and what has counted as, engineers and engineering knowledge in different countries and across time, the Engineering Cultures course calls attention to an under-recognized dimension of engineering judgment, i.e., working effectively with people who define problems differently. The syllabus seeks critical participation in the formation of engineers as agents, offers an expanded image of the engineering method as Problem, Definition and Solution, and proposes some practical strategies for the method's implementation.

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leadership in calling attention to the formation of professional identity and offer him my gratitude for the opportunity to participate in the Symposium and contribute to this issue.

1. Dean John Karakash, Graduation speaker, College of Engineering, Lehigh University (May 26, 1974).

2. Ken Alder, *French Engineers Become Professionals, or How Meritocracy Made Knowledge Objective*, *in* THE SCIENCES IN ENLIGHTENED EUROPE 94, 124 (William Clark et al. eds., 1999).

3. Andrew Abbott, *The Zen of Education*, 96 U. CHI. MAG. (2003), *available at* http://magazine.uchicago.edu/0310/features/zen.shtml.

4. *See* GARY LEE DOWNEY, THE MACHINE IN ME: AN ANTHROPOLOGIST SITS AMONG COMPUTER ENGINEERS 134–236 (1998); Gary Lee Downey & Juan C. Lucena, *Engineering Selves: Hiring in to a Contested Field of Education*, *in* CYBORGS AND CITADELS: ANTHROPOLOGICAL INTERVENTIONS IN EMERGING SCIENCES AND TECHNOLOGIES 117–42 (Gary Lee Downey & Joseph Dumit eds., 1998) [hereinafter *Engineering Selves*]; Gary Lee Downey & Juan C. Lucena, *When Students Resist: Ethnography of a Senior Design Experience in Engineering*, 19 INT'L. J. ENG'G EDUC. 168–76 (2003) [hereinafter *When Students Resist*].

The syllabus in Engineering Cultures is built on the view that education poses challenges to persons and, hence, that learning is a problem of identity formation. The pedagogical framework analytically distinguishes and highlights the problem of personhood. It treats educational experiences as creative responses by learners to challenges from dominant images, especially images of knowledge. As such, the syllabus draws inspiration from work in cultural studies of science and technology that follows metaphors of general cultural life into science and technology and back again into people's lives and experiences.[5] The course contributes to work in educational anthropology by examining education as the cultural production of persons.[6] It also participates in a philosophical and pedagogical movement in higher education that is calling attention to how teaching and learning always involve the sharing and acquisition of practices.[7] Drawing on this scholarship, the instructional design for Engineering Cultures incorporates the view that the forms of knowledge that engineering students encounter in their core engineering science curricula pose unique challenges of personhood to them as learners, and how they respond to such challenges constitutes a central problem of professional judgment, thus professional identity. In these terms, in order for engineering students undergoing professional formation to successfully establish the link between understanding and competence in professional judgment, they must also successfully resolve unique problems of knowledge and personhood.

Engineering Cultures has a dual moral or purpose. First, it seeks to enable engineering students to recognize and analyze the challenges of personhood they face and "talk back" to those challenges.[8] That is, the course endeavors to help them plot novel responses that take into account the unique configurations of challenges they face as students, and people, in

5. *See* Joseph Dumit, Picturing Personhood: Brain Scans and Biomedical Identity (2004); Emily Martin, The Woman in the Body: A Cultural Analysis of Reproduction (2001); Rayna Rapp, Testing Women, Testing the Fetus: The Social Impact of Amniocentesis in America (1999).

6. *See* Margaret A. Eisenhart & Elizabeth Finkel, Women's Science: Learning and Succeeding from the Margins (1998); Karen Tonso, On the Outskirts of Engineering: Learning Identity, Gender and Power via Engineering Practice (2007); Sharon Traweek, Beamtimes and Lifetimes: The World of High Energy Physicists (1988); The Cultural Production of the Educated Person: Critical Ethnographies of Schooling and Local Practice (Bradley A. Levinson, Douglas E. Folley & Dorothy C. Holland eds., 1995); Sharon Traweek, *Generating High-Energy Physics in Japan: Moral Imperatives of a Future Pluperfect*, *in* Pedagogy and the Practice of Science: Historical and Contemporary Perspectives 357, 360 (David Kaiser ed., 2005).

7. *See* William M. Sullivan & Matthew S. Rosen, A New Agenda for Higher Education: Shaping a Life of the Mind for Practice (2008).

8. *See* Bell Hooks, Talking Back: Thinking Feminist, Thinking Black (1989); Rosalie Rolon-Dow, *Seduced by Images: Identity and Schooling in the Lives of Puerto Rican Girls*, 35 Anthrop. & Educ. Q. 8–29 (2004).

engineering.[9] To this end, the course highlights the fact that students simultaneously face challenges from images that have gained acceptance at different scales. For example, students face images of engineering knowledge existing at small scales among narrowly-defined engineering communities, as well as images that have "scaled up" across broader populations, including images of gender, race and progress.[10] Also, to the extent Engineering Cultures helps engineering students rehearse the identification of, and response to, sources of influence and expectation in their lives, the course makes use of its peripheral location as an elective to respond to dominant practices of education in the engineering sciences.

At the same time, Engineering Cultures also takes a second, much riskier step of inserting itself into the heart of engineering education by claiming authority as a key site for producing better engineers. Specifically, it seeks to prepare engineers to go beyond serving as mathematical problem solvers who provide clients with technical support to pursuing leadership positions as problem definers committed to listening. In this second sense, Engineering Cultures claims membership in large-scale contemporary efforts to reform engineering education, both in the United States and in other countries, by purporting to help define what constitutes desirable objectives and what curricular strategies should be used to achieve them. At the same time, the course stands out in that it offers its learning strategies, not as a programmatic solution to a specific curricular failing, but with the broader goal of helping engineering students come to understand themselves and their work in new ways.

The course's main strategy is to push the idea of "integrated liberal arts education"[11] in the education of engineers to its logical endpoint by

9. With an analysis of "talking back," I am not claiming that the phenomenon of predominantly white male engineering students talking back to the dominant image of the engineering method is morally or politically equivalent to the phenomenon of black women and men or Puerto Rican girls talking back to images of white supremacy and black or hispanic inferiority that Bell Hooks and Rosalie Rolon-Dow examine. Rather, I seek to draw on their analyses of the challenges of racial images to argue that other dominant images can also be analyzed as challenges. For an account of responses by engineers to dominant images of technology, see *Engineering Selves*, *supra* note 4, at 130. Indeed, I maintain that mapping the dominant images that challenge engineers may be crucial both to understanding the privileges that accrue to engineering identities and to "scaling up" alternative images that could refigure these privileges for the better—both for engineers and those they serve. For an analysis of contemporary challenges to the privileged jurisdiction engineers claim over technology, see Gary Lee Downey, *Keynote Address: Are Engineers Losing Control of Technology? From 'Problem Solving' to 'Problem Definition and Solution' in Engineering Education*, 83 CHEMICAL ENG'G RES. & DES. 6, 583–595 (2005).

10. *See* Gary Lee Downey & Juan Lucena, *Knowledge and Professional Identity in Engineering: Code-Switching and the Metrics of Progress*, 20 HIST. & TECH. 393–420 (2004).

11. *See* LIBERAL EDUCATION IN TWENTY-FIRST CENTURY ENGINEERING: RESPONSES TO ABET/EC 2000 CRITERIA (David F. Ollis, Kathryn Neeley & Heinz Luegenbiehl eds., 2004); UNFINISHED DESIGN: THE HUMANITIES AND SOCIAL SCIENCES IN UNDERGRADUATE ENGINEERING EDUCATION (Joseph Johnston, Susan Shaman & Robert Zemsky eds., 1988); Kathryn Neeley et al., *Integration as a Means to Excellence in Engineering Education and Practice*, *in* LIBERAL STUDIES AND THE INTEGRATED ENGINEERING EDUCATION OF ABET 2000 (Kathryn Neeley ed.,

incorporating a key competence from the liberal arts as a core component the professional competence of engineers. Applied in the very process of defining and solving mathematical problems, that competence is an ability to identify and analyze oneself as occupying a "perspective" in a world of different perspectives. When this ability is made visible, the professional competence of engineers can no longer be construed as built only around a core competence in solving problems through mathematical analysis based in the engineering sciences; rather, it also includes the demonstration of competence in mapping and engaging competing perspectives in practical situations of problem definition.

Engineering Cultures also builds on broader aspirations. "Scaling up" the image and practice of leadership through mediating practices of problem definition can help enable engineers who might be motivated by altruistic dreams of contributing to society through their work. The formal recognition of collaborative problem definition with both engineers and non-engineers makes visible the responsibilities of engineers to go beyond competently fulfilling assigned tasks in an ethical manner to critically evaluating, and perhaps re-imagining, the larger dimensions of service that are performed by their work.[12] Educating engineers to work with people who define problems differently can be an important component in building an engineering that (1) is more attractive to members of the "underrepresented majority" (i.e., nonwhite, non-men), (2) prepares engineers to work more effectively in demographically diverse workplaces, and (3) achieves problem definitions and solutions that take better account of broader groups of stakeholders.[13] Finally, learning to work effectively with engineers and non-engineers who define problems differently is the crucial first step in becoming a global engineer.[14]

2002); KATHRYN NEELEY, LIBERAL STUDIES AND THE INTEGRATED ENGINEERING EDUCATION OF ABET 2000: REPORTS FROM A PLANNING CONFERENCE AT THE UNIVERSITY OF VIRGINIA (2003).

12. Joseph Herkert calls this a shift from microethics to macroethics. *See* Joseph R. Herkert, *Ways of Thinking about and Teaching Ethical Problem Solving: Microethics and Macroethics in Engineering*, 11 SCI. & ENG'G ETHICS 373–85 (2005); Joseph R. Herkert, *Future Directions in Engineering Ethics Research: Microethics, Macroethics and the Role of Professional Societies*, 7 SCI. & ENG'G ETHICS 403–14 (2001). Also, I am currently engaged in research accounting for the emergence of dominant practices in engineering formation in different countries as, in part, a response to distinct and changing images of progress. *See*, *e.g.*, Gary Lee Downey, *Low Cost, Mass Use: American Engineers and the Metrics of Progress*, 22 HIST. & TECH. 289–308 (2007).

13. *See* Ann Shirley Jackson, President, Rensselaer Polytechnic Institute, Address at the 2003 William D. Carey Lecture, Standing on the Knife-Edge: The Leadership Imperative (Apr. 10, 2003) *available at* http://www.rpi.edu/president/speeches/ps041003-aaas.html; Gary Lee Downey & Juan C. Lucena, Are Globalization, Diversity, and Leadership Variations of the Same Curricular Problem?, Address Before First International Conference on Research in Engineering Education (2007), *available at* http://www.nae.edu/nae/bridgecom.nsf/weblinks/NAEW-4NHMBG?OpenDocument; William A. Wulf, *Diversity in Engineering*, 28 THE BRIDGE 8–13 (1998).

14. *See* Downey & Lucena, *supra* note 13; Gary Lee Downey et al., *The Globally Competent Engineer: Working Effectively with People Who Define Problems Differently*, 95 J. ENG'G EDUC. 101–22 (2006).

The analysis below offers a narrative account of the Engineering Cultures syllabus as a deliberate sequence of pedagogical engagements with learners. Like all syllabi, it tells a story about who the course expects to engage and how it goes about managing its own challenges to students' identities. While tracing the steps Engineering Cultures employs to help students learn to "talk back" to their curricula and claim critical participation in engineering formation, the analysis also outlines a rudimentary theory of critical participation in professional formation built around five questions. These include the questions of knowledge and personhood, alternative knowledge, alternative practices, fit with dominant practices and "scaling up." Each section begins by introducing and describing one or more class assignments and then analyzes how it addresses one of the five questions of critical participation.

I. Refiguring Agency as Responses: The Question of Knowledge and Personhood

Homework: In four to five paragraphs, identify and describe the images that challenged you as you were considering and deciding to pursue a degree in engineering. Wander outside of yourself and identify the source(s) of those images. Then go back inside and figure out how they challenged you. How, for example, did these challenges combine or conflict with other challenges to shape your pathway? What images are challenging you now?

The purpose of this assignment is to help you begin analyzing yourself in social terms. Those of us who have been raised in the United States tend to describe our histories as sequences of decisions or judgments we made ourselves, since we see ourselves as autonomous individuals. We tend to see anything else that is contributing to our pathways as outside forces impacting on us. Images, however, live inside us, making the inside-outside distinction more difficult to sustain. There are other ways of thinking about our identities as people.

Note: We are introducing the course's main method of analysis, which we use repeatedly as we travel around the world. It may take you some time to get the hang of it. We'll work with you. Remember, by "images that challenge you," we are not referring to the series of decisions you made in deciding to become an engineer, the difficult courses you took, etc. Instead, focus on images you carried around in your head—of engineers, yourself as an engineer, yourself at the time, your goals and ambitions, your fears, etc.—as well as the sources of those images—parents, friends, relatives, teachers, television, books, etc.

Each semester, one hundred and fifty students enroll in Engineering Cultures, which represents roughly half the number of those who request the course.[15] Although this collection of predominantly white, male students arrives in the classroom along a variety of pathways, four patterns tend to stand out. At least some students feel themselves drawn in because they heard the course offers thought-provoking experiences that help, as the written description asserts with unabashed idealism, "to locate engineering problem solving in your lives while holding onto your dreams."[16] These students are looking for something they have not found in their engineering curricula. Other students are preparing themselves more instrumentally for gainful employment. One group hopes that learning about engineers and engineering knowledge in different countries will make them more attractive to an increasingly international world of engineering practice. Anticipating this perspective, the course description claims that, "[m]inimally, participants [will] gain some concrete strategies for understanding the cultural differences they will encounter on the job and for engaging in shared problem solving amidst those differences."[17] Another group enters the course having decided that, with the word "engineering" in its title, the course seems to be the least irrelevant humanities or social sciences elective available. Some members of this group are attracted by the fact that enrollment in Engineering Cultures helps fulfill requirements in two areas of the core curriculum: "Ideas, Cultural Traditions and Values" and "Critical Issues in a Global Context."[18] Both groups are hoping to get in and out as painlessly as possible, ideally while increasing grade point averages (but certainly without reducing them). The last pattern consists of students of color, international students and female students who are curious about the course because they heard it tries to grapple directly with issues that might pertain to them. Many students travel along more than one such pathway at the same time.

15. Note that this refers only to the large section of the course I teach, along with three graduate assistants. When Ph.D. students teach their own versions of the course, typically in the summer, enrollments are typically thirty-five to forty students who are divided into two groups for synchronous online discussions (typically using CentraOne® software).

16. The main source of evidence for this finding is the student response to the Reflections Assignment. Part 2 of the Assignment, completed by students at the conclusion of the course, is discussed further below. In Part 1, completed in week three of the course, students respond to the question: "Within approximately one page (minimum 250 words), reflect on why you are taking the course, your goals with respect to engaging with the course concepts, any concepts that cause you to struggle and why, and what you hope to gain from the class and develop within yourself." Students are typically candid in responding. To encourage them to be candid and, hence, initiate the process of building trust, evaluation of the assignment is based almost entirely upon a criterion of completeness with some attention to the mechanics of writing; the content belongs wholly to them. For a sample overview of the course, see Engineering Cultures, http://www.engcultures.sts.vt.edu (last visited Apr. 16, 2008). The actual materials students engage each semester is made available at Blackboard® sites, which are password protected.

17. Engineering Cultures, http://www.engcultures.sts.vt.edu/overview.html (last visited Apr. 16, 2008).

18. 2007–2008 Undergraduate Course Catalog & Academic Policies, http://www.undergradcatalog.registrar.vt.edu/0708/acapolicies/corrcur.html (last visited Apr. 16, 2008).

Asking students to map their trajectories into engineering is a first step in helping them understand themselves as occupying perspectives while also enabling them to work on familiar turf. Can engineering students recite narratives of admission into engineering by portraying themselves as "responding" to images that challenged them rather than "making decisions" as autonomous agents?

Conceptualizing and taking this first step is crucially important for students to be able to both understand and analyze more systematically the challenges of personhood they face in engineering and "talk back" by imagining and, perhaps pursuing, alternatives. As long as the site of professional agency is thought to lie solely in internal mechanisms of deliberation and judgment, the influences and expectations that originate beyond individual decision makers will appear to be less significant, potential sources of annoyance or just irrelevant. The only important questions are internal ones about capability, propriety and timing, and all professionals share roughly the same issues. Alternatively, if events of professional judgment are themselves the product of active responses to varying configurations of influences and expectations in their lives, including the knowledge contents of the field in question, the important questions multiply and the issues professionals in different fields face are only partly shared with one another. The professional agent is led to ask: what configurations of influences and expectations do I face in this program of study, and how am I responding to them?

When this opening exercise in mapping one's trajectory works with students, which it appears to in roughly half the cases, students present themselves in ways that make legible, and even highlight, the arrays of external influences that have inflected their trajectories. It also calls attention to differences among students. For example, many engineering students are attracted by images of themselves designing technologies to benefit society. Some are experienced tinkerers who extrapolate images of building things. Some yearn for the heroic status of astronauts or of technological icons such as Wernher von Braun.[19] Virtually all have been told that they are good at math and science. Many have family members they respect and want to emulate. All imagine an engineering education as a pathway to a good job and reasonable income. Relatively few, however, had any idea about what engineering training or practice involved prior to committing themselves to becoming engineers. All are well aware that gaining admission was just the first step; they still have to prove they can do engineering.[20]

19. Wernher von Braun was a German-born rocket engineer who became the iconic figure of the United States' space program during the 1960s and 1970s.

20. It is instructive that such is not the case in many countries, such as in France where engineering students in the elite *grandes écoles* know they have already proven themselves by completing the difficult entry exam, *les concours*, and gaining promotion into an engineering

In the image of engineering science education that has dominated in the United States for the past forty years, students encounter a well-honed method of analysis in the engineering sciences and are challenged to prove they can master it.[21] Performing the engineering method involves correctly applying configurations of mathematical formula to variable situations and following a strict sequence of steps. One common version of the method labels these as "Given," "Find," "Equations," "Diagram" and "Solution."[22] The student begins by pulling given data in numerical form from a narrative description of the problem and then decides what to find in order to solve the problem. This is known as "drawing a boundary" around a problem, which is always the essential first step. Then, by invoking established Equations and drawing an idealized visual Diagram of the various forces or other mechanisms theoretically at work in the problem, the student systematically calculates the Solution in mathematical terms. During their undergraduate years, engineering students solve thousands of problems either on paper or in computer programs, each time beginning with a sharply defined and well-bounded problem and then abstracting out its mathematical content, calculating answers in mathematical terms, and applying the numbers back to the original problem as its solution. The students know to keep any feelings they have about the problem out of the process; these are irrelevant and can only get in the way of reliable judgment.

The Engineering Cultures syllabus builds on the view that applying forms of professional knowledge in worlds of concrete action introduces problems of personhood. Different forms of professional knowledge challenge "knowers" differently. For example, as Traweek[23] and White[24] have shown, problem solving in theoretical physics (Euro-American versions) includes a challenge to reveal an essential feature of the self. The physicist must demonstrate and advance an understanding of underlying principles in order to show that he or she is the site of genius, with Albert Einstein as the role model. The body, along with other aspects of the physicist's identities, is deemed irrelevant to this core issue of selfhood. In contrast, the humanities and social sciences challenge apprentices to actively figure out and de-

school. One index of this difference is that such students subsequently identify themselves with their classmates according to the year of entry, rather than the year of graduation.

21. *See Engineering Selves*, *supra* note 4, at 117–42; Karen L. Tonso, *Engineering Gender-Gendering Engineering: A Cultural Model for Belonging*, 5 J. WOMEN & MIN. IN SCI. & ENG'G 365–405 (1999). Like all challenges from cultural images, this one is variable and context specific, with different institutions and disciplines confronting students with distinct challenges. At the same time, one can plausibly make the case that these differences constitute versions of a dominant model, or in some cases resistances to a dominant model, rather than evidence of something other than a dominant model producing privileged persons.

22. *See* J.L. MERIAM & L.G. KRAIGE, 1 ENGINEERING MECHANICS: STATICS 14 (1992).

23. TRAWEEK, *supra* note 6, at 74–105.

24. Tobin Frye White, *How to Solve a Physics Problem: Negotiating Knowledge and Identity in Introductory University Physics*, *in* GRADUATE PROGRAM IN SCIENCE AND TECHNOLOGY STUDIES (1996).

fine for themselves what might be called "places to stand," i.e., they must articulate where they stand in relation to a range of social and humanistic traditions. In so doing, the apprentices find themselves challenged to seek, or at least perform, a kind of congruence between an academic identity and a broader social identity. For example, where the researcher focused on making visible the perspectives of economically marginalized groups may feel pressure to minimize overt forms of conspicuous consumption, such as driving an SUV, the researcher focused on dominant traditions of Western civilization may feel pressure to demonstrate knowledge of high culture in France or Germany.

Education in engineering problem solving is certainly about demonstrating an ability to perform the method properly. In contrast with the attribution of fundamental genius, however, this ability is bounded—judged to be only a part of the student as agent. This "bounded-ness" is significant because it means that predispositions or influences from other aspects of one's identity must not interfere. Learning engineering problem solving is precisely about making the bulk of one's identity invisible in one's work.[25]

Engineering Cultures challenges students to consider that learning engineering analysis may have an unintended negative effect in engineering judgment on the job. Does defining a problem by drawing a boundary around it, the prerequisite to solving it effectively, also predispose the learner to divide the population of problem solvers into two groups: the right and the wrong? The practical reasoning involved in the process of drawing a boundary requires the problem solver to "take control" of a problem by applying a particular problem definition, e.g., a "kinematics" problem, a "fluid mechanics" problem, etc. The problem solver thereby takes up residence entirely inside a given definition in order to carry out the mathematical steps to find the correct solution. What does this mean for someone who is working outside the boundary as one has drawn it? Unless that person has, in fact, really defined the problem in the same way (i.e., drawn the same boundary) and is just plotting a different pathway to a solution, the outcome of that person's deliberations is, by definition, incorrect.[26] The person has approached the problem wrongly and will solve it incorrectly.

The five-step engineering method of mathematical problem solving includes no provision for solving problems with people who define problems differently. As a result, it arguably can have the effect of predisposing the engineering problem solver to see such people who do not share the same boundaries as possibly posing potential threats to proper problem solutions.

25. We must keep in mind that seemingly neutral images of knowledge might be anything but neutral in the challenges they pose to learners. Gender-neutral images of knowledge are a prominent case in point. *See* TRAWEEK, *supra* note 6; *see also* TONSO, *supra* note 6.

26. Many contemporary reforms in engineering formation are geared toward alerting students that defined problems can be solved in multiple ways. Each approach presumes and requires correct set-up.

Yet, encounters with both engineers and non-engineers who define problems differently may very well be a regular condition of problem solving on the job. Not only must engineers work with people who are trained differently and have different backgrounds, but working effectively amidst differences is the definition of a demographically diverse workplace. Although engineering problem solving provides students with the mathematical competence to solve given problems, might it also be undermining their professional competence by leaving engineers without guidance when their boundaries are different from, or even in conflict with, those drawn by others?

Engineering Cultures thus begins by introducing a discomfort; it displaces the acquired sense that the combination of theoretical and practical reasoning is both complete and sufficient for all times and places and that learning is purely a test of innate capabilities. Key to this displacement is the practical exercise of re-plotting one's own life trajectory from a series of decisions to a series of responses—now including responses to mathematical problem solving—all to grant students permission, and provide them with some new resources, to "talk back."

II. Multiplying Engineering Identities: The Question of Alternative Knowledge

Homework: Begin this assignment by writing the term "Japanese engineer" and putting below it a list of at least five images that an engineer in Japan may confront. Then write the term "U.S. engineer" with a list of at least five images that an engineer trained and working in the United States may face.

Now imagine that the two engineers switch jobs for awhile. Write the titles "Japanese engineer working in the U.S." and "U.S. engineer working in Japan." Beneath each title, write two paragraphs from that person's perspective, first person narrative. In these paragraphs, describe the images that would be most difficult for you to face, and why (especially given the set of images you have become used to facing). Be sure to draw from readings, classes, and personal reflections over the course of the semester.

Like many liberal arts courses for engineers, the Engineering Cultures course lives as an "elective." It is positioned as far intellectually from tightly-connected, prerequisite-laden engineering curricula as a course can get. The transformative struggles that students experience in their majors cannot be replicated in the elective environment, in which creating and maintaining an audience committed to learning is a central pedagogical problem. In contrast with the linked courses of a major in which students understand that the next course presumes success in a previous course, learning in the elective course depends entirely upon the encounters that take place within it. The student who is not wholly present cannot pick up the knowledge later. There is no "later;" there is also no "before."

An elective is not a voice from nowhere, however. A second common expectation among engineers that threatens to locate the course outside the engineering curriculum is that elective courses in the humanities and social sciences are "opinion courses." Here the word "opinion" is contrasted with "knowledge." In an opinion course, the major practical challenge for students is to figure out the opinion of the instructor and then work around it in order to get a good grade. The more clever students demonstrate a thorough understanding of the instructor's opinion and then take care not to dispute it directly. Attempting to locate itself instead as a "knowledge course" within engineering has significant implications for both the conceptual contents of Engineering Cultures and its methods for assessing student learning. In particular, this move forces the course to recognize and accept that, like other knowledge courses, it is making claims about the positioning of engineers in the world.[27]

A crucial step in enabling engineering students to work with people who define problems differently is to persuade them that such people in fact exist and, hence, deserve consideration. It is a question of alternative knowledge. The Engineering Cultures syllabus accepts its complicity in marketing by frankly and freely trading on the presumed pleasures of travel, implicitly presenting itself as a low-cost strategy for imagined study abroad in Europe, East Asia, North Africa, and Central and South America. Yet, leading tours across space and time is tricky, for tourists always travel with expectations about the foreign "Others" they will encounter on the trip.[28] Because such expectations structure practical responses to potential new understandings, they can significantly inhibit learning. The pedagogical challenge is thus to not only offer new understandings, but also enable the "tourists" to receive and apply such understandings in new ways. While disrupting expectations may be the first step, it is not the last.

One common expectation among students is that engineers from a given country are like one another in some fundamental way, as in "all Japanese engineers are alike." This expectation is an artifact of the dominant everyday concept of culture as students understand and enact it, which gains continued life through multicultural discourse.[29] That is, the cultures of the world are membership groups wherein members share some fundamental, underlying, gut-level beliefs or assumptions that are analogous to

27. This course necessarily operates in an historical context and arena of popular theorizing in which the world is real (even though the specific realities of its contents are contestable), phenomena of mind are separate from phenomena of body (even though the boundary is heavily blurred), and declarative sentences have referential value linking ideas to objects in the world (even though their semiotic operations are far more complex).

28. Ronnie Casella, *Pedagogy as View Sequence: Popular Culture, Education, and Travel*, 30 ANTHROP. & EDUC. Q. 187–209 (1999).

29. Observation from instructors (1998).

linguistic grammars. The idea of a bounded, shared culture has lost legitimacy among anthropologists.[30] While it once proved useful to describe contrasts among collections of people living around the world without ranking them as higher or lower than one another, it has fallen short in accounting for differences among people within a given collection, except through a search for smaller and smaller membership groups or "sub-cultures."[31] In principle, students who enroll in Engineering Cultures are quite prepared to accept that, for example, not all Japanese engineers are alike because they are accustomed to valorizing individual differences. Without a practical method for understanding individual agencies as responses to influences, at least in part, engineering students at work may fall back on the practical operations of the everyday culture concept and view actions by others as simply expressing features of their class.

Engineering Cultures works to isolate the problem of personhood and enable students to recognize the agency that, in principle, always exists between influences and responses. The course accomplishes this by implementing a theory of culture as "dominant images" that "challenge" people with their meanings or expectations. Thus, for example, rather than saying that all Japanese engineers "share" the concept of the "ie," or household, that defines persons according to the positions they hold, one can say that Japanese engineers are all "challenged" by the concept of the ie and have to figure out how to "respond" to it.[32] In this way of thinking, those confronted by cultural images share their practical challenges rather than their actual responses. Different engineers may respond differently to a given challenge. For example, while one Japanese engineer may fulfill the obligations associated with a given position in a corporate household by painstakingly building links and connections with other engineers, another Japanese engineer may focus on fulfilling the obligations of assigned tasks.

> *Exam question: During the eighteenth and nineteenth centuries, the ideal basis for one's acceptance into the elite engineering schools in France shifted from one's social status to one's merit. Describe what "merit" means in the French context, in contrast with social status. Also briefly explain how a student demonstrates his or her merit in order to be "promoted" into an engineering school.*

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30. The literature is vast, especially the journal *Cultural Anthropology*. *See, e.g.*, Stefan Helmreich, *After Culture: Reflections on the Apparition of Anthropology in Artificial Life, a Science of Simulation*, 16 CULT. ANTHROP. 612–27 (2001).

31. *See* Sherry B. Ortner, *Theory in Anthropology Since the Sixties*, 26 COMP. STUD. IN SOC'Y & HIST. 126 (1984).

32. *See* DORINNE K. KONDO, CRAFTING SELVES: POWER, GENDER, AND DISCOURSES OF IDENTITY IN A JAPANESE WORKPLACE 121–41 (1990); Sharon Traweek, *Cultural Differences in High-Energy Physics: Contrasts Between Japan and the United* States, *in* THE 'RACIAL' ECONOMY OF SCIENCE 398 (Sandra Harding ed., 1993).

> *Exam question: A key struggle for British engineers has been to establish themselves as "professionals." Explain the significance of this concept for British engineers by describing (a) the social class position of British engineers in the early nineteenth century and (b) how British engineers have used professional societies to advance their cause over the past two hundred years.*

> *Exam question: Does what BMWs do for Germany today compare in any way with what music did two centuries ago? In other words, explain the evolving roles engineering has played in the development of Germany as a country, and show how engineering education has been structured to fulfill these roles.*

Much of the daily work in Engineering Cultures involves systematically tracing linkages among emergent patterns in engineering practices and evolving dominant images of progress in different countries. Students are typically surprised to learn that, where French engineers have tended to place highest value on mathematical theory and aspire to work in government where they have constituted the highest-ranked occupation in the country, British engineers have continued to place high value on forms of practical knowledge and work in the private sector where, to this day, they constitute a relatively low-ranked occupation.[33] German engineers have exhibited yet other dominant practices, having attained the status of highly-valued workers only after the German unification in 1870 and then later of model German citizens, albeit in two distinct levels, through their commitment to precise, high-quality "technics."[34] As elaborated in a 2004 publication,[35] the analysis used in the course treats these patterned practices among engineers as responses to distinct images of progress. Such images include, corresponding to the cases above, advancing toward a future state of perfection that can be modeled mathematically, improving over the past through material comfort measured by increased distance from manual labor, and increasing emancipation and incorporation into human society of *geist*, or essential mind-spirit.

Because Britain and France had extensive colonial networks, emergent dominant practices among engineers in many countries exhibited responses to mixes of influences from colonial and domestic sources.[36] The United States, as a former colony of Great Britain and early ally of France, developed an unusual commitment to a "balance" between practical and mathematical knowledge in the pursuit of progress through the expansion of low-

33. *See* Downey & Lucena, *supra* note 10, at 393.

34. *See id.* In this context, the term "technics" refers both to technological outcomes and the processes for producing them.

35. *See id.*

36. *See, e.g.*, Juan C. Lucena, *De Criollos a Mexicanos*: *Engineers' Identity and the Construction of Mexico* [*From Creole to Mexican: Engineers' Identity and the Construction of Mexico*], 23 HIS. & TECH. 275 (2007).

cost production for mass use.[37] In Egypt, one finds responses to influences not only from the French, British, Germans and, more recently, Americans, but also efforts to recreate the past glory of Egyptian civilization and an economic union of Arab states.[38] In Japan, one finds explicit appropriations of British and German practices of engineering education beginning in the Meiji period, as well as appropriations of American practices after World War II.[39] Moving from case to case, the course seeks to throw into relief transnational dimensions of the present by showing how engineers have, since the eighteenth century, positioned themselves as agents in the construction of countries.

Accordingly, each module grapples with roughly four sets of historical questions. First, how did this country emerge? What were the key geographical, historical and demographic dimensions of its emergence? What has counted as "progress" or "advancement" in this context? Second, how have engineers emerged in this country? What has it meant to be an engineer? What knowledge have engineers valued, and how has this emphasis changed over time? Third, what is work and everyday life like for engineers? What counts as engineering education, and how has engineering education changed over time? Where do engineers work, and what is a typical career trajectory for a prospective engineer? Fourth, what trends are emerging today in relationships among engineers and countries? In particular, how are engineers grappling with images of economic competitiveness and globalization that direct their attention beyond the boundaries of countries?[40]

In a knowledge course, the assessment of students must include knowledge work. The exams in Engineering Cultures are structured to "feel" like engineering exams in that they require students to demonstrate that they have been systematically completing their reading, attending class and paying attention. While some exams do have short essays requiring fifteen to twenty minutes of writing, fifty-minute exams usually consist of seven to eight questions calling for four to five sentences each. The questions are distributed evenly across the material covered since the last exam, with highest importance granted to material found both in readings and in class discussion, followed by material in class discussion only (to reward class attendance), and then material found only in the readings (to reward the completion of reading assignments).

37. *See* Gary Lee Downey, *Low Cost, Mass Use: American Engineers and the Metrics of Progress*, 23 HIS. & TECH. 289 (2007).

38. Osman, Lotfy, El-Sayed et al., *Engineering and Engineering Education in Egypt*, 25 IEEE TECH. IN SOC'Y 17, 17–24 (2006).

39. *See* Gary Lee Downey et al., *Engineering Ethics in Comparative Perspective*, 13 SCI. & ENG'G ETHICS 463 (2007).

40. For elaboration of this last point, see Juan Lucena et al., *Competencies Beyond Countries: The Re-Organization of Engineering Education in the United States, Europe, and Latin America*, J. OF ENG'G EDUC. (forthcoming 2008).

III. Occupying Other Perspectives: The Question of Alternative Practices

Homework: For this assignment, draw on readings and class discussions about engineers in Europe, and construct a three-way dialogue. The conversants in the dialogue include representatives from two of the three countries and yourself. Assume the others are classically trained in their respective countries. Then, take some time and discuss amongst yourselves the differences in images you all share, how these might have come about, and especially how the other two might be impacting you right now. Feel free to include, in absentia, the third country's engineering tradition (but don't be too harsh on someone who isn't there to defend him/herself). Be as creative as you wish to be in setting the scene and developing the characters, but please limit your conversation to two pages.

Homework: Imagine you are the Poet-Laureate of the Soviet Union. Compose the equivalent of two double-spaced pages of poetry that captures the spirit of idealism that was built into the Soviet system and state. Poetry is an especially good genre for distilling the emotional content of a particular experience. For decades, mention of the Soviet Union evoked strong feelings around the world. See if you can describe and locate in historical context the emotional contents of Soviet dreams, aspirations, policies and plans, and their implications for engineers.

While understanding positions other than one's own depends upon knowing that other positions exist, such knowledge is insufficient preparation for engaging people who inhabit these positions as something other than differently-located travelers in a common reality. Engineering Cultures offers students practical experience in occupying different "perspectives," whether by role-playing distinct perspectives in class, in homework assignments, debating alternative views in threaded discussions or, again, in class. In homework assignments, students tend to perform alternative perspectives in stereotypical fashion, using their new knowledge of patterns to generate thin characters. Student-produced dialogs among European engineers, for example, routinely include French engineers who care only about theory and British engineers who focus only on craftsmanship. Students, however, still take the key step of dividing the world into more than two parts. In drafting Soviet poetry, students must move beyond a view of communism as simply "bad" or "wrong" and attempt to perform socialist idealism through a genre calling for emotive expression. In threaded discussions, students practice expressing disagreement with one another without dismissing interlocutors as simply incorrect or wrong. In class, instructor-led role playing or staged disagreements serve as a way for the instructor to model the occupation and, indeed, performance of different perspectives.

The practice of inhabiting different perspectives calls attention to the importance of problem definition as a dimension of engineering work. For example, while the specifics of work encounters always depend upon their circumstances, an American engineer who is solving a mathematical problem while also responding to a challenge to "be an individual" and seek "low-cost production for mass use" may understand the problem differently than a Japanese colleague who is also responding to a challenge to "fulfill obligations" and seek "harmony." If alternative definitions of a problem are likely to have different implications for the identities of those participating in the process, then it may be useful to take account of these at the outset rather than waiting to cope with them at the conclusion. By studying patterns in engineering identities and then practicing the performance of different perspectives, engineering students can begin anticipating working with people who define problems differently without asserting that such people: (1) somehow live in different realities, which can seem foolish to engineers committed to a singular reality; (2) are simply puppets of deterministic cultures, which constructs more barriers than it eliminates; or (3) are autonomous agents, which makes anticipation and prediction impossible.

> *Exam question: Explain how the mechanical engineer emerged in the United States, including the general time period and their key role within U.S. industry. Be sure to describe how these early mechanical engineers were trained. In addition, briefly identify how other engineering fields later emerged from mechanical engineering, and give at least one example.*
>
> *Homework: In class we have discussed two recent reform movements in engineering education, one working to expand participation from women and underrepresented minorities and another working to change engineering curricula to make engineers more flexible. Based on your experiences as a student, how would you change the way that engineering is taught in the United States? In one to two double-spaced, typed pages, develop a proposal for your ideal engineering educational model. Use a memo format for your document (you may address your memo to college administration, faculty, other students, etc.) and try to make a persuasive argument. Explain what changes you are proposing and back up your suggestions with evidence. Convince the reader that your plan is a good one! Also identify at least one perspective that may not agree entirely with your proposal, and briefly summarize the concerns that might be expressed about your proposal. You may use outside sources to develop your proposal, but be sure to provide citations for them.*

After traveling the world briefly and understanding other perspectives, the course returns home and examines the operations of differences among engineers in the United States—differences that live within the classroom itself. Pedagogically, this process can be most difficult when it means convincing students that positions other than their own, for which they already have pejorative labels, may be sites of legitimate alternative perspectives.

The practical strategy is to start by examining historical episodes and applying the method they have been mastering. Asking engineering students to locate themselves historically can be problematic because many have already positioned history as valuable only if it has utilitarian value in problem solving. When asked, "why study history?," some students always respond, "to avoid the mistakes of the past." Not understanding the limitations of the archival record, these students are not aware that the mistakes of the past can be difficult to find. Most have been buried. Furthermore, having explored the emergence of engineering identities in other contexts, students are now better prepared to understand that, when historical contexts change, what counts as successes and failures also change. Even a thorough understanding of past mistakes may offer little guidance to the present and future.

Students are quite interested in the origins and emergence of their engineering fields. They typically find it meaningful to learn that, whereas civil engineering in the United States continued trajectories that had originated in France and Great Britain, mechanical engineers were born inside the manufacturing shop during the mid-nineteenth century. Indeed, mechanical engineering emerged from the role of the shop superintendent through the same "scale-up" to mass production, which also generated what became known as "unskilled labor."[41] Other fields also emerged, drawing from both mechanical engineering and new sciences.[42] Thus, putting it in overly simplistic terms, adding physics to mechanical engineering produced electrical engineering, adding chemistry produced chemical engineering, adding social science produced industrial engineering, and so on.[43]

Students also easily understand and appreciate the emergence of a contrast between "design" and "manufacturing" engineers. This case is especially useful because engineering students may already understand and accept that more than one legitimate side appears to exist in this separation, both sides arguably possess knowledge important to industrial production, and yet, engineers typically end up on one side or the other. It is commonly said among engineers, for example, that design engineers throw their designs "over the wall" and force manufacturing engineers simply to cope with what is tossed their way.[44]

41. *See* Monte A. Calvert, The Mechanical Engineer in America, 1830–1910: Professional Cultures in Conflict (1967).

42. *See, e.g.*, Terry S. Reynolds, 75 Years of Progress: A History of the American Institute of Chemical Engineers 1908–1983 (J. Charles Forman & Larry Resen eds., 1983).

43. Lecture Notes of Gary Lee Downey, Engineering Culture (on file with author).

44. Author's observation.

Much more difficult is the articulation of perspectives among engineers that differ according to how they respond to dominant images of sex and race. Indeed, the most problematic moments of the course come when students directly confront the question of whether and how responding to biological stereotypes may play a role in distinguishing engineers from one another. The course limits itself to applying its now-routine method of analysis, which identifies dominant cultural images that confront engineers and then hypothesizes that engineers respond to different "configurations" of dominant images in different, but often patterned, ways. The case stands out because, although the images to which students must respond exist at large scales, they do not regard progress or the country.[45]

When engineering students see themselves as responding only to the dominant image of engineering problem solving, all of them become "alike." That is, all engineering students have to "prove" they are "rational," "capable" and "disciplined." When students see themselves as responding also to biological stereotypes of sex and race and not just classified by biological categories, the perspectives they hold begin to differ from one another. To take only one example, those students who are classified biologically as "white men" find themselves responding to a challenge to "prove" they are "strong" and "capable" as well as the additional challenge to prove themselves in engineering. White male students do not have to resist the stereotypical white man in order to become engineers. By contrast, female engineering students (i.e., those students who are classified biologically as "women" and who are working to prove themselves as rational, capable and disciplined engineers) do indeed have to resist, or at least figure out a way of coping with, a biological stereotype of being naturally "emotional" or "nurturing" human beings. Similarly, African-American students have to cope with an expectation that they are naturally "undisciplined" or "lazy."[46]

Differences emerge in the perspectives students occupy as students respond to these different configurations pertaining to sex and race. While some women may adopt the perspective that, "I'm not a woman engineer, I'm an engineer who happens to be a woman," others may assert that, "I *am* a woman engineer!" Similarly, while some black engineering students may respond, "I'm not a black engineer, I'm an engineer who happens to be black," others assert may assert that, "I *am* a black engineer!" The implications of such differences for problem solving become clear when students then discuss the appropriateness and value of diversity programs that seek to increase the extent to which women and minorities are represented in engineering. The white male engineering student who sees all engineering

45. A brief, schematic summary of an argument requires more in-depth analysis and sufficient evidence to make it demonstrably plausible.

46. Stacey J. Lee, *Up against Whiteness: Students of Color in Our Schools*, 35 ANTHROP. & EDUC. Q. 121, 123 (2004).

students as "the same" may be inclined to criticize diversity programs as giving differential "assistance" to some students. By contrast, someone who advances the identity of a "woman engineer" or a "black engineer" may be more likely to support such programs than someone who advances the identity of an engineer who happens to be a woman or happens to be African-American.

Exam questions that ask students to articulate the emergence of different perspectives among engineers reinforce the course's claim that such differences exist and are significant to engineers. Homework questions, such as the above assignment to formulate and justify a reform movement in engineering education, ask students to practice taking action in ways that acknowledge and take account of the presence of different perspectives. When this combination of strategies works best, which it does to an encouraging but still grossly insufficient extent, white male students in the class come to reclassify themselves as privileged while nonwhite, non-male students have new arguments about what makes the configurations of challenges they face in engineering different from those of white men.

IV. Linking Problem Definition to Problem Solving: The Question of Fit to Dominant Practices

Once the classroom has been fully populated with differing perspectives both far and near, the course turns to formalize the acquisition of competence in engineering problem definition by naming the practices they have been applying informally in class discussions and assignments as "Problem Definition and Solution."[47] Also, the term "Location, Knowledge and Desire" now appears as a formal mnemonic device naming the actual steps one might take in its implementation. Since this expansion of the engineering method arises from a liberal arts elective rather than an authoritative directive from their majors, the act of naming comes at the end of the learning process. Operating as both a curricular outsider and a wannabe insider, the course focuses on training engineers to accept and practice the method on their own terms before hypothesizing levels of legitimacy and rigor that, in fact, do not yet exist more broadly. The link between problem definition and problem solving thus remains provisional, depending upon the willingness of students to accept the value of collaborative problem def-

47. Naming these practices "Problem Definition and Solution" is a recent addition to the course, and it is a product of research undertaken in 2005 and reported in Gary L. Downey, Keynote Address: Are Engineers Losing Control of Technology? From "Problem Solving" to "Problem Definition and Solution" in Engineering Education (June 2005). Previously, the course had presented practices of problem definition as a supplement to competence in engineering problem solving. The change in 2005 was to show that engineering problem definition is a core competence alongside engineering. Juan Lucena and colleagues at Colorado School of Mines drew on the model of engineering as Problem Definition and Solution in their new course Engineering and Sustainable Community Development.

inition and to share it with others. In brief, the addition of collaborative problem definition involves the following:

> *First, identify each perspective that's around you and involved in the decision you face. Remember that problems often mean different things in different perspectives. You might be facing different disciplinary perspectives, career perspectives, corporate perspectives or national perspectives.*
>
> *To help you think through the features of each perspective you encounter, consider using the words "location," "knowledge," and "desire."*
>
> *Location: Who is defining the problem? Where are they located, or how are they positioned? Consider a debate between design engineers and manufacturing engineers. How do they get in their positions? Do you know anything about the history of their positions, and what led to the particular configuration of positions you have today on the job? Where are the key boundaries among different types of groups, and where are the alliances? All of these issues are crucial to consider while locating the perspectives you encounter.*
>
> *Knowledge: What forms of knowledge do the representatives of each perspective have? How do they understand the problem at hand? From what sources did they gain their knowledge? By virtue of advancing our own perspectives, we are inclined to treat other perspectives as somehow fundamentally irrational. Yet, at the same time, we might be dealing with people who are highly trained, have degrees, and are thinking through issues very seriously. So what forms of knowledge do they have? What are their assumptions? How did this knowledge evolve? So thus far, we have located relevant people in positions and then attempted to figure out what sorts of knowledge are built into their perspectives.*
>
> *Desire: What do the proponents of each perspective want? What are their objectives? How do these desires develop? Where are they trying to go? Learn what you can about the history of the issue at hand. Who might have gained or lost ground in previous encounters? How does each perspective view itself at present in relation to those it envisions as relevant to its future?*
>
> *Second, as one moves to formal problem definition, ask: "Whose definition is this?" Remember that defining the problem clearly, the consummate traditional engineering act, may very well assert one perspective at the expense of others. For me to define the problem in a way that might be clear in my terms just might not be clear in your terms. Once we think about problem solving in*

> *relation to people, we can begin to see that the very act of drawing a boundary around a problem has non-technical or political dimensions, depending on who controls the definition, because someone gains a little power and someone loses a little power. The core of mathematical problem solving by people includes politics.*
>
> *Third, begin moving from mapping perspectives to formulating resolutions by asking yourself: "Does a possible resolution fit, and whom does it fit?" More than likely, resolutions that occur to you fit your perspective best. But think things through. Does it fit other perspectives as well? Take a look, for example, at Perspective A. Does your resolution fit the location of those who represent this perspective? Does it fit their knowledge? Does it fit their desire? Now take a look at Perspective B. Does this possible resolution fit their location? Does it fit their knowledge? Does it fit their desires?*
>
> *Completing this step requires considerable effort, for it involves stepping outside of one's own perspective and attempting to see how one is positioned in other perspectives. It means accepting the discipline of an outsider.*
>
> *Fourth, to the extent you find that disagreement exists or that the achievement of fit is insufficient, begin asking yourself: "How might I adapt my perspective to take account of the other perspectives out there? Is there some way of accommodating myself to other perspectives rather than just demanding that the others simply recognize the inherent value and rationality of mine?" Is there room for compromise among contrasting perspectives?*

Loading collaborative problem definition into the front end of engineering work has the effect of repositioning the engineering sciences as one set of resources among many for engineers to use. That is, the engineering sciences are no longer *the* foundation or core of all engineering activity; rather, they become one crucially important resource alongside other important resources that now pertain to engineers engaged in collaborative problem definition with both engineers and non-engineers.

Formally incorporating problem definition into engineering work also has the effect of transforming the engineering concept of "trade-offs." A term that typically means trade-offs between alternative objectives or constraints now also means trade-offs between what might be good for one perspective versus what might be good for another. In other words, when one makes visible the alternative perspectives at stake in a given situation, the trade-off becomes:

> Will this solution be good for them? Good for me? Perhaps a particular decision was good for one, Perspective A, now. Per-

haps next time, we might formulate a solution that's good for the other, Perspective B. Or maybe we can reformulate our solution in a way that works better for both.

The existing concept of trade-offs presumes a single perspective that balances more than one benefit or more than one cost. However, the concept of trade-offs can now become one that increasingly involves resolving differences among distinct perspectives.

Take-home essay: The Reflections Assignment provides you an opportunity to chart your growth throughout Engineering Cultures. It is a two-part assignment in which you explore your personal experiences, relationship to others and problem solving methods, with the second part providing a more in-depth follow-up to the first. For the second: Go back and re-read your first reflection assignment. Also review your old homework assignments and notes. Then reflect on the entire semester of Engineering Cultures, the concepts and readings from class. Reflect on how you engaged this material and any concepts with which you struggled. In two and a half to three pages (approximately 625–750 words), share your evaluation of how well you met your goals, engaged with course concepts and readings, changed or developed in perspectives/problem solving, and your personal growth. Please feel free to share personal experiences of how you experienced course concepts in your own life.

The course concludes by asking students to assess who and where they are now after having taken the course. Even if students judge Engineering Cultures to have had no influence on them, they have to articulate how and why, thus adopting and defending a perspective in the process. The results tend to be quite positive, but by no means universally so. Over the past decade, roughly sixty percent reported the course to be an experience of major significance in their professional training.[48] As many as thirty percent saw themselves as profoundly transformed, viewing themselves as having a much deeper understanding of how to make engineering judgments in the working world. For another thirty percent, the course was well worth the effort, for it provided new insight into engineering problem solving and the world of engineering work. Of the remaining forty percent, perhaps half were moderately positive, feeling they learned some things they can use down the road but do not see themselves or their work as significantly transformed. Approximately fifteen percent expressed concerns of the sort that the course "was an awful lot of reading . . . and writing . . . , etc., etc." These students resist the challenge to incorporate new practices in their engineering work and appear to look forward to returning to the relative se-

48. These data and the data in following sentences are rough estimates based on reading Part 2 of the students' Reflections Assignments. We have not conducted a rigorous study of these contents. For a more detailed assessment of student learning in the course describing those instruments we have developed and implemented, see Downey, *supra* note 14, at 12.

curity of engineering courses. For the remaining five percent, Engineering Cultures was one of the worst experiences of their college lives, if not the worst, for it was either deeply threatening or, worse, thoroughly irrelevant. Helping students rethink agency is not always easy to accomplish.

V. Limitations of Engineering Cultures: The Question of "Scaling Up"

The historian Ken Alder accounted for the "other-directedness" in engineering knowledge and personhood by showing how eighteenth century artillerists working within the absolutist French monarchy developed a version of what we now know as engineering analysis to transform their identities and increase their status.[49] The artillerists based their legitimacy, not on birth and social status, but on their demonstrated facility with a "middle epistemology" of mathematical reasoning, which linked theory to practice in order to help society "progress" in new ways.[50] "Their method, deceptively straightforward," Alder observed, "was to describe quantitatively the relationships among measurable quantities, and then to use these descriptions to seek a region of optimal gain (as they defined it)."[51] In achieving significant improvements in ballistics, gunnery design, etc., they played the key role in replacing the longstanding system of siege warfare with more mobile methods of combat.[52] Applying these insights within the state in order to build its operations on a more rational foundation, "[e]ngineers," Alder concluded, "were *designed* to serve."[53]

The sense of service, or "other-directedness," that has long been built into the practical reasoning of engineering problem solving, and hence into engineers as agents, may perhaps be more important today as the expansion of multinational industry has populated the world with organizational identities defined by the maximization of self-interest. However, might an "other-directedness" that waits to be told what to do, or waits to be handed problems to solve, increasingly prove to be a fundamental self-limitation that risks eroding engineering into pure technical support?[54] For engineers to take responsibility for theorizing and articulating the problems that confront not only their employers but also other stakeholders, they seemingly have to extend themselves beyond the practices of engineering problem solving. To make a difference beyond obedient service, they have to transcend the so-called engineering method. Can that method be extended to support and enable engineers to be critical leaders?

49. Ken Alder, Engineering the Revolution: Arms and Enlightenment in France, 1763–1815, at 60 (1997).
50. *Id.*
51. *Id.*
52. *See* Alder, *supra* note 49.
53. *Id.* at 86.
54. Downey, *supra* note 9, at 583 (2005).

Key potential benefits from increased attention to problem definition in engineering formation include enhancing students' abilities to participate in decision making, creating leaders who listen and producing active mobilizers of support for perspectives that take account of other perspectives. One often hears in engineering education circles about the importance of engineers learning to communicate. What that usually means is improved ability in public speaking. Engineering Cultures focuses on what is perhaps a more important prerequisite to leadership: listening. Good communication arguably depends on listening to other people, hearing their perspectives, thinking through the contents and then acting in ways that respect their existence and take them seriously into account.

The dominant image of what liberal arts education accomplishes is the exercise of "critical thinking."[55] Achieving critical thinking typically means developing the ability to identify and analyze dimensions of human experience in the present in ways that facilitate imagining how things could have been different and, hence, could be different in the future.[56] In other words, critical thinking strives to make visible what has been hidden in the images that dominate the present. Depending upon a sharpened ability to listen, the attainment of critical thinking is judged to be a crucial dimension of intelligent judgment, whether one is functioning as a decision maker on the job or as a citizen in everyday contexts. One cannot propose what things might become if one is not accomplished at imagining how things might have been otherwise in the first place.

What counts as instruction in critical thinking in elective courses for students who are headed elsewhere, such as engineering students? Is gaining the ability in some courses to identify new dimensions in the present sufficient to achieve critical thinking when practical reasoning in the majority of one's courses pushes the student in another direction? Engineering students often use their credits in the humanities and social sciences to enroll in courses that introduce them to psychology, sociology, anthropology, etc.[57] Each of these makes students aware of the complexity of dimensions that might otherwise have appeared opaque. Such is also often the approach taken in interdisciplinary humanities or social sciences courses geared specifically for engineering students. For example, a course focused on emerging biosciences or information technology might enable students to see the social, political, ethical and other "value" or "human" dimensions of science and technology.[58] All of these can substantially expand the scope of

55. For elaboration, William M. Sullivan & Matthew S. Rosen, A New Agenda for Higher Education: Shaping a Life of the Mind for Practice (2008).

56. *Id.*

57. Confidential Interview, Senior Administrative Official in the College of Engineering (Jan. 2000).

58. For many years, my interdisciplinary courses for engineering and science students focused on making visible the myriad of nontechnical dimensions in technical issues and problems. I was helping students become aware of complexity and, to some extent, distinguish its features.

vision that engineers bring to their work. Yet, will these experiences provide students with sufficient guidance in practical reasoning after they have completed professional formation and find themselves confronting such complexities on the job? If the new awareness of complexity that students gain has not been coupled with practical training in applying such vision to problem solving, will engineers accept the challenge of adapting their methods of work, or, perhaps more likely, will they retreat to more comfortable and familiar modes of operation?

The typical liberal arts experience in the context of professional formation places responsibility on learners to articulate and implement the practical benefits from such expanded vision. Might relying entirely on students to theorize and enact integration from the liberal arts actually limit the extent to which students attracted by critical thinking are actually able to attain it, as well as maintain it beyond classroom discussion? Education in the liberal arts is rightly geared toward the education of citizens, but it is also nearly always engaged in the preparation of citizens with careers. Some liberal arts educators may resist the idea of participating in professional training more directly, concerned about selling out the liberal arts to utilitarian projects defined in industrial or national terms. Is it not the case that limiting the extent to which liberal arts education actually engages engineering education also limits the extent to which students learning engineering problem solving can benefit from the liberal arts use of critical thinking?

If the liberal arts courses that engineering students encounter assume that students are looking to become critical thinkers and only need guidance in identifying the relevant dimensions to consider, might these courses be missing the mark completely with non-liberal arts students who might be challenged to keep aspects of their identities invisible in their work? Might giving explicit attention to how practical reasoning in the liberal arts can enable students to become adept at critical thinking actually be an important strategy for advancing and extending the liberal arts education, rather than restricting it or selling it out? To the extent that broader acceptance of the value of the liberal arts education depends upon more than its championing by liberal arts graduates, then not only do the liberal arts have something valuable to offer engineering students, but it also needs them to affirm its credibility and legitimacy. Linking practical reasoning from the liberal arts to practical reasoning in engineering and other professions is not selling out the liberal arts education; it is helping to guarantee its future.

Engineering Cultures students who learn to identify and assess the implications of images that feel real because of their dominance also learn that every image makes some things visible while hiding others. Such is as much the case for an image of engineering as problem definition and solution as it is for the original image of problem solving. The Engineering Cultures syllabus imagines itself as a critical participant in engineering education and can even cite supporting evidence to that effect from its interactions with engineering students. It is one thing, however, to enact a course-level plan for integrating competence in collaborative problem definition and quite another to "scale it up" across the whole of an engineering curriculum. Can the practices of collaborative problem definition be "scaled up" across engineering education as well as other forms of professional formation?

The main source of resistance in engineering lies in the fact that the image of competence in mathematical problem solving continues to dominate the core of engineering curricula, despite many important interventions on the front and back ends.[59] Engineering Cultures lives as an elective, thus it draws sustenance by attracting students away from other potential electives. "Scaling up" training in collaborative problem definition (i.e., successfully integrating its practices within engineering curricula to the extent they become taken for granted) minimally requires extending its practices across more than one course. Naming the expanded practices of problem definition and solution that students have been implementing in class completes an introduction to those practices, but it is also only a starting point. Students also need to examine case examples of successful and unsuccessful problem definition in the midst of conflicting perspectives. Working alongside other students, they need to participate in, and reflect critically upon, practical exercises of engineering problem definition with both engineers and non-engineers.

Achieving a more thoroughgoing integration of problem definition with problem solving likely requires reformulating what counts as education in the engineering sciences. The image of engineering as problem definition and solution relocates the engineering sciences from the "absolute core" of engineering education to "crucially important resources" for engineering work. If engineering faculty found themselves having to compete for students rather than being able to count on department requirements to deliver enrollments, perhaps such faculty would be more motivated to explain how and in what circumstances kinematics, fluid mechanics, etc., serve as key resources in situations requiring engineering judgment. Having to compete with one another for students might also challenge faculty to bring into their classrooms the passion for their subjects they exhibit in faculty meetings. One can reasonably assert that all of the engineering sciences map interesting and beautiful mathematical worlds. What would happen to engineering pedagogy if engineering faculty and students indeed

59. Informal finding from the reading of student responses to Part 2 of the Reflections Assignments and a common personal observation at meetings of the American Society for Engineering Education. For further analysis of the centrality of mathematical problem solving, see *Engineering Selves*, *supra* note 4, at 117–42; *When Students Resist*, *supra* note 4, at 168 (2005).

viewed those worlds as separate, only partly overlapping and on call as needed, but not as the absolute core of engineering problem solving?[60]

In sum, the practices of Engineering Cultures are far from gaining widespread recognition and legitimacy in relation to the dominant practices of engineering formation. To the extent the course does successfully build competence in problem definition in ways that complement the existing development of competence in problem solving, the Engineering Cultures syllabus has at least taken the first key step in "scaling up" alternative practices and associated knowledge. It is difficult for engineering students to reject the syllabus as an outsider.

VI. Conclusion

For the critical contribution to professional formation seeking to challenge learners who see themselves as headed elsewhere, its key challenge is to structure its pedagogy (i.e., its strategic engagements with learners) in ways that take into account at the outset how those learners understand or position learning activities. It must address the *question of knowledge and personhood*. In the case of professional training, the challenge to personhood is from forms of knowledge engaged in service. What sort of outsider is this experience? Does it appear to pose particular dangers to quality judgment, or, worse, is it simply irrelevant? To be "not an outsider" for students pursuing other pathways, the purported intervention must demonstrate an understanding of the existing practical challenges students experience from instruction in the dominant practices of judgment in their field.

In order to intervene effectively in those challenges and make a difference in the learner's development of competence, the critical contribution must also take care to demonstrate something new and beneficial. It must address and grapple with the *question of alternative knowledge*. In so doing, the new knowledge must move beyond the simplicities of external critique, attendant comforts of resolute pessimism and the ad hoc contribution of supplementary information. That is, the critical contribution must venture down the treacherous pathway accepting the twin risks of cooptation by dominant existing practices, on the one side, and rejection as arrogant, external intrusion on the other. It must accept the *question of alternative practices*.

Furthermore, this critical participant must structure its practical experiences so learners find these relevant to the challenges that populate daily experiences in existing programs. Changes for the future always have to begin with what is positioned as given in the present. Even fundamental challenges to the hegemony of dominant practices have to address the *question of fit with dominant practices*.

60. For an overview of curricular strategies for "scaling up" attention to problem definition, see Downey, *supra* note 9.

Finally, the critical contribution necessarily depends upon the agencies of audiences. To formulate a vision and expect it to succeed through diffusion through the sheer force of virtuosity is likely to guarantee silence. Critical participation necessarily involves addressing the *question of "scaling up*." The task of "scaling up" involves extrapolating the activities of critical participation with students into parallel, analogous and complementary activities for all audiences positioned in a significant power relation to the existing dominant practices of professional formation. "Scaling up" a new image and achieving "givenness" in the curriculum is a process of attaining referential closure and broad acceptance of its link between concept and object. Successfully achieving such closure for new practices in relation to existing hegemonic practices, as well as maintaining an openness to future change, demands hard, persistent and creative work and the contributing agencies of all those who have been persuaded to accept its value.