Engineering Knowledge and Student Development: An Institutional and Pedagogical Critique of Engineering Education

by

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ABSTRACT

Educators have recommended the integration of engineering and the liberal arts as a promising educational model to prepare young engineers for global economic, environmental, sociotechnical, and ethical challenges. Drawing upon philosophy of technology, engineering studies, and educational psychology, this dissertation examines diverse visions and strategies for integrating engineering and liberal education and explores their impacts on students' intellectual and moral development. Based on archival research, interviews, and participant observation, the dissertation presents in-depth case studies of three educational initiatives that seek to blend engineering with the humanities, social sciences, and arts: Harvey Mudd College, the Picker Engineering Program at Smith College, and the Programs in Design and Innovation at Rensselaer Polytechnic Institute. The research finds that learning engineering in a liberal arts context increases students' sense of "owning" their education and contributes to their communication, teamwork, and other non-technical professional skills. In addition, opportunities for extensive liberal arts learning in the three cases encourage some students to pursue alternative, less technocentric approaches to engineering. Nevertheless, the case studies suggest that the epistemological differences between the engineering and liberal arts instructors help maintain a technical/social dualism among most students. Furthermore, the dissertation argues a "hidden curriculum," which reinforces the dominant ideology in the engineering profession, persists in the integrated programs and prevents the students from reflecting on the broad social context of engineering and critically examining the assumptions upheld in the engineering profession.

1. Introduction

1.1 The incessant reform

If we read the history of American engineering education, the word "reform" seems never far from the center of engineering educators' minds (Wickenden 1944; Gross 1969; Mosteller 1981; Wulf 1998; Felder, Stice, and Rugarcia 2000; Galloway 2007). A few years ago, the Accreditation Board for Engineering and Technology (ABET) formally required engineering graduates to be "lifelong learners" (Engineering Accreditation Commission 1998). Numerous engineering educators, however, had long before become "lifelong reformers." Such persistent zeal to reform should have brought significant changes to engineering education over the past half century, thus it might surprise the readers who are not familiar with this field that in some crucial respects few substantial changes have happened to how most engineers are educated.[1] Perhaps it is worth asking what it is in engineering education that the reformers repetitively try to change, and what accounts for their failure to achieve this goal?[2]

One of the answers might be the reformers remain a minority in the corps of engineering educators. After all, engineering educators, much like their colleagues in professional engineering, have the reputation of doing their job the way it has been done before. It just so happens that the virtue of being conservative often goes hand in hand with that of being quiet, thus the more vocal reformers might well misrepresent the determination of the community of engineering educators to renew itself. That said, reform can hardly be dismissed as mere "bouquet projects" in engineering education. Historians of American engineering education would recite numerous serious efforts toward change: the adoption of the ABET EC 2000, the creation of new engineering colleges (e.g., the Franklin W. Olin College of Engineering) and programs (e.g., the Picker Engineering Program), the National Academy of Engineering (NAE) Grand

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[1] Not a few senior engineering educators have expressed their disappointment at the lack of change in the field (Grasso and Burkins 2010). At the 2011 Annual Conference for the American Society of Engineering Education (ASEE), a retired professor contended that the ABET Engineering Criteria 2000 (EC 2000) brought few real changes, because the program evaluators hired by ABET have been trained in the old fashion and think in old terms (personal communication).

[2] Historians have examined engineering educators' recurring attempt to reform engineering education (Seely 2005; Akera 2011).

Challenge Scholars Program, the Engineering in K-12 Education Project (Katehi, Pearson, and Feder 2009), the campaign to increase diversity in engineering, and others. These are but a fraction of significant reform initiatives during the last decade or two.

The juxtaposition of numerous reforms and their scant outcomes raises a series of questions: Is "reform" just a quibble engineering educators are used to pronouncing? Or is it a serious project repeatedly attempted because systemic problems in engineering education are never sufficiently addressed? Might it be that piecemeal changes have occurred from time to time but some essential features of engineering education, the fundamental nature of engineering, or even the forces that give shape to engineering remain pretty much the same or get reinforced year after year? To get a sense of these issues, look at some recent discussions about reforming engineering education:

> The productivity of local engineering groups can be markedly enhanced by globally dispersed 'round-the-clock' engineering teams. Conversely, the disparity in wages may make outsourcing of engineering jobs the dominant feature of global connectivity. Other nations may learn from the lessons of China and India that educating their young people as engineers provides a ready pool of talent to be employed at home in engineering jobs outsourced from the high-wage-cost developed countries. In the United States this may have a chilling effect on domestic job opportunities. (NAE 2004, 39-40)

> The end of the Cold War and the shift from defense work has put pressure on university research to accept funding from industry for shorter term product- or process-oriented research. Meanwhile, industry has decreased its own in-house fundamental engineering research, making it even more important that universities conduct advanced basic research. Thus, this is a part of the engineering education infrastructure that must be preserved, but, at the same time, it must not lead to the neglect of the undergraduate engineering education experience. (NAE 2005, 2)

> In the 21st century, an ever-increasing need will emerge for a holistic breed of engineer—one who can work across borders, cultural boundaries, and social contexts and who can work effectively with nonengineers. As the trend toward a more global and more knowledge-based society continues, the practice of engineering must be changed, and this change must be accomplished through engineering education reform.

> The engineering curriculum can no longer remain as it has for essentially the past 40 years. The subjects of globalization, diversity, world cultures and languages, communication, leadership, and ethics must constitute a core component of the overall engineering education just as physics and mathematics do. (Galloway 2007, 46)

These voices indicate that the reforms they advocate are in part motivated by the following challenges facing engineering education.[3]

First, the condition of engineering practice is being reshaped by a globalized economy (Lucena et al. 2008). The end of the Cold War entailed a shift of focus in engineering from serving military might to serving economic prowess.[4] Accordingly, in the eyes of some engineering educators, the "applied science" paradigm which drove engineering education for decades should be replaced with alternative models that are responsive to new demands of high-tech innovation, design, business start-ups, etc.

Second, the reduction in governmental funding for military research and development (again thanks to the end of the Cold War), the dominance of an anti-spending governmentality, and economic hardships create a funding crisis for higher education. Colleges today have to either do the same work with less resources[5] or do more with the same amount.[6]

Third, contemporary society is witnessing the emergence of ethical uncertainties (and/or scandals), socio-natural catastrophes, and threats to public safety and welfare (NAE 2004; W. Perry et al. 2008). Some of these challenges call upon engineers' solutions; others are targets selected by engineers to continue their glorious tradition of

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[3] These challenges are presented by the "internalists," members in the community of engineering and engineering education. While partially representing the reality faced by engineers, these challenges reflect much of the engineering profession's self-understanding and its assessment of the relation between engineering and society. In some cases, the framing of the challenges and the proposed solutions have been critiqued by scholars outside engineering.

[4] The shift from military to economic strength and the reduction of federal funding for military research and development is suggested in the ASEE Green Report (Engineering Deans Council and Corporate Roundtable 1994).

[5] This is mainly the case in the U.S. Some engineering educators have suggested online education as a means for cost reduction (Vest 2012).

[6] This is the case in social democratic countries like Denmark (Akera and Tang, forthcoming).

serving the public good, although such glory is not without dispute. While some people view these "grand challenges" as opportunities for engineers to reaffirm their importance (in the post-Cold War world) and to play a more central role in technological civilization, others see the challenges as primarily resulting from engineers' ignorance or irresponsible practice and demand that engineers mend their own damage.[7]

Accompanying these "external challenges" are some internal problems tormenting the nerves of engineering educators: A number of countries are reporting or foreseeing shortage of engineers (Jacobsson, Sjöberg, and Wahlström 2001; Yurtseven 2002; Johnson and Jones 2006). Engineering continuously struggles at attracting high school graduates (Becker 2010). Women and ethnic minorities are persistently underrepresented in engineering programs and the engineering professions (Brainard and Carlin 1998; Leslie, McClure, and Oaxaca 1998; Burke and Mattis 2007; Slaton 2010).[8]

Engineering educators have proposed various strategies to cope with or respond to the aforementioned challenges. Some call for a "practical turn" in engineering training in order to better accommodate immediate industrial needs. Advocates of the "practical turn" suggest cutting the course hours in engineering sciences and dedicating the time to what they consider the "basics" of engineering: drawing, working with tools, making products, etc. (Sheppard, Macatangay, and Colby 2008). However, the meaning of the "basics" is far from unanimous among engineering educators. While the above interpretation reminds people of the "shop culture" of engineering, the "basics" are defined in opposite terms by another camp of engineering educators, who take pain to defend the technical rigor and difficulty of engineering training (Kett 2000). The latter group asserts the study of math and sciences as the invaluable basis for improving

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[7] Some critics of the "Grand Challenges" also point out that the framing of these challenges and the solutions proposed in the NAE report repeat some of the problematic assumptions widely upheld in the engineering profession (Cech 2012; Slaton 2012; Herkert and Banks 2012; Riley 2012; Nieusma and Tang 2012, Catalano 2012). Alternatively, scholars have proposed more comprehensive and inclusive approaches to advance social justice and sustainability via the teaching and practice of engineering (Riley 2008a; Lucena, Schneider, and Leydens 2010; Baillie, Pawley, and Riley 2012; Lucena 2013)

[8] Lucena (2005) points out that the need for more human resources in science and engineering in America results partially from scientific and engineering leaders' application of rhetorical strategy to reaffirm the importance and legitimacy of scientists and engineers for the security and prosperity of the nation.

engineering students' analytic and problem-solving abilities, which prepare students to solve not only the immediate problems confronting the industry but also unknown problems arising in the future. According to this point of view, extensive learning in math and sciences provides a great means to forge lifelong learners (Xeidakis 1994).[9] Besides having the interests of the industry at heart, another group of pro-application educators value the practical training not for its potential to mold engineers who fit the industrial machinery. By stressing the applicational dimension of engineering (as opposed to a focus on math and sciences), this group attempts to promote comprehensive approaches to engineering, taking into account its broad social, economic, and environmental contexts (Green et al. 2009).

These different groups of reformers have in common a point of recognition, which is this: merely changing the way engineering is interacting with the rest of the world is not going to suffice for meeting the grave challenges presented on page 3; to properly respond to these challenges we have to rethink the appropriate terrain of engineering practice, the knowledge and competencies that characterize the engineering profession, and the way young engineers are educated. For example, the global economy demands that engineers become multicultural and multilingual communicators. Making engineering education more economical requires creatively reorganizing the format of (team-based) engineering learning. Educating socially responsible engineers calls for ethically-sensitive teaching. Attracting and retaining engineering students entails more engaging and meaningful learning experiences within more open, supportive institutional environments. In a word, engineers ought to be more than technologists, and engineering education more than an assembly line for producing them.

An effective way to bring about these changes, I would argue, is to reconstruct engineering education as a liberal education. Here are the reasons. First, the current and emerging conditions require from engineers broad knowledge basis, comprehensive skillsets, and synthetic thinking, all of which are essential goals of liberal education

[9] The conflicting understandings of the "basics" of engineering are also present in non-U.S. contexts; for example, see Akera and Tang (forthcoming).

(LEAP 2014). Whereas in the past engineers have been defined as problem solvers, and versatile problem solvers at its best, engineers today need to be able to identify the problems (Downey 2009). This indicates a qualitative change of engineers from technologists with broad knowledge to broadly educated persons. The education of engineers, therefore, should care for the development of the whole person. We shall see no difference between the ideal engineers of our time and well-rounded persons: open-minded, independent thinking, dexterous, and empathetic. Again, to facilitate the development of the whole person is the widely shared mission of liberal education (Delblanco 2012).

I am not suggesting engineering education should give way to liberal education of the traditional kind. The traditional liberal arts have almost always been present in engineering education (Akera 2011; Bucciarelli 2011). The challenge is to effectively integrate engineering and liberal education, or as some educators suggest, to transform engineering into a liberal art for the technological age. Efforts toward such integration are relatively new (NAE 2005; Nieusma 2008; Christ 2010; Bucciarelli 2011). This thesis explores and compares some important contemporary visions, strategies, and effects of integrating engineering and liberal education.

1.2 Conceptual and research questions

Humanities and social science writers often depict engineers as a collective agent or focus their attentions on individual engineers who are significant and exceptional; rarely have ordinary engineers been carefully observed, listened to, and written about.[10,11] However, ordinary engineers deserve more scholarly attention not only for the crucial role they play in shaping our technological civilization but also for the common experience of living in a technological society, an experience that is shared by the rest of us.

[10] The collective treatment often appears in history and sociology of the engineering profession, whereas exceptional individuals in engineering often occupy the minds of biographers, who paint the lives of heroic or notorious individual engineers, such as Robert Moses, Herbert Hoover, etc.
[11] Exceptions to this omission are Downey (1998) and Tonso (2007).

In a world increasingly mediated and governed by a complex regime of money, power, technology, and ideology, engineers and other technoscientific professionals differ from many of their fellow humans in a critical aspect. They are absorbed into the regime not only as consumers of technology and the meaning symbolized therein, as recipients who think, talk, and act in ways expected by the regime; they are also blessed (or cursed) with the role of "producers" in the regime, helping reinforce and renewing the system. The knowledge they possess becomes the label to mark their specific roles in this regime.[12]

In the meantime, the story about engineers and engineering education mirrors stories lived by many more people in our time. It throws light on how global economy redefines the value of our work, how we adjust our priorities given constrained resources and options, and how we navigate in the midst of both traditional demands and the new dangers and opportunities of this historical period.

Thus this thesis studies the people (college administrators, faculty, and students), institutions (colleges and engineering programs), and actions (teaching and learning), that are centrally involved in endeavors to reinvent engineering as a liberal art and a powerful engine for economic growth and social improvement, while at the same time nurturing young engineers as innovators who create new techno-socio-economic opportunities, as responsible citizens who defend and advance public well-being, and as well-rounded members of an open, diverse, global civilization.[13] I hope this study will shed light on two conceptual questions: How does knowledge affect our self-reflection? How do we think about the concept of technology and its wide-ranging significance in our time? These questions concern every one of us as we live in what is often called a

[12] The so-called "knowledge workers" are not alone in "producing" the technoscientific facet of the contemporary social order. Scholars in Science and Technology Studies (STS) have examined the diverse agencies that "co-produce" technoscience and its corresponding social order (Jasanoff 2004).

[13] Wisnioski (2009) examines an earlier wave of reforms to provide liberal education for engineers in the 1960s. He documents curricular reforms in a number of colleges to strengthen engineers' learning of humanities and social sciences. Among the institutions studied by Wisnioski (2009) is Harvey Mudd College, the object of a case study in this thesis. This thesis continues Wisnioski's inquiry by examining contemporary efforts to teach liberally learned engineers at Harvey Mudd College. In addition, this research investigates multiple dimensions (e.g., institutional and pedagogical) of reforms to integrate engineering and the liberal arts at Harvey Mudd and two other educational initiatives.

"knowledge society" (Stehr 1994) or "technological society" (Ellul and Merton 1964). In particular, in this thesis I investigate dimensions of young engineers' self-understanding especially in relation to their views of engineering knowledge and how the concept of technology affects the space of engineering problems and solutions.

Engineering knowledge matters in young engineers' self-understanding not because learning calculus, differential equations, circuits, or embedded control can influence a student's personality, but because it provides a medium for engineering students to constantly inspect themselves against the expectations of the engineering profession. It would be naive to assume that people who work with numbers must be verbally awkward or a person who writes computer programs is indifferent to music. In response to stereotyping of this kind, thoughtful engineers have offered a range of compelling counterexamples (Florman 1996). I am rather concerned about questions like these: How do engineers understand the nature of engineering knowledge? How does such understanding affect what they see as legitimate problems and solutions? How do engineers resort to professional knowledge as a yardstick for their self-identities?[14] In engineering programs, answers to these questions are embodied in educators' ways of communicating engineering knowledge, in students' grasping and application of such knowledge in classes, homework, exams, and in some cases, production of new knowledge in research projects.

As much as I would like to define engineering in ways that go beyond its involvement with technology, the latter plays a significant role in this thesis. Yet I focus on no particular techniques or artifacts but instead the ways engineering educators and students think in relation to *the concept of technology*. For example, during my fieldwork for this project I encountered a familiar phenomenon which might be characterized as "when I (engineering students observed in this study) think of engineering problem solving I think of technology." It called my attention to the patterns and dynamics in which students consciously or unconsciously bring technology into

[14] Downey and Lucena (2006) examines how concepts of engineering knowledge and concepts of engineer are closely linked and how both change in response to shifting national priorities.

various stages of their thinking, using it as a medium for or a substitute of their own intellectual power. In this thesis I try to disclose the hidden power that is encapsulated in the concept of technology and how it defines the space for proper engineering practice (within educational settings). One way to approach this question is through observing how technology is habitually "enrolled" in engineering students' interpretation of the problems and how technology delimits their imagination about solutions. For example, during my case studies I found students willingly translated healthcare-related problems to the surveillance of health data and proposed "solutions" based on constant monitoring of patients' blood pressure, diet, lifestyle, etc., usually via smartphone apps. This incident might not seem unusual to people who are familiar with the practices of business, information technology, and medical research and development today. Yet few people in these fields seem to question the cultural and political implications of this practice. For example, what logic drives the reduction of the multiple dimensions of health to one-dimensional data? What political assumptions are embedded in the choice of technologies that emphasize surveillance (Graham and Wood 2003)?

The above conceptual questions led me to pursue the following research questions:

1. How do the reformers who try to integrate engineering and liberal education interpret the deficiencies of the mainstream, traditional modes of engineering education? What competences in engineering students do the reformers wish to facilitate via the integration of technical and liberal studies?

2. How do educators translate a broader vision of engineering into alternative ways of organizing educational programs, curricula, and different modes of teaching and learning? How do institutional characteristics, pedagogical choices, and the cultures of engineering and liberal arts disciplines help forward or constrain plans for a more well-rounded education for engineers?

3. In a learning environment that integrates engineering and the liberal arts, how do students understand engineering? In what terms do they engage the contextual factors in their approach to engineering problems? To what extent do they reflect on the assumptions and norms of engineering profession in historical, political, and social

contexts? How do they perceive the technical and social dimensions of engineering? How do they foresee their self-identities, personal development, career prospects, their strengths and weaknesses coming from a comprehensive learning environment?

1.3 Plan of inquiry

In the rest of this chapter I present my plan for inquiring into the research questions I raised above. I first review the important theoretical resources which guided my research. Two bodies of literature in STS are especially relevant here: engineering epistemologists' work on the concept of engineering knowledge and its relation to engineers; philosophical, historical, and empirical studies of technocracy. Following the literature review I explain the empirical data I set out to collect and the methods I used for collecting and analyzing data. At the end of this chapter I outline the following chapters in this thesis.

1.3.1 Theoretical resources

1.3.1.1 Engineering knowledge

The "middle epistemology"

Although many engineers firmly believe in the existence of an independent body of engineering knowledge, it is difficult to clearly define engineering knowledge and to specify its boundary with scientific, technological, and social knowledge.[15] Alder (1997) characterizes the eclectic nature of engineering knowledge using the term "middle epistemology." His historical work traces the artillery engineers in pre-Revolutionary France, one of the earliest group of formally educated engineers, who deliberately sought knowledge "combining theory and practice in the pursuit of technological novelty" (Alder 1997, 60). Engineering also has an ambiguous relation to scientific knowledge. For much of its history engineering has been understood as "applied science," yet engineers are not always pleased with the subordination of engineering to

[15] Noting that engineering is often lumped together with or buried in studies of technology, Downey, Donovan, and Elliot (1989) argue for a distinction between "engineering studies" and "technology studies."

science (Kline 1995). Vincenti (1990) explicitly distinguishes science and engineering: the former focuses on “how things are,” whereas the latter focuses on “how things ought to be” and how to get there. The utilitarian nature of engineering, says Vincenti, results in a higher degree of cognitive uncertainties in engineering knowledge. Besides the various kind of science used in engineering professions, Vincenti also notices the economic, military, social, and personal contexts in which engineering problems are generated. Thus, he calls his readers’ attention to the production of engineering knowledge in heterogeneous institutions and communities. However, Vincenti emphasizes what might be called an “external view” of the contexts of engineering: while the contexts are held accountable for the creation of engineering problems, Vincenti assumes the core activity of producing and applying engineering knowledge—design—as an objective and rational process. In contrast, Bucciarelli (1994) examines engineers’ general reluctance to recognize the social nature of design. Through extensive ethnographic studies in design companies, Bucciarelli describes design in terms of a social process, which combines material mechanisms with cultural and personal factors. However, the uncertainties, the heterogeneity, and the various social and material constraints which are present in the design process are often masked by a neat (technical) mechanism when the design is completed, to such a degree that even the engineers who have taken part in the social process of design are not fully aware of it (Bucciarelli 1994).

This research draws upon the insights on the eclectic nature of engineering knowledge, most notably the argument that engineering knowledge embodies both technoscientific principles and often implicit social conventions. Furthermore, it explores the ways in which different components of engineering knowledge are delineated by students who study engineering in a more comprehensive educational environment. The research examines whether these students are as oblivious to the heterogeneity of engineering knowledge as the design engineers observed by Bucciarelli (1994) and to what extent they develop a “pluralist epistemology” that recognizes different ways of knowing in technoscience and in the liberal arts.

Molding engineers

Another important question engineering epistemologists have dwelled upon focuses on the role conceptions of engineering knowledge play in shaping engineers' political ambitions, moral commitments, and professional identities. To begin with, a number of historians and philosophers agree that engineers' responses to epistemological questions are not purely intellectual; such answers are often intertwined with engineers' political and economic convictions and reflect their pursuit of proper social positions. Here again, French engineers in the eighteenth and nineteenth centuries illustrated how they enacted political and moral motives in choices of engineering methods and the education of young engineers. Picon assesses the impacts of ideological movements in engineers' methods of analysis: "eighteenth-century mathematization of engineering theory and practice had to do with a new concern for overcoming prejudice and achieving impartiality, something that was not on the engineer's agenda prior to the Enlightenment period" (Picon 2009, 21). The thesis that engineers' epistemological projects embody attempts to assert and justify their social and political status is echoed in studies of artillery engineers in pre-Revolutionary France and the training of military engineers in antebellum America (Alder 1997; Miller 2013).

Besides contributing to the collective prestige of the engineering profession, the contents of engineering knowledge provide a means for educators to mold the personalities and values of young engineers. For example, intensive mathematical training in eighteenth and nineteenth century French engineering schools was deemed not only instrumental for refining engineers' analytical faculty, but also essential for cultivating engineers' characters of precision and discipline (Weiss 1982; Alder 1997). Engineers, of course, are made to serve. The twentieth century American engineering educators discovered, however, whose interests engineers are prepared to serve can be partly affected by the contents of engineering learning. Noble (1979) documents how the contents and methods of engineering education in twentieth century American universities were designed to produce the kind of engineers who best met the military needs of the government and the economic needs of big corporations.

Downey (1998) and Tonso's (2007) ethnographic studies of engineering education visualize the impacts of engineering knowledge on students' formation of self- and professional identities at a more micro level. Through participant observation in a college class on computer aided design (CAD), Downey pinpoints students' excitement about a powerful technology, which promises control, and their frustrations when the machine in the end demanded their subordination. Tonso's study of first year and senior students in a public engineering school suggests two types of engineering knowledge: the "academic science engineering" and the "design engineering." According to Tonso's observation, the former enjoys overwhelming prestige over the latter in the engineering school, and this imbalance coincides with the fact that women students who are good at design engineering are systematically underestimated compared with the male students who achieve excellence in academic science engineering. Tonso concludes a masculine culture is masked behind a "gender neutral" engineering, which assumes the kind of engineering practice preferred by men as the norm.

As this dissertation shows, the values and norms of the engineering profession have strong presence in educational initiatives that aspire to teach engineering in more socially relevant ways. The dissertation assesses to what extent the integration of engineering and humanities, social sciences, and arts help students reflect on the implicit political and cultural messages encoded in engineering knowledge.

Technical/social dualism

Tonso's discovery of two types of engineering knowledge and the different treatment of each in the engineering school illustrates a tendency in the engineering culture to think in dualist terms. Faulkner (2000) systematically examines the technical/social dualism in engineering. She offers the following observations: First, in most cases the "technical" and the "social" co-exist in engineering and they exist in tension with each other. Second, engineers often prioritize the technical over the social. Third, the technical/social dualism in engineering often reflects codes of gender dynamics. Cech and Waidzunas (2011) find that the technical/social dualism provides engineers with a leeway to shun serious discussions of crucial social issues, such as sexual or gender inequality: “the technical/social dualism casts issues like the experiences of LGB (“lesbian, gay, and bisexual,” explanation added) students as ‘social’ or ‘political’ and thus irrelevant to serious discussions about the profession in classrooms, office hours, or study groups. The rendering of engineering as an ‘apolitical’ and ‘technical’ space, combined with the relegation of equality issues to the ‘social,’ may marginalize LGB students and lead them to feel as though discussions of their particular circumstances are silenced” (Cech and Waidzunas 2011, 4). Nieusma and Tang (2012) suggest the technical/social dualism and engineers’ persistent bias toward the “technical” undermine their ambition to assert leadership in addressing the “grand challenges” facing our civilization.

The following chapters suggest the technical/social dualism also exists in programs attempting to integrate engineering and the liberal arts, where tensions between the technical and social dimensions are often embodied in epistemological differences between engineering and liberal arts perspectives.

1.3.1.2 Technocracy

The unequal technical/social dualism occupies a significant place in engineers’ understanding of their own practice. In the meantime, a similar, perhaps more powerful, tendency characterizes many engineers and non-engineering groups’ approach to social problems. This tendency is associated with engineers and other knowledge experts’ inclination to project their visions of an ideal order, which is governed by familiar technical principles, to the real world. Instead of a dualist treatment of the technical and social dimensions, the technocrats eagerly seek to supersede political and social rules and to redesign our socio-political-economic landscape according to technical rationality (Fischer 1990; Porter 1996; Hoppe 2005; Lahsen 2005). As Picon (2009) documents, engineers in eighteenth and nineteenth century France were inspired by the Enlightenment thinkers’ praise of reason and recommended mathematical analysis as a reliable means to eliminate prejudice and partiality and to increase the efficiency in material and social arenas. The proposal to replace political elites with technological ones, however, was not the invention of the Enlightenment engineers. Winner identifies "the first modern version of a technocratic society," one that is "rule(d) by scientific and technical elites" in Bacon's *New Atlantis* (Winner 1977, 135). From Bacon's depiction of the Salomon's House in the Kingdom of Bensalem, Winner finds the prototype for modern technocratic utopia: a non-political society which is governed by the cleverest and the most knowledgeable. In the school of technocratic writers, Winner acutely senses a shift of the foundation of power: from the possession of political support to the possession of knowledge. According to Feenberg, the power of technocratic rationalization extends beyond the traditional political authority as "more and more of social life is structured by technically mediated organizations such as corporations, state agencies, prisons, and medical institutions" (Feenberg 1999, 75). As a result, Feenberg suggests, the technological order is deemed "natural" in social and cultural assumptions and becomes a form of social hegemony.

While philosophers express unease with the growing power entrusted to technocrats, historians and anthropologists of engineering remind us technocrats often achieved much less success in changing the material arrangement of the world than they aspired or promised to. Layton's (1986) work investigates the ambitious engineers in the Progressive Era, perhaps the most famous group of technocrats, who created a movement in their name (the Technocracy Movement). Layton explains how an "engineering ideology" was born out of engineers' ambiguous relations with business, how the ideology drove engineers to reorganize politics, production, and social life, and how such ideology eventually declined as a result of historical changes. In a more recent examination of the technocratic imagination, Downey (1998) describes how Computer Aided Design betrayed its promise of control, power, and economic prosperity and often left its faithful clients—engineers and engineering students—in disillusionment. Fischer (2000) contends that technical experts' narrow focus on empirical evidence in positivist policy analysis neglects the contextual differences of the data and fails to take into account normative concerns.

Among the STS scholars who have investigated different facets of technocracy, a common observation is the "technocrats" believe their approaches to political and social issues are superior to the usual politics or business driven approaches, as the former are based on rational analysis and are relatively free of biases and ignorance. Through observing educational initiatives that strive to bridge engineering and the liberal arts, this dissertation examines technocracy at the cognitive level. I argue that the technocratic students habitually enroll the *concept of technology* in thinking about social problems without rational analysis. Furthermore, I suggest technocracy as a habitual way of thinking is empowered by a complex of ideological forces which induces young engineers to conform to professional norms and to serve the existing political and economic order.

1.3.2 Empirical research

This thesis draws upon extensive empirical research. Empirical data is used mainly for two purposes. First, it is used to help understand a situation/culture. For example, I review primary and secondary literatures on historical and contemporary discussions about engineering and the liberal arts in order to understand the common concerns and attitudes found within the community of engineering education. In-depth case studies is the primary research method for this project, through which I inquire into the visions, strategies, and struggles of reforming educators who attempt to integrate engineering and the liberal arts, as well as the educational experiences, self-identities, and epistemological views of students who choose to study engineering in integrated programs. My second purpose for the empirical work is somewhat more controversial. I intend to make generalizable arguments about engineering education, the engineering profession, and our society, which is heavily moderated by technical knowledge; these arguments are based upon what I learn from the empirical research. Readers will find in the concluding sections of the following chapters, and perhaps more crucially, in the concluding chapter, speculation about the assumptions of the actors I have studied, my own evaluation of the initiatives to educate well-rounded engineers, and recommendations for more integrated teaching of engineering and the liberal arts. In so doing I have chosen to depart from common approaches in both positivist qualitative research and post-modern situational analysis (Clarke 2005; Hammersley 2008). I made this choice because the questions I have raised in this chapter are driven as much by practical concerns as by theoretical understandings; that is, through learning the successes and shortages of the existing initiatives, I intend to find lessons to help engineers become thoughtful intellectuals, responsible citizens, and reflective individuals and professionals with a more comprehensive education.

Empirical data for this thesis was collected and analyzed in two stages. On the first stage, I acquired numerous publications from professional organizations and academic journals which address the theme of engineering and liberal education. The bulk of publications includes reports authored by ASEE, NAE, ABET, articles in the *Journal of Engineering Education* and *PRISM* (the official magazine for ASEE), as well as papers presented at ASEE annual conferences. I also collected books and articles written on the theme of blending engineering and the liberal arts by leaders from professional engineering, engineering education, and liberal education. Based on these materials, I compiled a theoretical background for current efforts to merge engineering and liberal education.

In stage two I delved into three educational initiatives, two of them recent, the other a well-established college program several decades along, where engineering and the liberal arts are explicitly integrated. Chapters 3 to 5 in turn document the characteristics of each case. My rationale for selecting the cases was to find institutions in which there has been a serious, deliberate effort to integrate engineering and liberal education. I also looked for instances that exhibit institutional, historical, and pedagogical diversity along with their shared commitment to seeking positive changes in the way engineering education is done. The choices of the engineering program at Harvey Mudd College, the Picker engineering program at Smith College, and the Programs in Design and Innovation at Rensselaer Polytechnic Institute enabled me to observe reformist agendas and methods at work within institutions that are similar in some ways, but different in important respects, features that, I believe, make the discussion of possibilities, successes, and shortcomings more useful for my readers.

Harvey Mudd College (HMC) is a liberal arts college dedicated to science and engineering education. The college has a history of more than five decades; it is a member of the Claremont Colleges Consortium. Picker Engineering Program at Smith College is the first engineering program in a women's liberal arts college in the U.S.; it was founded at the turn of this century. Around the same time, the Programs in Design and Innovation (PDI) was founded at Rensselaer Polytechnic Institute (RPI), the oldest civil engineering school in the United States. PDI is an interdisciplinary design program that blends engineering, social sciences, entrepreneurship, and the arts. While the three cases share a commitment to providing engineers with a liberal education, each of them highlights a distinctive approach in their pursuit of this objective. HMC strives to teach a coherent liberal core to every student; in this way, it aspires to assist engineers' development as broadly educated and well-rounded persons. Influenced by the institutional culture of Smith, the Picker Engineering Program explicitly confronts the underrepresentation of women in engineering. The education at Picker also emphasizes social justice and sustainability. PDI employs intensive studio design pedagogy. While the rhetoric of innovation demonstrates the influence of business and industry, PDI students are also encouraged to reflect on the social significances of design with the active help of STS instructors.

Multiple methods of qualitative research were used for the case studies. Prior to and during my field trips, I collected and read books, articles, and other documents published by administrators and faculty and visited the institutional archives to learn the history of each program. I also interviewed administrators and faculty to further learn their educational philosophy and pedagogical strategies. Extensive participant observation was conducted in classrooms and at other academic or social activities on campus.[16] In the fall of 2012 I sat in two PDI studio courses for a whole semester (about a hundred and twenty hours in total), when I took extensive notes of what went on in the studios. In

[16] For an introduction of participant observation as a qualitative research method, see Bernard (2005).

the spring semester of 2013, I commuted to Smith College every week, sitting in the lectures, student presentations, group meetings, and two engineering courses (the total time of observation is close to sixty hours). While I was at Smith, I also took part in various kinds of student-organized political, academic, and social activities. I did two months of fieldwork at Harvey Mudd College in the September and October of 2013, during which time I sat in a number of classes, e.g., E4 (Introduction to Engineering Design), Political Innovation, WRITE One, Manufacturing. More importantly, I shadowed two student teams in the Engineering Clinic, a year-long capstone design course for which students work on projects for industrial clients. I participated in the project teams' weekly teleconferences, group meetings, and design reviews. I also observed a variety of club activities and social events organized by students and college staff; e.g., Engineering for a Sustainable World (ESW) weekly meetings, Five Colleges Divestment Campaign, employer info sessions, campus diversity lectures, academic talks, etc. I interviewed some thirty students from the three cases to learn about their choices of major, learning experiences, career goals, and their understandings of engineering knowledge. The design and analysis of the student interviews are reported in Chapter 6.[17]

1.4 The writing

Chapter 2 surveys theoretical discussions about engineering and the liberal arts and presents the historical origins of the three case studies. In a review of historical and contemporary literatures on engineering and the liberal arts, I examine the major questions which draw engineering educators' attention to the liberal arts and clarify their views about how liberal education contributes to the growth of engineers. I also report some curricular and pedagogical strategies currently being implemented by engineering educators who seek to provide engineers with a more comprehensive education. Chapter

[17] To protect the identities of the people I observed or interviewed, I use codes to replace their real names in this dissertation. Faculty are referred to as "Prof. [Letter One] [Letter Two]." The first letter indicates the program they belong to: H for HMC, P for Picker, and D for PDI (e.g., Prof. HA, Prof. PB). Students are referred to as "Mr. / Ms. [Letter One] [Number One]." The first letter also indicates the program they belong to (e.g. Mr. H1, Ms. D2).

2 ends with a brief history of the formation of the three case study programs. The historical account brings to light how each of the three educational initiatives originated from attempts to overcome critical limitations of the mainstream mode of engineering education at the time. It also presents the founders' visions of competent engineers for each program.

The following three chapters tell the stories of integrating engineering and liberal education at HMC, Picker, and PDI. In each chapter I focus upon capturing the philosophies, policies, and pedagogies which highlight the program's distinct approach to educating well-rounded and socially sensitive professionals. Each of these chapters sketches a unique trajectory of reinventing engineering as a liberal art. In addition, these chapters are organized by a roughly parallel structure which contains four components: institutional context, visions of education, social/technical integration, and development of professional identities.

Chapter 3 looks into Harvey Mudd educators' efforts to prepare students to work in complicated and uncertain situations. The administrators and faculty at Harvey Mudd pursue this mission with curricula that emphasize broad basic knowledge and an education philosophy focusing on cultivating students' abilities to learn by themselves. The chapter also notes some subtle choices by the faculty which prevent the integration of the liberal arts with the core of engineering education. Moreover, I question HMC students' complacency within the college's small and protected community, one relatively insulated from the "real world."

Chapter 4 introduces a more recent experiment in educating engineers in a liberal arts environment. The Picker Engineering Program at Smith College exemplifies how progressive social values can be integrated in the contents and format of engineering teaching and learning. The chapter shows how the engineering program includes course contents and teaching methods to empower women students to practice engineering in contextualized, sustainable ways. It also explores how Smith's campus culture, peer influence, and Picker students' extensive learning in the liberal arts contribute to more comprehensive understandings of engineering. While the engineering program connects to the college's agenda that seeks to advance diversity and social justice, these goals sometimes cause epistemological discomfort for engineering faculty and students who are committed to more traditional beliefs and norms.

In both HMC and Smith, the engineering programs are located in a liberal arts college, with the hope that an engineering student would build a broad knowledge base by taking a variety of courses in the liberal arts. In addition, the founders of engineering programs in both colleges expected the intellectual and interpersonal environment of a liberal arts campus—the vibrant campus culture, student organizations, student-faculty interaction, small and discussion based classes, etc.—to become a hotbed for engineers who are open-minded, morally sensitive, and independent thinking—the ideal student for a liberal education.

The third case study chapter presents a different approach of combining engineering learning with liberal studies. The Product Design and Innovation (PDI) program at RPI was explicitly planned to be a site of interdisciplinary learning. Students in the program—the majority of whom are engineering majors—have multiple identities at the same time: they are engineers, social analysts, and designers. The signature pedagogy of PDI—studio based design learning—consistently emphasizes the synthesis of engineering, humanities, social sciences, and arts. Chapter 5 observes how this synthesis happens when engineering, business, arts, and social sciences are brought together within the same physical space; it also examines the tension resulted from the co-presence of multiple educational philosophies, most notably from engineering and critical social studies of science and technology.

Chapter 6 answers the third research question by exploring a broad range of students' experiences of learning engineering in a liberal education environment. The chapter documents students' choices of colleges and majors, comments on courses and projects, epistemological standpoints, and career plans. The analysis of student interviews helps shed light on the impacts of students' educational experiences on their views of engineering knowledge and their development of professional identities. This chapter argues that most students in the case study programs develop limited understanding of the context of engineering: They often resort to the engineering profession as the primary context to make sense of engineering learning. The majority of interviewees did not position engineering in broad social, political, and cultural contexts beyond the profession. Very few of them indicated critical reflection on the assumptions and limitations of the engineering profession.

Chapter 7 wraps up the thesis by examining some general lessons about the visions and strategies of integrating engineering and liberal education I have derived from the case studies. Connecting my inquiries to the STS literature, I suggest an alternative conception of technocracy and question the structural forces that empower technocracy as a dominant way of thinking about the social role of engineering.

2. Theoretical Landscape and Historical Origins

The liberal arts have been included in the education of engineers since formal engineering education began in America (Akera 2011; Bucciarelli 2011). For example, Rensselaer Polytechnic Institute—the oldest civil engineering school in the U.S.—included in its 1850 curriculum "courses in English, foreign languages, and philosophy" (Bucciarelli 2011). Over the past one and a half centuries, educators from both engineering and the liberal arts at no time ceased exploring and debating the proper objectives, length, and format of educating engineers in the humanities, social sciences, and arts. Current discussions about and educational practice that advocate integrating engineering and the liberal arts (or transforming engineering into a liberal art), therefore, are influenced in one way or another by recurring inquiries about the proper visions and strategies of teaching the liberal arts to engineers.

This chapter briefly presents the theoretical and historical contexts of integrating engineering and liberal education to lay the groundwork for the case studies in later chapters. I begin by reviewing historical and contemporary understandings of the relation between engineering and the liberal arts. Then I survey some curricular and pedagogical strategies currently being utilized to integrate the liberal arts into engineering programs. I end the chapter by looking into the historical origins of the case studies. The historical narrative examines the formation of each program in light of the broad environment for engineering at the moment and the influential educational ideas that inspired its founders.

2.1 Engineering and the liberal arts

2.1.1 Cultivation of engineers

Although the liberal arts have been upheld as desirable or indispensable throughout the history of engineering education in America, until recently few scholars have sought to explore attempts to integrate engineers' learning in the liberal arts with the technoscientific disciplines.[18] For a long time, most engineering educators were content with retaining the humanities and social sciences in a curriculum separate from math, sciences, and engineering sciences.[19] While the liberal arts were often valued for the cultivation of engineers as decent professional members, persons, and citizens, it was common to exclude them—history, literature, philosophy, fine arts, and the social sciences—from the core of engineering education.

Early on, people who were concerned about the respectability of the engineering profession insisted engineers decorate their technical skills with learning in the liberal arts in order to make technical professionals more pleasant and elegant conversationalists. As Bucciarelli (2011) notices, educators driven by concerns about the professional image advised engineers to engage in the study of the fine arts and literature as early as 1860. John Frost, who wrote in one of the earliest mechanics textbook:

> By making himself master of those principles of science which are most intimately connected with his trade, the mechanic, while he is satisfying a liberal curiosity, may possibly be approaching some brilliant discovery, which will speedily conduct him to fortune and fame; and if the lighter reading, generally termed literature, promises no such result, it affords him the most dignified and innocent means of amusement and preserves the vigor and increases the brightness of his intellect. (Quoted in Bucciarelli 2011, 8)

This suggestion, indeed, represented an impressive progress in views regarding the "most dignified and innocent means of amusement" compared with the gentle society in rural Britain less than half a century ago. By comparison, in Jane Austen's *Pride and Prejudice*, Sir Williams offered praise for amusement of a different kind:

> What a charming amusement for young people this is, Mr. Darcy! There is nothing like dancing after all. I consider it as one of the first refinements of polished society. (Austen 2006, 26)

Besides considerations of professional image, educators also emphasized the importance of a liberal education for the development of engineers as well-rounded persons. For example, at the founding meeting of the Society for the Promotion of

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[18] Notable exceptions are Aydelotte (1917a) and ASEE (1956).

[19] A separate liberal arts curriculum for engineers was recommended in the ASEE Mann Report (Mann 1918), the two Hammond Reports (SPEE 1940, 1944), and the Burdell-Gullette Report (ASEE 1956), etc.

Engineering Education (the predecessor of ASEE), Burr recommended to engineers "a broad, liberal education in philosophy and arts, precedent to the purely professional training" for the development of "power of observation," "sound judgment," "healthy mental assimilation," and "a cultivation of human qualities" (Burr 1893). The ASEE Mann Report more succinctly pointed out the role of liberal education in "develop(ing) the man as a man" (Mann 1918).

One of the central objectives of liberal education throughout its history has been the preparation of students for civic life (Kimball 1986). The civic aspect of the liberal education was taken into account by engineering educators as well. Seely (2005) notes two persistent themes in the teaching of political knowledge to engineering students during the World War II and the Cold War era: cultivating faith in democracy and warning against communism.

2.1.2 Contributions to engineering practice

When viewed as a source for personal refinement, the focus of liberal education has often been regarded as more suited to cultivating engineers' personalities than to strengthening their abilities in professional practice. Yet the latter is not absent in engineering educators' estimation of the liberal arts. As Akera (2011) points out, "from the Perry Movement described by historian Larry Owens; to the Mann Report, Wickenden Investigation, Grinter Report and Goals Report mentioned above; to each of the liberal education studies discussed in the previous two sections, engineering educators have repeatedly turned to educational reform as a means of reconsidering the fundamental basis of engineering expertise." Accordingly, the role of the liberal arts is often articulated in lieu of particular understandings of the nature of engineering practice. For example, educational and professional leaders who see engineering as a public service routinely call for ethical and responsible practice of engineering to protect and advance public safety, health, and welfare (Vallero and Vesilind 2006). From this point of view, learning in the humanities and social sciences is essential for engineering students' development of social competencies and ethical commitment. Frank Aydelotte, professor of English at MIT in 1917, grounded his English classes for engineering students on a series of questions on the social role of engineering:

> What should be the position of the engineer in society in this new era of the manufacture of power, that of mechanical, hired expert, or that of leader and adviser? Is the function of the engineer to direct only the material forces of nature, or also human forces?" (Aydelotte 1917)

Aydelotte then based the objectives of liberal education for engineers on answers to the above questions:

> If the engineer, who has created this new epoch of the manufacture of power, is to fulfill the promise made to society by his achievements hitherto, he must view society broadly, must address himself to the solution of its problems, which are human problems no less than material. ...it must be a training in thought, the influence of which is to clarify and humanize the student's character and his aims of life (Quoted in Bucciarelli 2011, 15).

The concern about socially appropriate and responsible engineering was echoed the ASEE Report "Liberal Learning for the Engineer." Published in 1968, the report stressed "students were to be trained to understand the role of technology 'within the total human culture,' and to control its adverse effects" (ASEE 1968).

Besides public service, engineering has often been regarded an engine of economic growth. For this purpose, engineering educators once again looked to the liberal arts for both direct knowledge about economic affairs and the necessary skills to act competently in local and global economy. In the mid-20th century, The *Grinter Report* recommended studies in the humanities and social sciences as proper preparation for engineers who were to join the managerial class later in their careers (Grinter 1955). The attention to economic conditions was renewed in the latest wave of engineering education reform, epitomized by the ABET EC2000 and two reports published by the National Academy of Engineering (NAE 2004, 2005): "the focus became that of producing engineers who have the skills necessary to compete in a global marketplace" (Akera 2011). Seely (2005) succinctly summarizes the main concerns about general education for engineers, "in short, they wanted engineers to fit easily into the large corporations that dominate our capitalist society" (120).

2.1.3 Engineering as a liberal art

During the past two decades, renewed understandings of the changing context of engineering practice, the social expectations of engineers, and the complex nature of engineering learning have driven a number of educators to question the boundary that stands between engineering and the liberal arts, or between the liberal and the technoscientific components of engineering education. Visions of blending engineering and liberal arts education or transforming engineering into a liberal art have been proposed, discussed, and put into action.

According to Goldberg, the predominance of technical education for engineers was evoked by the economic and technological development after World War II and during the Cold War era (Goldberg 2006, 2010). This paradigm, he suggests, has become outdated for an information-driven, globalized economy; therefore Goldberg calls for the education of "entrepreneurial engineers," who are broadly educated so as to effectively communicate, work in teams, and otherwise practice multiple engineering assignments in interdisciplinary environment (Goldberg 2006). While agreeing with the need to broadening engineering education, some educators consider the challenges facing the engineers beyond economic ones. Sjursen (2006) considers it a mistake to reduce the liberal arts education to "skills based communications courses, the study of management, the development of entrepreneurial tendencies, and something called leadership training" (153). Instead, engineers have to synthesize "technical skills, civic virtue, intellectual eros, and practical wisdom" in order to help humanity come to terms with the most grave challenges, such as climate change (Sjursen 2006). Bucciarelli challenges the inadequacy of the mainstream engineering education in preparing students for complex social problem solving. In his opinion, "we do very well at preparing the object-world worker—but pay little attention to the rich and varied and social/political contexts of engineering practice" (Bucciarelli 2011, 22). To "broaden the undergraduate education of, not just the student inclined and/or committed to engineering but any individual who recognizes the essential role science and technology play in our lives," Bucciarelli (2011) proposes a Bachelor of Arts degree in engineering, which centers on studying the subjects of engineering from liberal arts perspectives. The need for a more holistic approach to engineering education also arises from the ever-increasing complexity of engineering learning. As Guthrie (2010) points out, complex engineering systems and their extensive contexts require too much knowledge than can be taught in a four-year engineering curriculum. Therefore, instead of futilely trying to teach students endless tools and techniques, Guthrie (2010) suggests educators focus on students' awareness of contexts, basic technical skills, and the ability to collaborate and share expertise. In a word, engineering education should prepare students for lifelong learning (Guthrie 2010).[20]

Discussions of teaching engineering as a liberal art in the community of engineering education happened concurrently with conversations in the liberal education community about rethinking the boundary between liberal and professional education. Some leading liberal educators have come to realize that professional and liberal education have a lot to offer to as well as to benefit from each other (Lemann 2004; Shulman 2005). Carol Christ, the former president of Smith College, argues forcefully for the inclusion of engineering in the liberal education:

> Just as the modern languages and the natural sciences came to be regarded as liberal arts over the course of the 19th century, engineering and computer science must become part of a liberal education in the 21st century. We must determine not only how best to educate engineers in the traditional liberal arts but what role engineering might play in the education of musicians, economists, political scientists, and philosophers. (Christ 2010, 77)

2.2 Curricular and pedagogical strategies for integration

During much of the history of American engineering education, educators agreed engineers' liberal education (or general education) could be met through a stand-alone curriculum of humanities and social sciences, which took from twenty percent to one quarter of the students' course time (Mann 1918; SPEE 1940, 1944; ASEE 1956). The stand-alone liberal arts curriculum, however, posed a challenge for students to synthesize

[20] The importance of learning the context of engineering has also been recognized outside the U.S. (Christensen and Delahousse 2009; Williams and Figueiredo 2014).

the liberal studies and the technoscientific learning. To alleviate this challenge as well as counteract the dominance of technoscience in engineering curricula, Bucciarelli (2011) proposes a reversed curriculum for a bachelor of arts in engineering degree: students will spend three quarters of their course time studying engineering and technology from the liberal arts perspectives, questioning the assumptions, limitations, and uncertainties of technoscientific solutions. The last quarter of the curriculum is dedicated to free electives, for which students might take courses in the traditional engineering science. Bucciarelli (2011) also stresses that students will learn mainly through discussion, reflecting, questioning, and critical thinking.

Traver et al. (2011) survey a wide range of curricular and pedagogical strategies for the integration of engineering and the liberal arts. Based on the educational innovations presented at the Union College Symposiums on Engineering and Liberal Education, Traver et al. (2011) report the integrative strategies in five categories:

- First year or introductory material. These introductory courses and activities include topics from both engineering and the liberal arts, and they often focus on helping students formulate design problems. Students are introduced to hybrid styles of learning via courses on design, entrepreneurship, and learning communities.
- Core engineering courses. To assist the students to learn engineering in context, some educators apply pedagogies typically found in the liberal arts to core engineering courses, such as engineering seminars or design courses. Some educators also integrate liberal arts modules into core engineering courses or use models to connect courses from different disciplines.
- Capstone and extra-curricular. Integrative design projects often place students in multidisciplinary teams, so that students from engineering and the liberal arts work together on projects like commercialization or community service. Community or industrial collaborators are often included in these projects to enrich students' understanding of multiple stakeholders.
- Projects that span the curriculum. In some cases, new programs or curricula are created to connect engineering with the liberal arts. Examples in this category include curricula based on the Grand Challenge for Engineering (W Perry et al. 2008), degree program in design, and living-learning community to explore sustainability.
- Faculty development. A number of faculty development initiatives bring together engineering and the liberal arts faculty and/or partners from outside the academy.

Interdisciplinary collaborations are supported by co-teaching courses, innovation workshops, and educational tools for developing new and integrated courses.

2.3 Historical origins of HMC, Picker, and PDI

2.3.1 Harvey Mudd College

Harvey Mudd College was chartered in 1955. It welcomed its first class of students in the summer of 1957. The national and local contexts of founding a liberal arts college for science, engineering, and mathematical education were recollected in the memoir of Joe Platt, the founding president of Harvey Mudd.

After World War II, the U.S. faced a national need to expand its higher education so as to accommodate the generation of "baby boomers" (Platt 1994). In the State of California, the expansion of the public higher education was outlined in the Master Plan (Platt 1994, Akera 2010). The need for an expanded higher education was accompanied by a national shortage of scientists and engineers, which was considered a threat to America's economy and defense. This shortage was acutely and emotionally perceived in 1957 when the Soviet Union launched the Sputnik (Lucena 2005). It was clear to many Americans that their country was in great demand of engineers and engineering colleges. The national and regional demands coincided with the local planning of the Claremont Colleges. In 1923, the president of Pomona College James Blaisdell proposed what was known as the Claremont Group Plan. Instead of expanding Pomona into a larger university, Blaisdell preferred gradual creation of new institutions to a college consortium—the Claremont Colleges (Claremont University Consortium 2010). By the mid-1950s, four institutions had been included in the consortium: Pomona College, Scripps College, Claremont Men's College, and Claremont University Center (Platt 1994). The existing colleges had had respective excellence in the humanities, social sciences, and the natural science; organizers of the consortium therefore preferred a technical college to balance the group (Platt 1994). Hence the national, regional, and local needs led to "the first college of engineering and science to be founded in this country for three decades" (Bright and Dym 2004).

When Platt was appointed the first president of Harvey Mudd, the trustees expressed two hopes for the new college: Harvey Mudd students should receive a liberal education; they should also develop sound understanding of the basic sciences and math. These expectations were faithfully legislated into the structure of the college: a general engineering program was created; all students were required to take a Common Core curriculum, which includes intensive math and science courses; in the early years following the founding of the college, one third of the curriculum for every major was dedicated to the study of the humanities and social sciences. These features of the new college, while responding to the particular philosophy of its founders, also reflected the impacts of the national conversations about engineering education at the time. In particular, I would argue, the design of Harvey Mudd College was influenced by a professional drive to upgrade engineering education and a moral drive to educate socially responsible scientists and engineers.

Platt (1994) cites the *ASEE Grinter Report* as a major source of inspiration for the design of Harvey Mudd College. The tenor of the *Grinter Report* was the recommendation of an extensive engineering science curriculum for the education of young engineers (Harris et al. 1994). Fueled by two world wars and the close interaction of science and technology in the 20th century, the explosive rate at which new knowledge and tools were created rendered the traditional practice of engineering as a craft impossible. Under this background, the *Grinter Report* highlights engineering analysis and problem solving; it further suggests these essential skills can be developed with the study of science and math (Grinter 1955). The educators at Harvey Mudd agreed with Grinter's assessment. Faced with the fast renewal of engineering knowledge, the Harvey Mudd educators concluded that engineers would not be able to keep up without lifelong learning. Hence founders of the college focused on developing students' ability to learn by themselves via a general engineering program. The advantages of a broad, general engineering education over more specialized engineering majors were agreed upon during the college's first curriculum study in 1958: "All of this argues for a broad grasp of human knowledge based upon a strong science but incorporating above all else intellectual power which can be transferred readily from one area to another. To put it simply, we need a man with a capacity to specialize rapidly wherever he needs to rather than one committed to a specialty" (Harvey Mudd College Curriculum Study 1958). Later educators at Harvey Mudd offered an additional interpretation for the choice of a general engineering program: it was meant to provide "a broad basic preparation in engineering science fundamentals with subsequent specialized engineering studies postponed until graduate school" (Bright and Dym 2004).

The creation of a general engineering program was also influenced by the limited space reserved for engineering courses. During the early years, Harvey Mudd students spent one third of their course hours studying a Common Core curriculum that emphasized basic sciences and math. In addition, another third of their course time was designated to the study of the humanities and social sciences (Harvey Mudd College Curriculum Study 1958). The extensive curriculum in the humanities and social sciences embodied the college founders' commitment to helping students grasp the social implications of science and technology and find the proper roles for scientists and engineers in society. Dick Olson, an early student and lifetime faculty of Harvey Mudd, linked the Harvey Mudd's commitment to liberal education to the moral reflections on science and technology at the time:

> In the aftermath of World War II, there were broad worries within the engineering and science communities brought on by the perception that complicated modern technologies had a rapidly growing impact on both the physical and social worlds that all of us live in (Olson 2011).

Platt, himself a renowned radio physicist, refused to work on the Manhattan Project for ethical concerns (Klawe 2014). Another faculty of Harvey Mudd attributed the mission of the college to the impacts of nuclear weaponry, which became a "wakeup call" to the world of scientists and engineers:

> What came out of this 'wakeup call' was the realization that scientists and engineers should not allow themselves to become simple-minded tools of massive political or economic regimes. They must be educated to think through the human and social ramifications of their work; they must be able to argue through their own responsibilities in newly created situations; and they must be fully ready to engage with the social and political world around them, equipped with a sense of history, with

> political sensitivity, and with a strong sense of human values (Beckman 1997).

2.3.2 Picker Engineering Program

The first class of Harvey Mudd College contained only one woman student (Platt 1994). Although a considerable number of women had worked in the technological and industrial fields during World War II, educators in the immediate postwar years seemed not anxious to continue the flux of women into the technoscientific area.[21] The indifference to the gender imbalance in technical education, however, was not to remain undisturbed in the 1970s, after a decade long social movements had changed the political climate in America. In 1976, Smith College, one of the nation's largest and oldest women's college, parted with the University of Massachusetts, Amherst (UMass) to create a dual degree program in liberal arts and engineering (Waugh 2012). The program allowed Smith students to pursue a B.A. degree in a liberal arts area from Smith College and a B.S. degree (and an optional master's degree) in engineering from UMass. The program marked Smith's efforts to redefine the boundary between liberal and engineering education; in the meantime, it "was introduced to academic and corporate communities as a response to the national shortage of qualified women engineers" (Waugh 2012, 23). Despite popularity among students and employers, the dual degree program was terminated in 1992 for financial and administrative reasons (Waugh 2012). This experiment, however, planted the seed for a bold vision to fuse professional and liberal education for women.

The seed did not wait long to meet the light again. In 1999, "[h]oping to add more women to an overwhelmingly male-dominated profession, Smith College's board of trustees voted Saturday to open the nation's first engineering program at a women's college."[22] The newly founded Picker Engineering Program not only continued Smith College's commitment to promote women and minorities in underrepresented

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[21] See Bix (2004, 2014). Harvey Mudd's founding board of trustees voted to admit women to the new college (Platt 1994).
[22] "Women's College Offers Engineering." *Chicago Tribune*, Feb 21, 1999.

professions but also crystallized its founders' vision of a holistic model of engineering education.

At the turn of the new century, a significant shortage of workers in science, technology, engineering, and mathematics (STEM) was again predicted in America (National Science Board 2000). People in engineering and business grew more alarmed as the number of high school graduates interested in the STEM majors continued to decline; severe terms like "brain drain" or "workforce crisis" were used to describe the emergency (Bakos 1992; Gibson, Dickson, and Mentel 2001). A good number of engineering leaders and educators believed the crisis would be significantly alleviated if engineering could attract more women and minorities, who were currently underrepresented in engineering programs and within the profession (Commission on the Advancement of Women and Minorities in Science, Engineering, and Technology Development 2000). In a reflective article about the educational experiments at the Picker Program, two of the program's founding faculty call our attention to the gender imbalance in American engineering education: fewer women than men enrolled in engineering programs, and women engineering students had a lower retention rate than men (Mikic and Grasso 2002). As a *New York Times* report points out, the creation of the Picker Program coincided with an attempt at Smith to change this "largely white, historically elite institution" to welcome students with more diverse backgrounds (Bronner 1999). The report cites John M. Connolly, then provost of Smith, who noted in California the majority of high school seniors who wanted to study engineering were ethnic minorities. Connolly felt Smith would not attract these groups of students without offering majors of interest to them (Ibid).

Besides the insufficient number of graduates during that period, the quality of the mainstream engineering education in America was also called into question; its narrow focus on technical training was deemed out of touch with the contemporary globalized and information-based economy. In a provocative article, Domenico Grasso, the founding director of the Picker Engineering Program, challenged American engineering colleges to justify their existence in the face of technically prominent engineers trained in Indian and Chinese universities with lower cost (Grasso 2005). Grasso is a critic of the kind of education that produces engineers "in narrow, vocationally oriented disciplines" (Grasso 2002). Such traditional model of educating engineers, Grasso suggests, belonged to a manufacturing based economy of the mid-20th century, not the more complex economy of the twenty-first century (Grasso and Martinelli 2007). Grasso (2002) also points out the traditional model, with its excessive focus on teaching technological information, fails to address the social relevance of engineering. For example, he observes most engineering curricula "teach math, mass transfer, heat transfer, continuum mechanics—they teach these courses, and at the end, they may say, 'OK, there's some society or ethical issues we have to retrofit—or at the beginning—but it's lost in the overall picture" (Clayton 2000).

Grasso turned down an offer from Columbia University and joined Smith to found a new engineering program, with the hope of educating engineers "beyond their traditional roles as problem-solvers to become problem-definers," who will practice engineering with "the human spirit" (Grasso 2004). A model of holistic engineering education, the Picker Program was designed to assist students' "critical thinking using techniques usually associated with study in the liberal arts and through structured problem solving, which is typically associated with an engineering education" (Ibid). To allow students extensive learning in the liberal arts, the Picker Program offers a B.S. degree in Engineering Science, which helps students "think broadly in fundamental and integrative ways about the basic tenets of engineering;" more specialized technical courses are scaled back and reserved for graduate training (Grasso 2005).

To correct the usual peripheral role of social and ethical issues in engineering curricula, founders of the Picker Program made ethics "an integral part of an engineering education" (Riley, Ellis, and Howe 2004). At the beginning of the program, faculty designed a cross-curriculum ethics education: ethical components were included in five core engineering courses, taught with different pedagogies (Ibid).[23]

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[23] This design was not strictly followed in later years, see Page 114.

2.3.3 Product Design and Innovation (PDI)

During the same year (1999) that Smith College created the first engineering program in a women's college, a dual-degree program in Product Design and Innovation (PDI) was launched at Rensselaer Polytechnic Institute, a joint effort of the schools of Engineering, Architecture, and Humanities and Social Sciences (H&SS) (Nieusma 2008). This unprecedented interdisciplinary design program met the requirements of two B.S. degrees: one in Engineering Science and one in Science and Technology Studies (STS). The founders of the program, "an anarchist philosopher, a feminist architect, and a design engineer committed to 'the social side' of engineering" (Nieusma 2008), sought to create a new paradigm of design education, which would help students integrate three dimensions of design expertise: "the technical, the social/culture, and the aesthetic" (Schumacher and Gabriele 1999).[24] The initial design curriculum contained both engineering and STS courses, but the core of the curricular innovation lay in a sequence of eight design studio courses, one offered each semester. These studios were co-taught by "an engineer, an STSer, and an artist and/or architect" (Schumacher and Gabriele 1999). The studio courses required students to conceptualize, sketch, present, make, and test new products, thus they allowed students to encounter and address the technical mechanisms, social contexts, and aesthetic appeal of products simultaneously.

The creation of the PDI program represented this venerable polytechnic institute's attempt to renew its undergraduate education in lieu of the changing environment for engineering in the 21st century. The birth of a unique design program, in the meantime, can be credited in no small ways to the STS faculty's pursuit of socially relevant scholarship and an institutional atmosphere that encouraged interdisciplinary collaboration at the time.

Starting in the early 1990s, Rensselaer engaged in a series of initiatives to innovate its undergraduate education. Internal grants and administrative actions supported new

[24] The three founders of PDI were John Schumacher (Chair of the Department of Science and Technology Studies), Frances Bronet (Associate Dean of the School of Architecture) and Gary Gabriele (Associate Dean of the School of Engineering).

multidisciplinary courses, a reformed engineering curriculum, and the adoption of studio teaching in a number of engineering and science courses (Lahey and Gabriele 1996). Nationally, engineers were called upon to take the lead in meeting the challenges brought about by "a highly competitive global economy" while at the same time help "share social well-being and restore the natural environment" (Schumacher and Gabriele 1999). Educators at Rensselaer felt these challenges called for expertise that transcends the traditional disciplinary boundaries; they turned to design as a powerful means to cultivate engineers' ability to identify and solve problems with synthetic and systematic approaches. In their proposal to National Science Foundation (NSF) about creating the new design program, the authors cited NSF Acting Deputy Director Joseph Bordogna, who urged engineers to integrate the social and technical components of design:

> Design becomes the leverage point of determining a product's impact on our lives. In this sense, when we educate our engineering students we must instill in them not only technical expertise but we must also lead them to examine and question the goals and value-system of the society they are being prepared to build. And, we must also help them recognize that their skills as engineers allow them to alter dramatically the present and future direction of that society. (Quoted in Schumacher, Gabriele, and Bronet 1998)

The reinvention of engineering learning with a new emphasis upon design education at Rensselaer was prepared by a series of inner- and cross-school efforts to develop design scholarship and pedagogy. In particular, the Department of Science and Technology Studies had been pursuing an emphasis on design studies since the early 1990s. In a proposal to develop "an STS Focus on Design," the authors fervently called for STS researchers to grapple with the most crucial questions in our practical life; they also suggested design as an appropriate topic for such questioning:

> Design is an important arena for science and technology studies because it is that part of the technology making and using process that offers the best chance for deliberate, collectively debated and chosen matching of technical means with social goals. (Department of Science and Technology Studies 1997)

The authors also endorsed the study of design for its promise to strengthen the relevance of STS scholarship to audiences outside the academic community, for "the relatively concrete and practical focus helps nudge graduate students and even faculty member away from excessive preoccupation with abstract generalizations" (Ibid). An alliance was formed in the STS Department by faculty who were interested in the philosophical, cultural, and political questions of design. Several doctoral students were recruited to study design at workplace and in classrooms.

The STS faculty's enthusiasm for design was met with interested colleagues inside and outside the School of Humanities and Social Sciences. Throughout the 1990s, cross-school, interdisciplinary collaborations supplied the backbone for the development of design pedagogy, and later the design program, at Rensselaer. In 1991, a multi-disciplinary design course, "Engineering and Society: the Art of Design," was offered to first-year students. Co-taught by faculty from architecture, engineering, and STS, the course included readings and discussions of works in the humanities and social sciences as well as engineering sciences that address different dimensions of design; students in the class also worked on design projects. Several efforts followed suit: a few humanities companion courses were coupled with engineering design courses; six-credit design studio courses were created, which integrated engineering and the humanities and social sciences.

The PDI program itself was also developed through a gradual and collaborative process. With the support of an NSF grant, the founders of PDI organized a series of week-long summer workshops, where faculty from engineering, architecture, H&SS and professional product designers were invited to review and redesign the existing studios and to plan for the studio courses to be taught the following year (Gabriele, Bronet, and Hess 1999). To encourage participation by faculty who had not been involved with the program, the Steering Committee of PDI organized an additional summer workshop named the "PDI Deep Dive." The workshop invited eight faculty (four from STS, two from engineering, and two from architecture) to work on a week-long design project; the experience was similar to what students experienced in a design studio course. The "PDI Deep Dive" succeeded successfully communicated the idea and experience of PDI to colleagues and got them excited about the new program. Some faculty joined the teaching team of PDI after the workshop.

The origins of the three educational initiatives to integrate engineering and the liberal arts all demonstrate efforts to meet the needs of the engineering profession as well as attempts to renew engineers' social roles. The founders of HMC wished to produce broadly learned, adaptable engineers envisioned in the *Grinter Report*. The creation of Picker responded to the engineering profession's need for more women and minorities. The start of an interdisciplinary design program, instead, highlighted the increasingly noted importance of professional skills in identifying and analyzing complex sociotechnical problems. In addition, the three programs all included extensive studies in the liberal arts as a means to help engineering students better understand and assume greater social responsibilities.

Besides demonstrating the impacts of professional thinking and social expectations, the origins of the three initiatives also reflect the unique approaches taken by educators at each institution according to contingent factors.[25] For example, the identity of HMC as a liberal arts college reflected influences of the other member institutions of the Claremont Colleges. Picker's emphasis on promoting women in engineering resonated the mission of a women's college. The initial structure of PDI was specifically designed to couple with mechanical engineering, a long standing program at RPI.

[25] As Akera (2014a) suggest, "there is no single solution to the problem of engineering and liberal arts integration." Throughout the history of engineering education in the U.S., engineers repetitively updated the epistemological foundation of engineering to reflect changing time and social conditions (Akera 2014a).

3. HMC

3.1 Small is beautiful, and/but…

Claremont is an oasis in the overcrowded Los Angeles area. It sprawls along a strip between two interstate freeways: I-210 in the north, and I-10 in the south. Drive 50 miles east from LA on I-210, which takes from 50 minutes to two hours, then take the exit toward “Claremont School of Theology,” you enter this “city of trees and PhDs.”

Pick up any brochure of Claremont, you will read a variety of options transporting to this city: Caltrain, freeways, and two nearby airports. But Claremont exhibits some distinct characteristics among the busy commuting suburbs in the LA metropolitan area. A few years ago, the city banned fast food restaurants, a move that cast a shadow on my stay as food choices were limited in town. In reality, however, a five-minute drive eastward or westward on Foothill Boulevard, the “main drag” of Claremont, would take you past the city limit to eat what you please.

Claremont City Hall lies half a mile south of Foothill, between Harvard Avenue and Yale Avenue. The area surrounding the city hall, named the Claremont Village, is the symbolic heart of Claremont’s commercial and communal life. The village has the usual units for a municipal center: post office, public library, train station, etc. There is also a sample of ethnic cuisine: Middle East grill, American burgers, Italian pasta, Indian buffet, and a Mexican bar among other choices. On weekdays, hungry customers flocked to the village at lunch hours: public servants, librarians, shop owners, elders, and business people, but I saw few college students there.

Students of the Claremont Colleges, the main residents of the city, live in their own world. Seven independent but interrelated educational institutes form the nucleus of the city. Although two graduate schools—Claremont Graduate University (CGU) and Keck Graduate Institute—were added to the Claremont Colleges in recent years, people are still used to calling them 5C, referring to the five liberal arts colleges: Pomona, Claremont McKenna (CMC, or Claremont Men's College in the old days), Scripps, Pitzer, and Harvey Mudd (HMC).

Harvey Mudd College, a liberal arts college for engineers, scientists, and mathematicians, occupies thirty-three acres of land that wedges into the slot between CGU and Pitzer on the north rim of the Claremont Colleges. It faces Claremont Theology School on the other side of Foothill Blvd. As of October 2013, HMC enrolls 807 undergraduate students. During my stay there, I was repeatedly told that with few exceptions, every student knows everyone else on campus. One student said she immediately discovered I was not a Mudder (nickname for Harvey Mudd students) when she first saw me sitting outside the Starbucks on campus.

The Starbucks has become the cathedral for informal social gatherings at Mudd. It is located on the ground floor of the newly built Shanahan Center for Teaching and Learning, unveiled shortly before my arrival in September, 2013. Since then, most classes meet in this single building. A few tables are scattered on the T-shaped walkway outside the cafe, making the space a natural square. The three columns in the square are often patched with posts: SportsClaremont offers cheap tickets to LA Galaxy games. Theatre play on Sunday at Scripps. Office of Institutional Diversity hosts lecture series. Earn a master's degree in engineering management. Study environment at sea. Looking for an SAT tutor. Claremont Colleges Fall Concert schedule. 7 Colleges Queer Resource Center Dialogue Series. Girls' Halloween party at Scripps. D E Shaw&Co is hiring. Dodge ball tournament. Philosophy lecture at Pomona on Thursday. Career Fair preparation workshop in the aviation room. Pan-African Student Association meet this week. Happy National Coming Out Day….

The square had no regular dweller but me. I used it as my office, where I faithfully performed my duty: writing, interviewing, people watching. There aren't many people to watch during class hours. The exterior of this modern, LEED-certified green organism for learning revealed few inklings of the hundreds of Mudders (and students from other colleges) taking classes in its cells. You could tell when the classes are about to break, when the silent and static air is suddenly rippled by a whisper or a chuckle from nowhere. Then you see torrents of people building up, until the silence is finally mangled by laughter, greetings, and the grinding noises of longboards and scooters. In a flash the cafe would be flooded with people thirsty for caffeinated drinks. A savvy dweller knows to avoid consumption in the cafe during the rush moments, for when the bell rings, all the motions would evaporate, and the building resumes a solemn organ of teaching and learning.

3.1.1 The honor code

Students at Harvey Mudd gather not only in a physical building; they are also bound together in a close community, thanks in part to the small size of the student body and the consequential fact that people here know each other. Such bonds have also been inscribed within the campus Honor Code, which provides the foundation for students' self-governance. The Honor Code states "students are expected to act as responsible individuals, to conduct themselves with honesty and integrity both personally and academically and to respect the rights of others. The college considers these standards to be essential to its academic mission and its community life" (Harvey Mudd College Honor Code 2014). Every guided campus tour for prospective students and parents highlighted the Honor Code, thus potential new members of this community are "socialized" before they are officially admitted. The guides of campus tour (voluntary Mudders) do an excellent job visualizing the life legislated by the Honor Code: you are brought to witness that no hands but the owners' would lay upon the untended longboards parked outside the dining hall, because the Honor Code requires respect for others' property; you are taken to the dorm and advised to imagine taking your mid-term at 3am in your bed while eating food, because the Honor Code warrants your academic integrity to your professors. Upon entering the college, the frosh (the way freshmen are called at Mudd) have to go through a more formal ritual, signing their names on a six-inch thick roster book using a feather pen, taking an oath that they will act in accordance with the Honor Code. Anyone who has possibly violated the Honor Code is supposed to self-report to a board, which holds trials of the potential violators, gives them amnesty, or sentences them to apology and/or community service.

3.1.2 Small classes

At Mudd I sat in a variety of classes, including introductory engineering design (E4), freshmen academic writing (WRIT ONE), an engineering elective (manufacturing), capstone senior design (the Engineering Clinic), and an elective in humanities, social sciences, and arts (Political Innovation). In none of these classes did the number of students exceed twenty-five. In "Introduction to Engineering Design" (E4), three professors taught sixteen students. In WRIT ONE, every professor taught eight students, and usually two sessions—two professors and sixteen students—met together in one classroom. "Political Innovation" had the most students among the classes I observed: twenty-two. The small class size and dedicated teachers[26] created a learning environment where students receive intense attention from their professors. In E4, for example, the professors frequently sat with students in small groups and helped each student articulate his or her own thinking process.

During one day that I observed, the professors sent the bulk of the class to work on finite element analysis in the computer lab, and later called student groups back one by one to review their progress with the second course project: function analysis of an electric toy fish. A week ago, each group (containing two or three students) had been given a fish and a multimeter. Their assignment was to "reverse engineer" the fish: taking it apart, sorting and drawing the parts, figuring out how the mechanical and electric systems work, and recommending improvements to its design. When they came back to the classroom, each group first handed the professors a report that contained a picture taken of each part and a description of every subsystem in the fish. The professors read the report and provided feedback.

[26] At HMC faculty understand teaching as their first and foremost obligation to the institute.

The first team had performed a thorough anatomy of the fish, but their presentation of its various parts was somewhat arbitrary, lacking a clear logic. Prof. HA suggested they organize the parts according to the fish's functional systems so that the readers could see what functions were performed by each system. Prof. HA joked that a text search for verbs in the current report would not yield many results. He asked the team a few more questions to help them articulate how each system functions and develop a conceptual understanding of the fish.

The second group, upon hearing a similar suggestion, asked the professors what they meant by "organizing by functions instead of geometrics." Prof. HC explained it to them. These students had had a hard time figuring out what was going on with the circuit board in the belly of the fish, because much of the electrical knowledge required for this task had not been taught. Prof. HB suggested the students look at the circuit board as a "black box," and Prof. HC elaborated the "black box method"—a black box is an entity in which different inputs and outputs are connected. Hence, the fish has three sets of inputs and outputs: energy, signal, and material. Without knowing how the system operates inside the black box, Prof. HC suggested, the students could describe the inputs and outputs.

After reviewing a few reports, the professors exchanged among themselves some common concerns they had discovered from different groups. They found students easily confused by the difference between a geographic and a functional based topology to categorize the systems; they also found many students had difficulty dissecting the "unknown" circuit board. For the following groups, the professors explained these issues more purposefully. Prof. HC repeated the "black box method" to students a few more times.

One group organized the systems in their report using a different functional logic. Prof. HA acknowledged that the organizing principle chosen by the team was different from his own but equally effective. The students might not have been fully conscious about what they did, but Prof. HA's comment called their attention to their own thinking process and helped elaborate it.

3.1.3 Small but complete

Harvey Mudd College has seven departments: engineering, math, computer science, biology, physics, chemistry, and the Department of Humanities, Social Sciences, and Arts (HSA). Policies of the college hold that there will not be any major or minor outside the field of engineering, science, and math. Thus, only the former six departments offer degrees. Resources for learning, however, were not limited to what is available on campus. Many Mudders take music classes at Scripps or Pomona, where they receive one-on-one tutoring from renowned musicians. I also met Mudders who took theatre classes at Pomona. The Claremont Group plan, laid out by former president of Pomona College James Blaisdell, mandates all the member institutes of the Claremont Colleges to share facilities and resources. If one walks three blocks south on Claremont Avenue, the street that marks the west end of Harvey Mudd campus, one reaches the Library for Claremont Colleges. This five-story building serves members from all seven institutes of the Claremont Colleges. The seven institutes also share health and consulting service, student clubs, and sports teams.

3.1.4 Too small?

During interviews, many students told me they chose Mudd because they had gone to a small high school and cherished the familial feeling or because they had been to a large public high school and had had enough of it. Unlike those gigantic universities, such as U.C. Berkeley or Rutgers, Harvey Mudd "is a place defined by its people," a campus tour guide said emotionally to a prospective student and her mother. It is a place where the president tries to remember the name of every incoming student (she also frequently stops to chat with students in the Starbucks, where she stands in line with students waiting for coffee). Despite all the sweet comments you can hear from the students, there are moments when Mudders cannot help sighing and admitting "we are too small."

I heard this expression at a weekly meeting of Harvey Mudd Engineers for a Sustainable World and Mudders Organizing for Sustainability Solutions (ESW/MOSS). ESW@HMC merged with MOSS because both had limited and overlapping membership. ESW/MOSS meet every Monday evening in the Aviation Room inside the Hoch-Shanahan Dinning Hall. I saw people coming with food: salad, rice, grilled meat–things they had grabbed from the buffet bar next door. At first the attendants sat randomly around several tables, but soon a senior student asked them to relocate according to the specific mission everyone was involved with. Each mission group took a table: groups for the green dinning service, outreach, and financial study. There were eight interested students in the financial study group, led by two seemingly senior members. The rest in the group were frosh and sophomores. Only one engineer sat at the table. Mudders do not have to declare majors until their fourth semester, so most of the young students in the group were not yet declared. ESW/MOSS was planning to plead with the college to set aside a fund for sustainability projects on campus. The financial study group had volunteered to peruse HMC's financial reports for the past five years in order to locate funding sources for which ESW/MOSS might apply. For years, ESW/MOSS had been constrained by lack of funding and had remained mostly an awareness group. Its inability to act not only incurred criticism from outside the club, but also frustrated its own members. At the meeting I tried to connect with the attendants by sharing what I knew about ESW@RPI, which deployed a project in Haiti a year ago. Some students at the table knew that; they had been to an ESW national meeting the year before, where they were inspired by well-resourced and active ESW chapters, such as those at RPI, UCSD, University of Buffalo, and others. They also talked enviously about the astonishing amount of funding received by ESW at MIT and Harvard. "We are too small," said one of the senior students.

Being small could also mean little faculty availability on areas beyond their direct obligations. Mr. H5 spent his senior year of high school in a South American country and the experience kindled in him an interest to help the environment and people in developing countries. During his first year at Mudd, Mr. H5 sought to start an Engineers Without Borders (EWB) chapter and to bring a group of interested Mudders to the village where he had stayed in South America. However, the idea met a number of "road blocks" and failed. One of the lessons Mr. H5 learned: people are busy here. Mudd professors are usually occupied with teaching during the school year, and summer is their prime time for research. Escorting a team on a ten-week trip overseas as a faculty advisor is too big a commitment. Being busy is not the only hurdle, however. In the year 2013, the Student Council of HMC disapproved ESW's application for $300 to pay its registration fee to the ESW national team. As a result, ESW@HMC was technically not part of the national organization at the time. To answer my confusion about the lukewarm interests in ESW at a school full of scientists and engineers, one student described, among other things, a "Mudd Bubble." Living comfortably in this bubble, my informant observed, many Mudders are not used to looking outward.

Some "legends" shared among Mudders suggest the boundary of the "Mudd Bubble." For example, untended longboards on campus are secured by the Honor Code, but bikes need locks because "townies"—indecent people outside the college—might steal them. Or, it's OK to play with fire ("Mudders love fire"), but no fire should exceed the height of dorm buildings. The reason: once upon a time Mudders' played with fire and scared someone at Scripps, who called the firefighters, thenceforth no fire should be seen by people at Scripps. Mudders also believe the food served in their dining hall the best among 5C. In comparison, Pitzer is known for vegetarian diet and "save the cow" stuff. Scripps has good salad, sushi, and exotic food. Pomona? It's too far away. Some Mudders told me that students there are lazy and they hate to walk. For that reason few Mudders have dined at Pomona.

3.1.5 Diversity

The "Mudd Bubble" not only prevents students from experiencing or recognizing the outside world, but it also elides differences among Mudders themselves. To be wrapped in the campus bubble is to live in a world which operates according to a few principles, ones derived from simple and well-intended assumptions—well-intended maybe, but sometimes extremely simple. The culture of collaboration, the love for intellectual challenges, the Honor Code, the legendary games, the practical jokes, and the glory of nerds contribute to a wholesale self-image of a typical Mudder. When students join this community, they are expected to share its assumptions and conform to the wholesale image. The community, however, is not prepared for swift changes in itself to accommodate members who do not fit the expected mold. At Mudd, the differences among students, especially those related to non-traditional ethnic or economic backgrounds, are not made very visible, although the demography of the student body has changed.

Over the past decade, and especially since the presidency of Maria Klawe, a female computer scientist, HMC has made significant progress in recruiting more female students. [27] There have been more Asian students as well, both American-born Asians and international students coming from China, Korea, Vietnam, and so forth. Asian students seemed confident academically, yet in social life the international Asian students (e.g., Chinese) seemed to mix primarily with their own nationals. Doing homework together was a major tradition at Mudd, but I heard more Asian students expressing no interest in group homework, either because they work better on their own or they found the homework too easy and no need for collaboration.[28] There was a small and growing body of Hispanic students. Hispanic students also seemed the primary object of the college's diversity initiative. The college's Institutional Office of Diversity held a series of talks and workshops, many of which focused on Hispanic population, such as a talk on immigration reform by a Mexican immigrant scholar. Black students were nearly invisible on campus. Throughout the two months I spent at Mudd, I saw only one black student, an international student from Africa. A retired professor from the HSA department once wrote that the environment at Mudd is more congruent for increasing Hispanic students, because they have already reached the "critical mass." In

[27] As of Oct 2013, the gender distribution of the HMC student body is 54% male and 46% female. The racial/ethnic distribution of the student body is the following: African-American/Black: 1%; American Indian/Alaska Native: < 1%; Asian-American/Asian: 22%; International: 11%; Latino: 9%; White: 47%; Multiracial: 4%; Unknown: 5%. (Harvey Mudd College Student Body 2014).
[28] This observation is based on my interaction with a few Mudd students who came originally from Asian countries. It is worth noting the difference between these international Asian students and the Asian-Americans, who have been historically stereotyped as "model minority" (Osajima 2005).

contrast, black students are so rare that they could not feel belonged (Olson 2011). Some faculty member also pointed out a “double bind” that curtails HMC’s appeal to black students: black students want more black faculty as role models they can relate to, whereas black faculty are reluctant to come unless they see a significant body of black students.

Minorities are somewhat invisible at Mudd, not only due to their lack of physical presence. It occurred to me they are invisible even when they present themselves and voiceless even when they break the silence. There are a number of initiatives for diversity causes among the 5C. Meetings and lectures on diversity topics are regularly posted on Mudd campus. I went to one of the workshops organized by the HMC Institutional Office of Diversity. The workshop happened in the Aviation Room during lunch hour. The moderator led the participants to explore various privileges that arise from one’s identity: men, white, straight, well educated, etc. A lively discussion happened among the participants: faculty (white, Indian …), black, Indian, and Asian students. No white students came.

3.1.6 The controversial college expansion

While at Mudd, I witnessed an incident that turned the whole campus into secret excitement and seriously tested people’s faith in the smallness of the college. One afternoon I arrived at my office—the little square outside Starbucks—to find a student handing out questionnaires. He dutifully asked every passer-by if he or she had filled the survey on college expansion. When classes resumed and he became idle, I inquired about his business. He was a member of the Mudd student government, and he was helping the College survey students’ attitudes toward the college expansion. The survey was conducted efficiently. Within two days the student government had collected feedback from some five hundred students; their goal was to survey every student. I learned that the president of the College had proposed to increase the number of students by one hundred in the next ten years, making the total number of students close to nine hundred in the year 2023. Enough said. The student resumed his silent work. His caution was not unusual. During the following days a number of people chuckled, asked “do we have to talk about this?” or requested me to turn off my recorder when I brought up the college expansion. Still they were a few who didn’t mind having their views made public. From these piecemeal clues I was able to construct a mosaic of the expansion story.

The Board of Trustees deemed the College a great success over its first half century and encouraged its expansion. The entrepreneurial-minded board, acting on a “grow or die” credo, felt it was time to make the business of educating excellent engineers a bigger deal. HMC also needs tuition from some fifty more students to make it financially viable. The faculty was divided. Some welcomed the expansion, anticipating it would bring more colleagues, richer academic opportunities, and a more diverse student body. Others worried that the increase of students and faculty might create intellectual and personal ghettos. There were also doubts about the financial feasibility of the expansion.

While the college community was still deliberating the pros and cons of an expansion, the president decided to speed up the process by putting the proposal up for a vote by the Board of Trustees on November 1, 2013.[29] Some faculty members were “caught off guard” by the pace of deliberation (or the lack of it). In a crisis management mode, meetings were held to include faculty inputs, and student attitudes were surveyed.

Students I spoke with expressed unanimous worry about the expansion. They considered the expansion a threat to the small and close Mudd community and to the efficacy of the Honor Code. Some students suspected the current size of Harvey Mudd is already reaching the threshold of remaining a community where everyone knows everyone else. Junior and senior students said they could no longer recognize every face in the lower classes now. One student told me more professors had withdrawn take-home exams, because cheating in dorms had been reported more frequently in recent years as the number of students continued to grow. Admitting more students would make it harder to maintain the Honor Code, some of my informants told me.

[29] On November 1, 2013, the HMC Board of Trustees unanimously voted for the expansion (Bald 2013).

Rumors among students suggest more aggressive expansion was already underway. In 2013, the college reported that it "mistakenly" recruited more students than it had planned, adding the total number of students to 807. In private, students questioned whether the administration had intended the "mistake." Some students consider the college expansion as the president's tactic to increase minority students. According to this scenario, the president wants to recruit more black and Hispanic students. However, it appears that she is worried that by simply increasing the ratio of minority students, the overall academic quality of the student body might fall. Hence, she proposed to increase both mainstream and minority students (It appears that this reasoning assumes that black and Hispanic students are academically less competitive.).

3.2 Visions of learning: "Well versed in all"

The Association of American Colleges and Universities explains liberal education as "a philosophy of education that empowers individuals with broad knowledge and transferable skills, and a strong sense of values, ethics, and civic engagement" (AACU 2014). Educators at Mudd pursue a similar, but not identical, philosophy to the one stated above. HMC's philosophy of education is inscribed in its mission:

> Harvey Mudd College seeks to educate engineers, scientists, and mathematicians well versed in all of these areas and in the humanities and the social sciences so that they may assume leadership in their fields with a clear understanding of the impact of their work on society. (Harvey Mudd College Mission and Strategic Vision 2014)

In 1958, one year after the college had opened its door to students, President Joe Platt led HMC's first curriculum study. The study enacted the academic trajectory of a Mudder, consisting of learning in three equal stems. A Mudder is supposed to spend one third of her class time studying a common core, another one third studying the humanities and social sciences, and one third studying her major. This structure pervades the curriculum design at Mudd for the next five decades, although the terms have been amended slightly: computer science and biology were added to the science curriculum; arts were added to the humanities and social sciences to form the HSA curriculum. The class time dedicated to each stem also changed following these revisions. For example, class time for the study of HSA and one's major was scaled back to give space for computer science and biology in the common core as well as some free electives. In practice, many students use the free electives to take upper division courses in their majors. As a result, the major change compared with the curriculum structure proposed in 1958 is a reduction of HSA course time from one third to about a quarter at present.

3.2.1 The common core

Upon entering the college, Mudders take a Common Core curriculum for the first three semesters. The Common Core is a platter of samplers from every department. "It includes three semesters of mathematics, two and one-half semesters of physics and an associated laboratory, one and one-half semesters of chemistry and an associated laboratory, an interdisciplinary or disciplinary 'Core lab' selected from a changing set of offerings, a half-semester of college writing, a course in critical inquiry offered by the Department of Humanities, Social Sciences, and the Arts, and one course each in biology, computer science and engineering" (Harvey Mudd College Catalog 2013-14, 26). The latest Common Core results from a committee study at the request of the current president Maria Klawe. The committee discovered students did not get much space for free electives in their first three semesters. As the lack of free choice was considered contradictory to the spirit of a liberal education, the new Common Core scales back the time for math, physics and chemistry; it also drops an Integrative Experience requirement, which leads students into inquires that involve two or more academic disciplines. The curriculum space released from these changes enable students to take one free elective per semester while they complete the Common Core.

3.2.1.1 Math

Math takes the lion's share in the present Common Core. Several subjects in the Common Core are taught in "half courses." A half course is worth 1.5 credits and meets for half a semester (~8 weeks). All the math subjects in the Common Core are "half courses." A typical schedule for Mudders' math courses in the Common Core looks like this:

Semester one: calculus, probability and statistics.

Semester two: linear algebra one, differential equation one.

Semester three: multivariable calculus, linear algebra and differential equation two.

One student told me that a Mudder takes as much math in the Common Core as a math major does in four years at Scripps. Students I interviewed often noted that their math courses are difficult. Calculus, the first math course, is proof based. Even students who had taken AP classes on calculus in high school found it very challenging.

In the eyes of HMC engineering educators, math provides a crucial role in preparing students as future leaders in the engineering profession. According to some engineering administrators and faculty, a systems/math component lies at the core of HMC's general engineering program. This view holds math provides a language that enables Mudd engineers to "talk horizontally" with engineers from different disciplines, which would in turn allow them to understand the big picture and act with leadership capacities.

3.2.1.2 WRIT ONE

The Common Core also includes a half course on academic writing, best known among Mudders as WRIT ONE. Students take WRIT ONE during their first semester at Mudd. The course is staffed to have a student-faculty ratio of eight to one. Instructors of WRIT ONE come from every department on campus. Usually an instructor who teaches the course for the first time will be paired with an experienced instructor to co-teach two sessions of sixteen students. WRIT ONE indicates the college's commitment to communication training across curricula. As one of the syllabi suggests, "[t]his course is the first component of a broader effort across departments to develop your writing abilities" (Esin and Menefee-Libey 2013).

3.2.1.3 Critical inquiry

In the spring semester of their first year, Mudders take a course in Critical Inquiry (HSA10). Included in the Common Core, this course is the debut of the HSA curriculum. Critical Inquiry is offered in a number of sessions, each taught by a faculty from the HSA department, who organizes the session around a topic related to her own specialty. Topics include evaluating psychological claims, economics, Chinese culture, and so on. The different sessions are united by two common components: First, every session has to convey to students the procedure of designing, implementing, and presenting research, i.e., the logic of critical inquiry. Second, each session has as a prelude a discussion of the meaning of liberal arts education for HMC. The first writing assignment asks students to argue whether Harvey Mudd is a liberal arts college.

3.2.2 The HSA

In addition to the Critical Inquiry, a Mudder has to take ten courses in HSA. The HSA curriculum includes a concentration requirement—taking at least four courses in a disciplinary field—and a breadth requirement. Students have to take at least five courses offered by the HSA department at Mudd, and the rest can be taken from any of the Claremont Colleges.

I found Mudders in general enjoy the extensive HSA curriculum; some consider it one of the main reasons they chose HMC. The faculty and students I spoke with all estimated HMC had a higher percentage of students who were genuinely interested in the liberal arts than at an average technical institute. Yet they recognized Mudders' interests for HSA learning would fall along a spectrum. Some students study really hard in the HSA courses. I heard repetitively from Mudders that for humanities, "you get as much as you put into it." Mr. H5 illustrated his attitude toward HSA learning in a personal vignette: the night before our interview he was up pretty late doing a problem set, but the next morning he got up early to do the 130-page reading for Political Innovation, a political science course he was taking. Mr. H5 said he did it not for participating in the discussion, pleasing the professor, or a good grade; he did it because he has a genuine interest in the topic and the material. Mr. H5 knows he is not alone in studying the humanities classes diligently. For some Mudders, the HSA courses provide a nice opportunity to breathe in a non-technical atmosphere and to refresh their minds that were otherwise saturated with technical terms.

Inevitably there are people who try to "game" the system and choose HSA courses tactically to balance the heavy workload of technical courses. Mr. H2 concentrates in economics for his HSA requirement. He enjoys the contents of economics but regrets a little that it is less like the other HSA courses, which involve a lot of reading and writing. For him, "econ" feels more like engineering math. In some semesters when he does not have "a hell lot of difficult tech courses," he chooses an HSA course that stretches him more, such as political science. Mr. H2 enjoys being stretched whenever he has the space, but as an engineering major, he does not usually have it. So in a really busy semester, he chooses economics courses to get away.

Some Mudders understand the HSA education more pragmatically. For example, economics is favored by many students not only because it seems more "scientific" but also for its "usefulness." During a campus tour, the guide introduced the HSA curriculum to the visiting high school students and parents as "everything that's not about math and science." To illustrate the benefits of the HSA education, the guide said he was taking financial economics, because it is good to learn how to manage your wealth and then go to make a lot of money. For believe it or not, the guide said, Mudd graduates make "a reasonable amount of money," and if you are a CS major, even more.

3.2.3 The major: Engineering

Planners of education at Mudd seem to cherish the number "three." This preference embodies itself in the trio structure of the general curriculum—the Common Core, the HSA, and the major—as well as in particular departments, such as engineering. Engineering learning at Mudd consists of three stems: design, engineering sciences, and system. The design stem includes Introduction to Engineering Design (E4), Experimental Engineering (E80), and the Engineering Clinic. The engineering sciences stem crystallizes Mudd's vision of a general engineering education; it requires students to take at least one course in each of the basic engineering fields: mechanical, chemical, electrical, and computer engineering. The system stem is designed to convey to students a systematic approach to problems; it includes three courses on signals and systems. The system stem starts with E59 (nicknamed "baby STEM"), the only engineering "sampler" in the Common Core; hence it opens a window for every Mudder to see what engineering looks like. In the spring semester of their sophomore year, engineering majors take E101 and E102—the big STEM.[30] Beyond the requirements of the three stems, an engineering major has to take at least three upper division technical electives.

The Engineering Department at Mudd offers an ABET-accredited B.S. degree in general engineering. Instead of teaching the detailed knowledge in particular engineering disciplines, the Engineering Department prioritizes learning the "fundamentals" of engineering, knowledge and skills that provide students with a basis for further learning in any field. This educational choice reflects a central vision of undergraduate engineering education shared by Mudd educators: they see their task as preparing students for a broad variety of careers, for which the particular knowledge required is unpredictable. Hence the Engineering Department focuses on a few generic abilities deemed essential for its graduates to succeed and lead in their professions: first, the ability to understand, communicate with, and collaborate with people in any engineering or technical field; second, the ability to work in unknown and uncertain conditions; third, the ability to learn by oneself the necessary knowledge to solve unfamiliar problems.

To make students "multilingual" in diverse engineering or technological (and non-technical) fields, engineering educators at Mudd strive to teach students a common language of engineering, which is based significantly on math and topped with basic knowledge in major engineering fields: electrical, chemical, mechanical, etc. In addition,

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[30] HMC had all these confusing slangs. E.g., "stem" and "STEM" meant different things. Also, the "system stem" does not mean the usual "system engineering" but rather "signals and systems" in a broad sense, which focused on conveying a system perspective.

Mudd engineers are taught the ancient body language that once symbolized the craft of engineering: the ability to use tools and to make things. The prospect for Mudders to function in multidisciplinary teams is further ensured by consistent training on oral and written communication and intensive teamwork experiences, which are emphasized by the Common Core, the engineering curriculum, as well as broad learning in the humanities, social sciences, and arts. Mudd educators also believe no matter how much one learns at school, a professional frequently works under uncertain conditions and encounters unknown problems. Thus the broad learning in engineering and the liberal arts focus on preparing students for the journey of continued and self-guided learning. The Engineering Department makes a lot of efforts to help students "learn to learn," especially to learn from failures and to move beyond them.

3.2.3.1 The sacred hands-on experiences

When he visited HMC as a prospective student, Mr. H2 stayed with a computer science major, who was taking a tool class. Later that night, the student took Mr. H2 to the machine shop, where a group of students in the tool class built a hammer together. For Mr. H2, the scene of building a hammer with your friends late at night illustrated the kind of college life he was looking for. Although HMC is known for students' academic achievements, many Mudders are also enthusiastic disciples of the "shop culture" of engineering (Noble, 1979). If you tour the campus with a guide, there is a good chance you will be led to a machine shop underground the Parsons Engineering Building. The shop is open to all Mudders twenty-four seven. Your guide might stop a student passing by and ask where the scooter she's riding came from. She might tell you she made it herself in the engineering shop. What pride riding the work of one's own hands![31]

Although E59 is the sampler engineering course in the Common Core, many non-engineering students take E4, a hands-on and project based design course, to find out what engineering really feels like at Mudd, or simply for the fun of working with their

[31] From my experiences, the strong interests toward hands-on experience seem true for both male and female engineering students at Mudd. Other observers have suggested that the pleasure experienced with technology has more subtle gender-related implications (Kleif and Faulkner 2003).

hands. E4 has three major projects, each of which requires as much work from the hands as from the brains. Project One: design and build an alarm clock using only the materials available on an uninhabited island: wood, sand, water, stones, rope, and so forth. Project Two: "reverse engineer" an electrical toy fish, the task mentioned earlier (see page 43). For the final project students often work with an NGO to design something for people living in developing countries. In the past E4 students worked on, among other things, chicken coops for a Guatemalan women's cooperative, a food packaging device for farmers in Cambodia, and efficient stoves for people in Uganda.

My opportunity to observe E4 took place in a studio space where students gathered. The front half of the room looked like a typical classroom: a projector, whiteboards, and tables. There were only four or five tables, and each design team sat around a table. Mobile whiteboards were plenty; in class students frequently stood up to write sentences, draw tables, or sketch design ideas on the boards. Under the side windows there was a long cupboard stacked with things made by previous faculty and students. Among the display was a piece of cylinder-shaped metal. At the first class, Prof. HA pointed at the cylinder and told students it was the "gut" of a laundry machine, invented by a Harvey Mudd professor. Prof. HA said the invention "literally changed history" and shifted gender dynamics in families.[32] Students turned to the side and eyed the "gut" with awe. The back half of the studio was a workshop space with broad workstation tables and various suppliers: plastic tubes, hand-saws, Styrofoam, knives, wood, ropes, and a first aid kit. Students ran between the studio and the machine shop downstairs the weekend before their first project was due. In the shop they learned to work with electrically-powered tools. Prof. HA told me some students felt a little uneasy when they first started with the tools in the lab sessions of E4, but by the end of the semester everyone used them comfortably.

[32] Prof. HA didn't spell out the actual ways in which gender dynamics are changed by the invention of modern household technology. Some historians of technology argue that the inventions of household technologies in the twentieth century, such as the washing machine, did little to reduce the domestic duties of women (Cowan 1985).

3.2.3.2 Learn to fail and learn from failure

When speaking of failure, students often pointed to E80, Experimental Engineering, which is well known at Mudd as "an impossible course." Faculty described the class as essential for getting students used to the unknown and to learn by themselves, and more importantly, for getting them used to failures. As described by faculty and students, E80 is team-based and divided in two major sections. The first half of the course contains a series of individual labs related to different engineering disciplines, such as electrical, and mechanical engineering. In the second half, every team assembles a rocket, designs and installs sensors on the rocket in order to measure some data of the team's own choice. At the end of the semester, each team launches the rocket for a few times to collect and analyze the data they set out to measure. Most students take E80 the spring semester of their sophomore year, before they have taken upper division engineering courses. This means students in E80 have to complete a number of labs that require disciplinary knowledge not yet taught. To make things more difficult, all the teams rotate in different labs based not on the schedule of the course but on their availabilities. As a result, students are often assigned to a lab before the instructor lectures on it. Students fail their labs often. Failure, however, is considered a "shaky concept" in E80. Ms. H1 received 40% score for at least three out of the seven or eight individual labs in total; her rocket also failed twice out of the four launches. However, Ms. H1 didn't think one can really "fail" in E80; or rather, the experimental course is designed for students to fail. In her eyes, "the point of the class is to deal with failures; it's not to make things work." The way of reacting to failures Ms. H1 learned was to calm down, debugging, and trying to find out what went wrong.

Although it is entirely possible to fail at Mudd, failure is not often punished. Even though Ms. H1 failed at least one third of her labs in E80, she got an "A-" for the course. She didn't hear anyone ever failed the course either. E80 is not exceptionally "lenient" in this regard. Most courses at Mudd are very difficult, but instead of being left desperate and alone, students often receive substantial support from faculty, the college, or from other students. To reduce students' pressure of transiting from high school to college, all the courses for the first semester freshmen are graded "pass and fail" and not calculated toward students' GPA. HMC also hires a Director for Learning Programs, who oversees both the Writing Center and the Academic Excellence Program. The Academic Excellence Program runs weekly workshops for five difficult subjects in the Common Core: chemistry, physics, biology, engineering, and math. Students who need help come to the workshops to do homework together. Senior student tutors, who have taken these courses, are paid and trained to answer questions and help students at the workshops. Mudd also seeks to foster a culture not of competition but of collaboration. A lot of Mudders are used to doing homework together. In the Campus Center, I frequently saw groups of students gathering around whiteboards, drawing diagrams, writing equations, and discussing questions in their homework.

Besides getting her used to failures, the experience of E80 also helped Ms. H1 feel comfortable about unknown situations and learn strategies to deal with them: "because there are so many times you don't know what's going on, you have to learn to deal with that. You have to learn to get into those situations and know where to start looking for things." Preparing students for the unknown is one of the higher-level goals of Mudd engineering educators. The engineering curriculum has been designed in part to encourage students to delve into fields of inquiry for which they are not fully prepared. Thus E80 is required before students can take upper division engineering courses, which supply the knowledge needed for completing the labs in E80. Reflecting on the pros and cons of the reversed order of course offering, the instructor of E80 highlighted an iterative learning process in the curriculum: Students encounter complex, uncertain problems early in the curriculum and try to figure them out as best as they can. When they take specialty courses, they will be able to see how the knowledge they learn by trial and error in E80 is connected. After that, they get to apply the systematic knowledge to solve complex and ill-defined problems again in the Engineering Clinic, which happens in their third and fourth years. With the experience of dealing with uncertainty and unknown in E80 and systematic learning in specialty courses, students come to the Engineering Clinic better prepared for seeking knowledge by themselves to solve ill-defined problems.

3.2.3.3 The engineering clinic

Engineering education at Mudd culminates in the Engineering Clinic. The Clinic program offers a bridge, carrying students from classroom to the professional world through three semesters of team-based project work on "real-world" problems under the supervision and guidance of industrial liaisons.[33] In following sections and chapters I will revisit the Engineering Clinic to examine how students are "socialized" as young professionals in the program and how the social dimensions of engineering are presented to and grasped by students through this experience. Here I introduce the basic structure of this program and assess it in light of Mudd's educational vision of preparing students for complex and uncertain conditions and for tasks that require knowledge and skills yet unknown.

The Harvey Mudd Engineering Clinic was conceived in 1962 by two engineering professors who were inspired by "elements of cooperative education, the engineering practice school, and the medical school's clinical practice" (Bright and Phillips 1999). Over the past half century, the Engineering Clinic has become "a hallmark" of the college, which is widely appreciated by its students, alums, employers and Clinic sponsors (Bright and Phillips 1999; Harvey Mudd College Clinic Program 2014).[34]

At present, the Engineering Clinic consists of year-long, team-based projects sponsored by industry, research laboratories, or the government. The Clinic has a director and an associate director, both of whom are faculty from the Engineering Department. Furthermore, virtually every engineering faculty advises one or two student teams in the Clinic every year. In the sessions I observed, the companies that sponsored the Clinic projects dedicated a few employees as industrial liaisons for the Clinic teams and provided the initial problems for their projects. These problems were "real" in the sense that they were derived from projects the sponsors were undertaking, and outcomes of the Clinic projects would contribute to new products, services, or next steps of

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[33] Harvey Mudd had multiple Clinic programs, run by different departments. For example, the Math Clinic, the Physics Clinic, etc. I use "the Clinic" to represent the Engineering Clinic hereafter.

[34] The Harvey Mudd Engineering Clinic has also inspired similar programs in other colleges.

research and development in the companies. In general, every engineering senior takes the Engineering Clinic for two semesters. Students in their junior year are enrolled in a Clinic team for one semester to get teamwork experiences in a quasi-professional environment. A Clinic team usually has four to six students, with one student as team leader for the fall and spring semester respectively. Each team is assigned a faculty advisor from the Engineering Department. The faculty advisors participate in group activities, such as the weekly teleconference between the students and their industrial liaisons, occasional team meetings, and the weekly design reviews, where four teams meet together to present their progress, answer questions, and receive comments and suggestions from other teams and their advisors. The faculty advisors are also responsible for reviewing all the documents written by the student team (usually before they were sent out to the liaisons), providing feedback, and grading students' performance in the course. However, the faculty advisors are not responsible for the team's technical work. Technical advices come mainly from the industrial liaisons, who are practicing professionals. When a company signs a contract to sponsor a Clinic team, it also commits regular contact between its employee liaisons and the students. For example, the Engineering Clinic requires every team to have a one-hour teleconference with their liaisons per week.

In the fall of 2013, twenty-four Clinic projects were sponsored. Before the start of the semester, a description of all the projects was presented to the incoming engineering juniors and seniors, who were asked to submit their top three choices of projects. A number of the sponsors enrolled the Clinic teams into ongoing projects of research and development, and the particular goals and scope of work for these projects were not clarified at the outset. As a result, some students who chose projects based on the initial description ended up working on tasks unexpected. Such was the case for Ms. H1 and Mr. H2, both of whom joined the team sponsored by Company A, thinking they would be working on a project that involves significant work with electronic hardware. It turned out Company A wanted the team to write computer programs that coordinate the communication between different hardware on aircrafts and ground stations, and the actual implementation of the programs on hardware was beyond the scope of the project.

The team was asked to use programming languages C++ and C#. Programs written in C++ are very stable, so C++ was required for programs running on in-flight hardware by the aviation industry for safety concerns. The liaisons recommended C# for the programs running on ground stations for its ease to use.

None of the six students in the Company A team had learned C++ or C#. The required computer science course in the Common Core (CS5) teaches Python, a more "user-friendly" programming language. For engineering students who don't go out of their way to take more courses on computer programming, Python is the only programming language they have learned by the time they start the Clinic. From what I observed, Ms. H1 was one of the more programming savvy students in the team. She had taken a number of courses from the CS Department during her first two years, while she was lingering between the engineering and computer science majors. Ms. H1 had not used C++ or C#, but she had learned Java, which is structurally similar.

No one in the team was put off by the barrier of unknown programming languages. They quickly familiarized themselves with the project by reading the technical documents and earlier iterations of the programs, which were written in Python by a Clinic team the previous year. About twice every week, the team met in a particular Clinic room designated by the Engineering Department and discussed the functionality modules and the structures of the programs. The new programming languages were temporarily "black-boxed" in these discussions. Students used their generic understanding of computer programming and their knowledge of Python to sketch the structures of the upcoming programs. At times when discussion got too complicated, a student would pick up a marker and started to draw arrows, boxes, and to write texts on the whiteboard, trying to clarify what they had come up with. Other students would in turn walk up to the whiteboard and amend the drawing, suggest changes, and add details.

The Company A team also used every opportunity to seek help from more experienced programmers. Besides asking numerous questions of their liaisons during the weekly teleconferences, the team got in touch with students who participated in the

Company A Clinic project the previous year and learned some practical concerns about debugging the programs. They also reached out to Company A's collaborators in other companies. The design review also became a learning resource for the team, where they eagerly asked for suggestions on managing large-scale software project and materials for learning C++ and C# from professors and students who had more experiences with programming.

To balance the workload, the Company A team decided half of its members would learn C++, and the other half would learn C#. They also split the three junior students in the team to two tasks, so that when they rotated out of the team in the spring semester, the remaining seniors would be able to lead the programming with both languages. In less than two months, the team was able to sort out the major functional modules and the structures of the programs, and they started coding as they learned the programming languages.

Although Ms. H1 joined the Company A team through a misunderstanding of its job and found herself not doing what she had wanted, she discovered an unexpected benefit. She had intended to take a course on C++ in later semesters, but the Clinic project "jump started" her learning of that programming language. She reckoned if she could learn enough C++ from the Clinic, she would save the course time for something else. Reflecting on this, Ms. H1 felt even though she got thrown into something that was not technically what she wanted, it was still a learning opportunity. The same open and positive attitude toward learning was shared by Mr. H2, who considered it an "anti-Mudd way of doing things" if one does not put full effort to learn in every field, including those they are not strongly interested in. Mr. H2 understood this passion for learning as a primary manifestation of liberal education at Mudd: "the love of learning mentality is more important to liberal arts than whether a class is humanities or tech. We kind of learn to love learning by taking some humanity classes that aren't so easy for us and figuring out this is how I want to approach things I don't necessarily love."

3.3 Work on society

As I have indicated in previous sections, people at Mudd practice the College's mission faithfully in the day-to-day teaching and learning. This is true for ethical education at Mudd as well, where "a clear understanding of the impact of their work on society" supplies the pivot goal for students' ethical development, and to some extent, serves as the compass for liberal education at the college (Harvey Mudd College Mission and Strategic Vision 2014). Before examining the particular ways in which "social impact" affects students' moral imagination at Mudd, I want to highlight and briefly speculate upon the conceptual and practical differences between "work in society" and "work on society."

"Work in society" suggests simultaneous evolution of the person who works and the society in which the work happens. A person who works in society becomes one with it. Society as the context frames the scope and nature of the work; meanwhile, society is changed as a result of the work. In this process, both are remade by one another. The implications of "work in society" for engineering is exemplified by a volume *Engineering in Society*, written by a panel of the National Research Council (NRC) to study "Engineering Interactions With Society" in 1985 (NRC 1985). The book opens with the admission that "the panel that was formed to examine the broad questions of engineering's functioning within the societal context decided to entitle its report 'Engineering in Society.' This title is meant to set a prevailing tone appropriate to the symbiosis that exists between the profession and the surrounding culture" (NRC 1985, 11).

Such "symbiosis" is highlighted as a cure for an often assumed false dichotomy:

> It is tempting to view any occupational grouping, whether engineers, lawyers, or teachers—or, for that matter, plumbers or police—as a distinct entity, separate from the society in which it develops and functions. Yet such distinctions, inevitable as they may be, are always artificial. The hard dichotomy thus established is in many ways inadequate for describing the complex, dynamic interactions through which society molds professions and professions shape society. Moreover, the habit of dichotomizing can do damage to the popular

> conception of a profession and its role within the larger society. This may be especially true in the case of an occupation such as engineering, which is subject to rapid change, much diversity in its makeup, and a considerable degree of mystery (from the standpoint of the general public) regarding the nature of its activities. Under such conditions, it is all too easy for an "us and them" point of view to take root. (NRC 1985, 11)

In contrast to the symbiotic relation expressed in *Engineering in Society*, "work on society" implies an image of society as a static and receptive object of work, something passively and readily waiting to be affected by the free and unpredictable will of the worker. In practice, analysis of the impact "on society" often appears as an afterthought upon the completion of work, and in most cases it focuses on bookkeeping the gains and losses, while the process of work is shielded from scrutiny. As a result, learning the social impact is severed from questioning the work itself: How are goals and limits defined? What assumptions undergird the choice of problems and approaches? What additional groups should be involved into decision making? What precautions should be built into the various stages of design and deployment? [35] As the reader can see, other questions in the same vein can and do arise. To be sure, analysts of the social impacts sometimes produce fair assessment and critique of the outcomes of engineering, and their calls for changes in engineering are plausible at times. Yet, short of questioning the engineering process, these analysts are not very competent at proposing concrete interventions into the ways engineering is practiced.

3.3.1 The "social impacts/implications" model and its limits

For many Mudders, "impact on society" provides the primary framework for them to connect the technical work to its social dimensions and to their liberal arts education. Mr. H4 chose economics as his HSA concentration. Economic knowledge, thought Mr. H4, would be important for him to understand the impacts of his decisions on community and on the world when he took managerial positions later on. Mr. H4 also

[35] Policy scholars have called for more precautions in regulating the risk brought about by technological research and development (Morone and Woodhouse 1988).

valued learning in HSA subjects for raising his awareness and changing the way he viewed the world, “we are not studying to learn the facts; we are studying to be aware.”

Analysis of the “social implications” was a regular assignment in the Engineering Clinic sessions I observed. Every team was required to start their second design review (in the first review they presented the problem statement) by presenting the social implications of its project. As with many other components in the Clinic, the social analysis was taught in a “learn by doing” style. Without much structured instruction, students mainly worked among themselves to explore the social implications of their work; occasionally they consulted with their faculty advisors and industrial liaisons. Supposedly, the social analysis, like other components of the project, would be strengthened by questions and comments from the audience at the design review.

The Company A team worked on a new wireless communication standard the company was trying to develop. With a new communication protocol, Company A sought to provide a standard infrastructure for transporting data from aircrafts to ground stations using wireless network. Once implemented, this standard communication infrastructure would replace the multiple servers for different applications currently used on aircrafts. The Company A team made its first attempt to analyze the social implications of this project during a team meeting for another purpose. One of the industrial liaisons had asked the team to draft a white paper to elaborate their understanding of the project. After deliberation, the team decided the white paper should focus on presenting the work of the team, not on introducing the standard. As the team went over the draft word by word, pondering on organization of paragraphs, phrasing, and word choices, someone suggested they could also include the social implications of the project, hence killing two birds with one stone, as they were required to present the social implications at the design review in a few weeks.

Upon hearing this suggestion, the team started brainstorming the social implications. As if instructed by a tacit voice, the search of social implications concentrated on the potential benefits of the new standard. Without any verification, the team agreed on two benefits, that the new standard would increase the efficiency and lower the cost for industrial stakeholders. Then the team moved forward to dig the technical mechanisms that might account for the efficiency improvement and cost reduction. The discussion soon turned into a heated search for technical details, until one student asked “are these social implications?” “Not at all,” someone murmured. The team then decided to delete the “social implications” section from the white paper and to revisit this assignment for their next team meeting.

At the teleconference the following week, the question was posed to an industrial liaison. The team explained that they were required to present the social implications of their project in the upcoming design review, and they had come up so far with only one major implication: air travel safety. The liaison told the students the standard was related to safety as well as commercial concerns. The aviation industry, according to the liaison, cares about two major things: cost and safety. The liaison went on to explain the way in which the new standard could translate into savings for aviation companies, and eventually, price drop for air tickets.

The design review happened the following week. In a meeting prior to that day, the team had decided to open their presentation with the social implications, because few people were impressed by their project at the previous review. The outline of the presentation was displayed as following:

-Background and social implications

-Proposed system

-Topology; code architecture; necessary functions

-Test cases & visualization

A student first explained the motivation for this project. He reported that the team had consulted with their liaisons about the reasons for this project, who told them that currently there was not good data flow from ground to aircrafts (e.g., real-time weather data could not be used because it was not approved). The presenter called attention to recent flight accidents to highlight the importance of real-time weather data. He added the project would increase the fuel and time efficiency of flights with real time data.

The presentation of social implications went on for about five minutes, and the rest forty or so minutes were dedicated to the other aspects of the project as the outline indicated. At the end of the design review, after the presenters and audience had exchanged questions and suggestions about the format of data, objects of testing, tips for learning C++ and large software engineering. Prof. HD asked a question about the social implication: Why did it take so long for aircrafts to adopt new technologies (e.g., wireless data transmission)? The team members said they didn't know for sure, but they suggested FAA regulations and safety concerns as possible causes. One student recalled the field trip to Company A, when the team saw very old technologies still being used on aircrafts. A student from the audience asked whether the standard would spread to other countries. The team believed so.

Another Clinic team presented the social implications of their project the week after. This team worked on power generation solutions; they were helping a company improve the design of a heat exchanger. Like the Company A group, this team also opened their presentation with the social impacts: waste heat recovery, increased efficiency, saving $200,000 per year, significant savings in developing nations (e.g., Afghanistan). After a short while the presentation turned to the technical assumptions, modeling, and manufacturing of a heat exchanger.

A number of engineering educators have emphasized the importance of introducing the "social work" into engineering classes (Tonso 2006; Kabo and Baillie 2009). In particular, scholars have noted that questions about the social aspects of engineering have more credibility to students when they are posed in engineering classes (with the guidance of engineering professors) rather than in humanities and social sciences electives (Felder and Brent 2003; Kumar and Hsiao 2007). From my observation, the Engineering Clinic achieved some success in this regard, conveying to students the importance of the social implications through a formal assignment. In the case of the Company A team, students discussed this topic among themselves for several times and consulted with their advisor and liaisons (I also observed another Clinic team consulting their advisor on this topic). The questions and comments students received at the design review also reminded them of other social aspects of their project (e.g., Prof. HD's question led the Company A team to think about the organizational and regulative aspects of their project). However, the way "social work" was introduced in the Engineering Clinic also shows a number of limitations.

First, the assignment asked students to explore the social aspects of their work without teaching them effective, scholarly frameworks and tools for doing so. Short of structured guidance, most students were not capable of analyzing the social implications with comprehension and depth. There appeared a dominant trend of translating sophisticated social dimensions of the projects into benefits alone —usually in economic terms—for narrowly defined groups (usually the clients, or the sponsoring companies). From my observations of what students actually did in their projects, it occurred that even the narrowly defined "social implications" were more often grounded not upon careful (empirical) research but on commonly held assumptions, e.g., the assumption that new technology always lowers cost and increases efficiency. Second, students' presentations of the social implications, usually within the first five minutes of the design reviews, were often brief and superficial. After the short presentation there seemed to be an atmospheric change suggesting "let's get to the real business—the technical report." Although the social analysis had been strongly emphasized in rhetoric (e.g., in the Engineering Clinic Handbook), faculty advisors at the design reviews did little to challenge students' shallow understanding of the social implications and to question the mentality of seeing the social aspects as an appendix to the technical work. Third, a focus on the impacts of the Clinic projects "on society" implied a false dichotomy between engineering and society, one that the NRC (1985) study carefully warns against. This dichotomy prevents students from connecting their analysis of the social impacts to corresponding changes in the engineering process. As a result, few students demonstrated an intention of using the results of their "social impact" analysis to refine the way engineering work was conducted in their teams, e.g., in redefining the problems, adjusting objectives, revising methods of analysis and criteria of judgment, etc.[36]

The limits of "social impact" as a framework for ethical education reflect a more profound gap between the technical education and the liberal studies at Mudd. Most faculty and administrators I spoke with admitted that the status of achieving an integrated, interdisciplinary education at Mudd had not lived up to their professed ideals. Many of them wished to see much stronger integration between the technical learning and the humanities, social sciences, and arts, yet they had not come up with feasible ways to mend the gap, a gap sustained by the tension between a technoscientific and a humanistic culture, as well as by the imperative of providing students with a genuine liberal arts education, as I discuss in the following section.

3.3.2 Teach "authentic" liberal arts

The HSA Department at Mudd had serious debates about teaching liberal arts in the context of science and engineering education versus giving students an "authentic" taste of history, literature, political science, and other disciplines in the humanities and social science. Lively debates of this kind can be traced back to the Curriculum Study in 1958, which laid the foundation for curriculum development at Mudd. Back then, people who planned for the curriculum cautioned against undermining the intellectual value of some disciplines by teaching shortcut version courses, such as "Math for Engineers." As a few HSA faculty pointed out, a similar caution against the "shortcuts" has prevented a wholesale transformation of the HSA curriculum to reflect the rise of recent developments in STS—Science and Technology Studies—that is, to focus the HSA education on helping students understand the economic, cultural, philosophical, and political issues engendered by the interaction between society and science and technology. Thus, to a certain extent, HSA faculty have wanted to preserve the virtues of more standard "liberal arts" approaches to teaching knowledge from literature, history, philosophy, and the social sciences.

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[36] See Page 13-14 for a review on the "technical/social dualism" literature.

3.3.3 Examples of integration

In spite of the HSA faculty's determination to preserve disciplinary authenticity, they are not hostile to interdisciplinary collaboration. In the previous Common Core curriculum, every student was required to have an Integrated Experience, one fulfilled by courses taught by faculty from different departments. Although the Integrated Experience requirement was removed from the new Common Core, the spirit of integrated, interdisciplinary inquiry is retained. The writing course (WRIT ONE), for example, is often co-taught by a HSA faculty and a faculty from the science, engineering, or math department. Some instructors also try to teach writing via themes that intersect both science and society. Prof. HA, a professor of engineering management, regularly introduces students to the social and humanistic aspects of science and technology in his writing course. One semester he used *One Nation Under Google* as a course reading to provoke students' thinking and writing on the interplay between society, corporation, and technology (Barney 2007). In the fall of 2013, Prof. HA taught a session of WRIT ONE that led students to examine the evolving role of gender in science as depicted in science fiction movies.

Although HMC makes no rules to force its science, engineering, and math professors to include social topics into their teaching or to command its HSA faculty to teach courses like "history for engineers," its self-identity as a liberal arts college allows interested faculty to explore with students the interaction between science and technology, and the human society, or to teach methods of inquiry that transcend the boundary between the "two cultures" (Snow 1959). Efforts toward integrative education are not prohibited but welcomed. For example, HSA faculty who have interests or background in STS regularly offer "STSish" courses like Introduction to Anthropology of Science and Technology, and Social and Political Issues in Clinic. The latter is a companion course offered to students who are taking the Clinic courses.

Although the Engineering Department is considered the most vocation oriented in the college by some internal observers, individual engineering professors, especially those more closely affiliated with the "design stem," attempt to make visible to students the connections between engineering and a social world that goes beyond the traditional imagination in the engineering profession. In recent years, Prof. HA have tried to communicate his updated thoughts of engineering ethics in the E4 class, which are based on the understanding that engineering decisions embody political commitments. Prof. HA is also planning for a new course on human-centered design.

3.3.4 Different voices

Not all students appreciate the attempt to connect learning of science and technology to inquiries into the human, social, and aesthetic world. After all, some students come to Mudd for its reputation of producing PhDs and winners of national physics contests.[37] For her Critical Inquiry class, Ms. H6 chose a session that focused on psychology. She chose psychology because it is at least related to science, although she didn't think the main topic of the session—evaluating the validity of psychological claims—"scientific." She couldn't understand how the students who chose Chinese culture could learn the logic of research from such topics.

The overwhelming workload also poses challenges for students to treat their technical and liberal arts learning equally. As Mr. H2 admitted, whenever he could afford it, he would take "authentic" liberal arts courses where substantial reading and deep thinking is required, but the demanding technical courses often make such choices impossible. When it comes to choices between the technical and liberal arts learning, Mudders know the answer clearly. Mudders can take maximum one course for "pass and fail" every year, and many a Mudder applies that option to an HSA course so as not to worry about the grades. The different stake of technical and liberal arts learning at Mudd was characterized by a HSA faculty: "I think of this place (Harvey Mudd) as Caltech meets Swarthmore, and Caltech wins."

[37] HMC often publicizes the fact that it used to be ranked "No. 1 for percentage of undergraduates who go on to earn PhDs in science and engineering" (Harvey Mudd College Career Services 2014). According to a recent study by the National Science Foundation, HMC ranks No.2 in the country (NSF 2008).

3.4 Leaders in the fields

"Leadership" is a favorite buzzword in business and higher education these days, and engineering education is no exception. At Mudd, however, teaching "leadership" is not only talked about, but is emphasized as a key objective. The education at Mudd is designed to prepare its graduates to be leaders, no matter what field they choose to enter. The meanings of "leaders" vary from person to person at Mudd. However, whatever vision of "leadership" one subscribes to, most educators at Mudd take it seriously and use it as a vantage point to understand their own teaching. In general, the cultivation of leadership at Mudd is achieved through two means. First, students are prepared for high standards of intellectual development through a set of pedagogical approaches discussed in Section 3.2. In the meantime, educators at Mudd work hard to align students to the values and attitudes widely upheld in professions. With few exceptions, the scope of leadership education in the Engineering Department is defined mainly "in their fields." That is, the mindset of engineering students is significantly shaped by the popular expectations, concerns, and assumptions within the engineering profession. The alignment of students toward professional expectations is a complex process; the structure of this process has been analyzed in a body of literature on "professional socialization" (Grusec and Hastings 2008; Keltikangas and Martinsuo 2009; Trede, Macklin, and Bridges 2012). My observations suggest that Mudd engineers' images of themselves as future leaders are forged, in addition to the widely recognized elements of students "professional socialization" (e.g., knowledge learning, repetitive effort, role-playing, etc.), by exposure to role models and enchantment of shared legends. Furthermore, the efforts of certain agencies in and outside the college, such as those related to students' job-seeking, also magnify particular colors and patterns of students' self-images.

3.4.1 Role models

Some of the "great models" for Mudd engineers have retired or passed on, yet they still speak loudly to the students through their incarnations on campus, like the awe-inspiring "gut" of a laundry machine in the E4 studio. Similar monuments are also present in a glass cabinet at one entrance of the Engineering Department: machine parts designed by Mudd faculty, textbooks written in earlier years, measuring tools used in old times, and so on. The sacred items stand in order and silently tell the glory of Mudd engineering predecessors' accomplishments and their commitment to discipline, service, and innovation.

The glory of engineering is also personified by the famous engineers brought to campus. For example, the Engineering Seminar invite accomplished engineers to give talks every few weeks. Every engineering major is required to attend this learning ceremony. In fall 2013 the first guest speaker for the Seminar series was Rusty Schweickart, a veteran astronaut who flew on Apollo 9 as well as a back-up commander of the first Skylab mission, who also saved the mission from a catastrophic incident. Mr. Schweickart (2013) delivered his talk, "An Asteroid for All Seasons," which stressed the urgency of protecting the earth from potential destructions by asteroids. Although the lecture addressed issues related to the physics of asteroids, the knowledge and techniques for planetary defense, and the geopolitics and status of international collaboration in protecting the earth against asteroid impacts, Mr. Scheweickart declared that the key purpose of his talk was to remind the students of the importance of their education in science, technology, and engineering, which is capable of making "a huge difference in the world and in the whole evolution of humankind." Science and technology, remarked Mr. Scheweickart, give us the ability to "modify things, not just our behavior. […] We are also at a point now we can begin very slightly in our own way to shift the universe." In conclusion, Mr. Scheweickart enrolled the audience to a sublime mission:

> In some sense I think we have a responsibility since we can affect this to ensure that this evolutionary process, which we are a part as human beings on this small planet in this corner of the universe, continues. Using our technology today, we can begin ever so slightly to reshape the solar system to enhance the survival of life on this planet. […] You guys are all involved in this. (Scheweickart 2013)

Before his presentation, Mr. Scheweickart performed an important duty for which he was invited. He awarded the Astronaut Scholarship, a scholarship offered by the

Astronaut Scholarship Foundation, to a student in the Engineering Department, for his achievement in rocket science research.

Honoring students was an important tradition in the Engineering Department. Every academic year, the Engineering Seminar starts with a student awards ceremony. The awards recognize students' accomplishments in numerous areas: mechanics, system and communication, electrical engineering, experiments, and engineering design. Specific awards are also given to engineering sophomores, juniors, and seniors. Most students win awards for their quality of study or technical competencies, yet there are a few awards that celebrate students' outstanding performance of leadership, charity, and entrepreneurship. Virtually all faculty and students in the Engineering Department attended the award ceremony in September, 2013. The ceremony was hosted by an engineering professor, while the department chair gave out the awards. Before every award was given out, a professor from the department was invited to the podium to introduce the winner(s) and the accomplishments for which they were honored. These introductions in a condensed way conveyed the values cherished in the Engineering Department: The students awarded for outstanding performance in E4 not only exhibited excellent design learning but also went out of their way to help their teammates and students from other teams. The instructor of E80 recognized and thanked a student team for making "the impossible course" possible through their courage to challenge the unknown. The team who won the best presentation in Engineering Clinic gained the respect of professional audiences with their presentation during their field trip to the sponsoring company. One student was honored not only for his research in the robotics lab, but also for his compassion in bringing robots to young children in underdeveloped regions during outreach activities. Some awardees seemed well loved by their peers. When their names were announced, thundering cheers arose in the lecture hall. Before the ceremony ended, the host reminded that the award winners represented the excellent performance of all the engineering majors; he also urged the winners to thank their teammates and classmates. His words conveyed a message of solidarity for the engineering community.

In their day-to-day teaching, advising, and research collaboration, the faculty in the Engineering Department supply some of the most intimate models to the students as they grow into young professionals. The department put a great deal emphasis on hiring faculty with extensive professional experiences. At the first class of E4 in fall 2013, the instructors declared their professional credentials as part of their self-introduction. Prof. HB told the students he had had thirty years of experience working in the industry. Prof. HC was a new hire by the Engineering Department and had taught in another renowned research university; he added that he had worked in the industry for about the same length as Prof. HB did. The instructors' rich experiences with the industry become the fountain that supplies a steady flow of professional scenarios into the classroom. For example, one of the themes often repeated in the E4 classroom was the communicability of one's design. The instructors returned once and again to the importance of communicability in the professional settings. When teaching mechanical drawing, the instructors explained the bits and pieces of drawing in light of its readability to different workers on the production line: machinists, factory supervisors, colleague engineers, and so forth. To broaden students' understanding of the professional setting, the instructors reminded that the parts they design might be made from a factory in China or Bangladesh and assembled in Detroit, Michigan. These scenarios drew a multitude of invisible players into the classroom. Most of these players are not engineers, so they are invisible in the engineering classroom. But they will be working side by side with the engineering students once they step into the professional world.

Experienced instructors I observed passed down to students not only their intellectual understandings of professional work, but also the attitudes and emotions deemed proper for the profession. When Prof. HA introduced the "studio method" of design learning—i.e., students learn by doing design and examining each other's work—in E4, he stressed these abilities were part of "professionalism." Before students turned in their peer evaluations of teammates after the first design project, professors urged them to "be professional" and reminded them of forming a "professional relationship" with their teammates. The particular meaning of "professional" was not explained in these cases, but a sense of sacredness was communicated. At times, contrary to the usual aloof description of engineers (in public), the professors in classes personified the "live engineers" with feelings and emotions. At the beginning of the "reverse engineering" project (see page 43), Prof. HA asked students why they should look at others' designs. "Seek improvement." "See what you don't like about the design." Students did their best to answer like mature, professional designers. "It's fun." Prof. HA suggested an unexpected answer, "that's in the soul of real engineers—intellectual curiosity." Then Prof. HA shared with students what he took to be the three words that characterize engineering: "check this out!" He made an inviting gesture accompanied by gleaming eyes and a smiling face, intoxicated by the pride of creation.

In the Engineering Clinic, the industrial liaisons supply another important repertoire of professional models. Some liaisons work for well-known and widely-respected companies in the field, whose presence in the projects give students substantial pride and delight. The sponsoring companies who have employed Mudd alumni often appoint them to the liaison teams. Many of these alumni have completed the Clinic themselves a few years ago; hence they act like lively exemplars of the trajectory from Mudd students to professional engineers, providing visible embodiments of "leaders in their field." The liaisons play multiple roles in the Clinic teams. Many Clinic teams work on a fraction of bigger projects in which the liaisons are involved, so students and their liaisons are colleagues in this sense. Like project managers, the liaisons are also responsible for supplying initial descriptions of the Clinic projects, explaining their goals and components, as well as suggesting potential approaches of work. As students move along with their research, the liaisons serve as technical advisors, answering questions, pointing to resources, and occasionally sharing their experiences and knowledge about hardware, programs, and so forth. Meanwhile, as liaisons represent the companies that sponsor the Clinic projects, they are the clients of the Clinic teams. As a result, interactions between the students and their liaisons happen on a number of layers. In particular, students make repetitive efforts to gauge their liaisons' expectations; they also negotiate with their liaisons on the scope of work, timeline, deliverables, etc., based on their expectations, the capacity of the team, and the schedule of the Clinic. Most students are able to accurately calibrate their differences from the liaisons in terms of experiences, expertise, social roles, and institutional contexts; hence students usually make no attempt to emulate their liaisons directly but use the latter as a reference to measure how much they acted like a professional.

3.4.2 Shared legends

A number of legends fly over HMC campus. Like a breeze, these legends usually do not take a singular shape. One just comes across them over and over again on various occasions in the college websites, faculty's words, and random chats with students in the lab. These amorphous legends affect the student body not unlike the way winds drive a ship at sea: stand beside a mast, you feel the winds coming from all different directions, yet their net force steers the ship steadily toward one destination.

One such legend conveys Mudders' expectations about their careers. It holds that Mudders are competent to work and lead in every field, and they are going to succeed both career-wise and financially. This confidence reflects Mudders' faith in their broad education. Mr. H5 observes that engineering education at Mudd is well-rounded and transcends the usual boundaries separating different engineering disciplines. It is widely believed that such comprehensive training better prepares Mudders for creative and novel engineering positions. For example, a number of people named SpaceX as an ideal workplace for Mudders (and some Mudders did get employed by SpaceX). A belief that Mudd graduates are popular among employers is also repeated by faculty, administrators, and college agencies for admission and outreach, via daily conversations, college news, public presentations, etc. Some statistics are often recited: E.g., Mudd graduates earn the highest mid-career salary;[38] HMC is named a "Best Value College."[39] A particular legend about the Engineering Clinic suggests so many students get hired by their sponsors while doing the Clinic projects that employers who do not sponsor a Clinic project might face a shortage of available applicants.

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[38] See (Harvey Mudd College News and Events 2012).
[39] See (Harvey Mudd College News and Events 2013).

Contrary to the rosy legends about Mudders' bright future, however, students' perceptions of the present job market paint a much gloomier picture. One Mudd engineer who led a Clinic team called the job market "cruel." Students I interviewed generally agreed they had to be more aggressive in reaching out to the employers. Engineering students also felt HMC's employment records were unevenly represented, as the major hiring interest has moved to computer science (it was agreed CS majors needed no job hunting) and that the companies present at the campus Career Fair are mainly looking for CS majors.

Another commonly mentioned legend was a little puzzling to me, for I never perceived from the Engineering Department an explicit fondness for companies with famous brands, yet the students seemed to assume that such was the case. When one of the Clinic teams met for the first time to discuss their team charter (a document required by the Clinic to lay out the objectives and deliverables for the team), the team leader expressed excitement about working for a "big brand company." When the team discussed their project budget, some members raised concerns about the travel cost for their field trip. Many teams worked with local companies so field trips were cheap. This team, however, had to fly to the sponsoring company. The leader assured the team that the Clinic Program would be willing to pay the higher cost because their team worked for a "big brand company." In general, there is affection for the companies that sponsor Clinic projects, which spring from students' multiple imaginations about their sponsors. For example, the liaisons, as representatives of their employers, often impress the students with their expertise and professional maturity. Students who buy into the legend about the Clinic as a magical career broker often regard the sponsors as potential employers. The halo of the sponsors is also brightened by marvelous descriptions of the projects they bring to the Clinic. A mixture of various favor-incurring influences often lead students to translate their success in the Clinic to the sponsors' satisfaction.

Such was the case, when the Company A team considered its number one mission "evangelizing Company A." While I never found an occasion to ask the students exactly what they meant by "evangelizing" and how they had planned to evangelize a company, a resonant echo occurred on my long drive to California. From the radio I happened to hear a church pastor talk at length about “re-evangelizing Christianity.” Besides the more mundane interpretation of re-evangelizing the secular world, that is, to preach the truth of Christianity to the faithless and the pagans, the man placed the focus upon re-evangelizing the disciples. The principle of re-evangelization, he said, is to incessantly scrutinize oneself, to question whether one has always acted according to God’s will, and to reveal when one violates God’s teaching, out of selfishness or unenlightened motives. If, by “evangelizing Company A,” my friends in the Clinic team meant something similar to this interpretation, against which will of Company A’s were they putting themselves under scrutiny? Whether evangelizing Company A or not, the Company A team, like their peers in other Clinic teams, did scrutinize themselves continually according to the expectations of their liaisons, the industry, the corporation, their faculty advisors, the Clinic Program, and the Engineering Department to ensure they acted like devoted disciples of the profession.

3.4.3 Influential agencies

Students’ strong commitment to the professional world is refined by dedicated career specialists at the college and tested by potential employers. Like many other colleges, Harvey Mudd has an Office of Career Services. The ubiquitous presence of career offices across universities and colleges does not diminish questions about their relevance or the character of the distinctive stamp they place on students’ sense of career and life choices. E.g., why is it a college’s job to advise students on career but not marriage? Why does HMC set up an independent career office, while it shares a number of other student services, such as health and counseling, with other members of the Claremont Colleges? In particular, why do Mudd graduates, who are claimed to be extremely popular among employers, need career consulting at all? During my time at Mudd, I had a few opportunities to see for myself how the Career Services did its work, sometimes in collaboration with employers, on preparing students to become decent employees.

Mudders are known for their busy schedules filled with classes, projects, research activities, so much so that they usually cannot afford much time for job-seeking even during their senior year. The Career Services hence make a great deal effort to bring employers to campus, explaining to them what a great regret it would be for them to miss these talented students. On the orientation day of the Engineering Clinic, a staff from the Career Services came to the Green Room in the Platt Campus Center, a room reserved for meetings of formal business, and made a pitch about the Career Fair to the representatives of the Clinic sponsors. The Career Services staff distributed a handout of HMC graduates' employment records to the audience. She also reminded the audience that many Mudders were hired by their Clinic sponsors by November every year, so those who were interested in hiring Mudders had to act quickly. Despite her presentation of employers' enthusiasm for Mudd graduates, the staff admitted that the year before students complained about the scarcity of engineering employers at the Career Fair and invited the Clinic sponsors to the campus Career Fair to be held the coming October. Because Mudd graduates are much in demand, the staff encouraged companies to contact the Career Services to set up extra information sessions before the Career Fair.

The Career Services staff also make efforts to help students meet employers and demonstrate their value and potentials. A week before the Career Fair, a preparation workshop was held in the Aviation Room. That night, the Aviation Room was filled for the first time the two months I was there. Students came from all class levels: younger students looking for internships, and seniors looking for full-time jobs. Systematic strategies for acting at the Career Fair were presented to the students: Study the map of company tables. Plan your route. Don't go to your dream companies first. Tailor your CVs. Practice your pitch. Prepare smart questions to ask the employers. Ask for their contact information to follow up. If you're a senior, wear a suit. Junior or sophomore? A suit maybe, but not necessary. Look a little more conservative than you usually are on campus. Cover up your tattoos.

As the fall hiring season unveiled, posters of corporate information sessions took over the walls of the Campus Center, the Center for Teaching and Learning, and the dining hall. Some companies wooed potential employees in "tech talks." Qualcomm Research gave its "computer talk" on a Tuesday evening in the Green Room. A Lebanese buffet dinner was served. Corporate hosts of the talk also promised plenty of gifts for engaged audience: T-shirts with Qualcomm logo. Before an engineer from Qualcomm presented her research on neuromorphic engineering, the head of Qualcomm's R&D division announced their hiring plan: Qualcomm was seeking some five hundred interns and three hundred new graduates to fill its R&D offices in San Diego. The company pledges to rely on its engineers, who form 60% of its employees. Interning at the company was described as a good pathway for those seeking jobs later on, because, as the firm's spokesperson indicated, some 70% of interns were eventually hired in to full time positions. The hiring information attracted more than computer enthusiasts to the "tech talk." The Green Room was filled with students of different class levels, among whom were a good number of engineering majors.

Earlier that evening, free pizza was served in the Aviation Room by PA Consulting Group, who promoted hiring for its Global Energy Consulting Group. The company valued Mudders' intellectual enthusiasm and work ethic, qualities deemed ideal for analysts at PA Consulting. The Global Energy Consulting Group did not seem to look for any particular expertise other than enthusiasm for the energy industry. Some in the audience were probably expecting requirements they had been more familiar with. One student asked the hiring staff: "You mentioned a lot soft skills. What tech skills are you looking for?"

3.5 Conclusion: Questions for the "Mudd bubble"

Claremont, the "city of trees and PhDs," is a human-made oasis. Were it not for decades of intensive irrigation, the town would look like the landscape less than a hundred miles away eastward or northward, exactly what the place used to be: a desert. Even at present, this city of trees, this living monument of human initiatives and creativity is not freed from the occasional revelation of its turbulent geographic reality: Southern California is very often subject to wildfires. The first Wednesday after I arrived in Claremont, I stopped at the north rim of Harvey Mudd campus, accompanied by dozens of stunned students who forgot their scholarly duties and gazed at a violent fire just across the street. The fire was burning in the Rancho Santa Ana Botanic Garden, where students of the Claremont Colleges used to have their biology classes. The street was blocked by police cars; airplanes flew low and sprayed dry-ice; firefighters busily poured water toward the flame that was licking the trees, grass, and earth. By the evening the fire was put out, but that didn't save the botanical garden from being burned into charcoal.

The interior of the "Mudd Bubble" in a way resembles the harmonious, vital, and prosperous flora in Claremont. Like the disparate tropical plants, Mudders seemed to live in harmony; they respected and cared for each other regardless of their differences. Surrounded by the sky-piercing pines and giant cactus that fence the five colleges, Mudders' intellectual vitality is sustained by tireless study. Their broad appetite for knowledge in science, technology, as well as the study of society and arts nurture a prosperous intellectual culture at Mudd much like the enormous exotic species that greened the city. However, I was struck by how much this garden of intellectual excitement and interpersonal fraternity is shielded from the "real world" out there. Many of the residents inside the "Mudd Bubble" painstakingly protect its glassy wall, fearing the expansion of this wonderland to even a hundred more students would be not a path to new possibilities but opening of a floodgate.

I wonder what would happen when the young graduates of Harvey Mudd meet the outside world in its more troublesome shapes. If the secret of keeping one's job turns out to be not disruptive ingenuity but uncritical conformity, have they the resilience to readjust their ambitions and the patience to wait for opportunities? If corporate politics makes the workplace not a community of trust but an arena of hunger game between relentless competitors, have they the shrewdness to navigate their journey amid the storm? If they find out with disillusion, that their intellectual prowess is used not toward benign transformation of the world, but toward battling and extinction of the opponents, either in a metaphorical war of conflicting interests, or, perhaps more disturbing, in actual warfare, have they the strength and courage to act according to their moral principles?

4. Picker

4.1 A liberal arts college for women

4.1.1 Northampton

When I told a friend I was going to study students' perceptions of their engineering education at Smith College, my friend, who had gone to Hampshire College, reminded me that a student in Northampton, MA is likely to be much happier than one in Troy, NY regardless of the college, simply because Northampton is such a pleasant place. I agreed with him and confessed there was nothing I could do about it. I was looking for alternative models of educating engineers, not "controlled experiments."

I had witnessed for myself the charm of Northampton twice before I officially became a "participant observer" at the place. One afternoon in Sept 2011, my friends and I drove from Columbia County, NY to the Mountain Park in Northampton to catch the last outdoor concert that season. Fleet Foxes was playing that night. We sat down in slightly wet grass on a hill, chewed chicken wings and drank beer. That night the band blew the crowds away with their music. In the darkness my friend detected the smoking of marijuana in the audience.

"Really? How do you know?" I asked.

"You can smell it."

I inhaled deeply. It was a light fresh smell.

"It smells like grass, like the freshly cut lawn."

"Ha! You just decoded its nickname. It is also called grass."

Another time I was invited to an Indian restaurant in Northampton on our way home from Boston. We drove into downtown Northampton at night. It was cold and few people were outside. Yet the brands of fashion stores, cafes, and everything else reminded me of Saratoga Springs or a typical tourist town in upstate New York. The lamb and rice and chicken curry was wonderfully tasty in the Indian restaurant. Our host was a professor at Smith College. Then we discovered the woman who waited on us also went to Smith. She had not met our host before, but they soon found some people or class or something of common acquaintance and began chatting.

I drove to Northampton by myself for the first time in January 2013—my first field trip to Smith College. The snow had not quit, so the drive took longer than Google Map suggested. I was already late by the time I turned onto Main Street. Then I found myself mysteriously slowed down. There were few traffic lights; but the cars in front of me seemed in no hurry and stopped frequently. My puzzle was answered when I saw one after another crosswalk painted on the street. Pedestrians crossed the street freely.

I commuted to Northampton once or twice per week during that spring semester. The Smith College Campus Police issued a free parking pass to me, so most days I drove directly to campus and had lunch in the campus center. There is a small dining hall in the campus center, with a salad bar, an American grill counter, cold and hot drinks, etc. Some dorm buildings on campus have their own dining service, but an ID card is required for access to the dorm buildings. During RPI's Spring Break, I rented a room in Springfield, MA—a half hour drive from Northampton—and came to Smith every day for a week. During that week I also spent more time in downtown Northampton before or after the classes and events I meant to attend in the college. Every morning I parked on Main Street and crossed it to get coffee and pastry in an European bakery. Sometimes I could see a homeless man on a bench beside the parking meter. He sat erect in the golden morning sun with a joyful expression. He smiled to and greeted people walking by with such dignity that I felt embarrassed to offer him money. I smiled back. Some days a police on early duty walked toward the bench and the two had conversations like long-time acquaintances.

There are a variety of food choices in town: Japanese Noodle, Thai, Indian, Chinese, and an American Sandwich shop. There is also a Tibetan restaurant that serves Yak Dishes. Most restaurants are within fifteen minute walk from Smith campus. During the announcement section prior to each class I observed, dinner and party invitations were announced frequently. Three bookstores reside along Main Street. One of them sells used books exclusively. Another one has good collections of new and used books. In this store I bought *Reading Lolita in Tehran*. Another day I bought *Moby Dick* for three dollars.

4.1.2 The campus

March is not yet the high time for warm and sunny spring in the New England. But when the first inch of sunlight melted the snow that had covered the lawn for four or five months and unveiled the green underneath, the Smithies, having waited for an endless winter, put on their dresses and welcomed the new season with festivity. At noon, when I sat on a lunch table in the campus center, my attention was irresistibly drawn to the scene outside the glass wall. A table was set by the steps leading to the entrance of the campus center. A loudspeaker sat on the table and played various kinds of music with a strong pounding beat. Six arms were lifted into the air and waved like trees in the wind; occasionally two arms twisted like a double-helix, as one dancer slowly rotated herself by the rhythm of the music. One of the dancing women seemed to be Indian and wore a black dress frosted with white flowers. She danced gently as if following the design of a choreographer. The woman next to her had on a blue baseball cap, a T-shirt, and a pair of jeans. Her dance was more free-style hip-hop, and she paused often to smoke. The third woman also smoked but less frequently. She wore a leather vest often seen on Harley-Davidson riders. The dancers frequently greeted and hugged the people walking by, some of whom joined a flash mob dance, holding their salad boxes. The president of Smith passed by smiling and nodding to the dancers. At another table set on the lawn facing the campus center, used clothes were given for free. Some students stopped by the table to try on a woolen cap or a sweater. Further into the lawn, people sat or lay in circles, chatting and enjoying the sunshine. Such was the locally famous "DJ on the Lawn" program.

West of the lawn, behind the library, a smaller green land is carefully maintained. It contains a greenhouse and a botanic garden. The garden barely exceeds the size of two parking spots, but in this tiny oasis grew numerous plants from a great variety of latitudes, such as violaceae, berberidaceae, geranium, and campanula. The plants came from all over the planet: North America, China, Caucasus, etc. Watering for the garden has been configured so that plants with different preference of humidity could all thrive. The co-existence of disparate plants contributes to the vibrant, dynamic, and diverse ecology at Smith, much like what I observed in its student body.

4.1.3 The quest for diversity

One of the most remarkable changes in Smith College during the past decade has been the significantly increased diversity of its student body.[40] When the tenth president of the College Carol Christ retired in summer 2013, she wrote a letter to the editors of *New York Times* highlighting the efforts of women's colleges to increase the economic and ethnic diversity of their students:

> Women's colleges like Smith succeed at enrolling an economically diverse student body to a greater extent than many of their peers. At Smith, 25 percent of students come from families eligible for federal Pell grants. (Christ 2013)

President Christ also told *the Sophian*, a newspaper run by students at Smith, that one of her "most notable accomplishments" had been the increase of diversity at Smith:

> Smith has become much more diverse. 13% of the class of 2015 are international students and a third are U.S. women of color. A decade ago 8% of our students were international, and 21% were U.S. women of color.[41]

At its beginning, the founder of the College Sophia Smith integrated progressive social values into the mission of Smith College:

> I hereby make the following provisions for the establishment and maintenance of an Institution for the higher education of young women, with the design to furnish for my own sex means and facilities for education equal to those which are afforded now in our Colleges to young men.
>
> It is my opinion that by the higher and more thorough Christian education of women, what are called their "wrongs" will be redressed, their wages adjusted, their weight of influence in reforming the evils of society will be greatly increased, as teachers, as writers, as mothers, as members of society, their power for good will be incalculably enlarged. (Smith 1870)

However, one makes no greater a mistake confusing water and oil than assuming one set of social values can be seamlessly mounted to another; for example, to equate Smith's original mission of promoting women in higher education with attempts to

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[40] Smith College's effort to diversify its student body started before the last decade. E.g., the Office of Institutional Diversity was created in 1996.

[41] Quoted in "Carol Christ Resigning as President."

provide higher education to women who are ethnic minorities, children from lower-income families, or minorities of other kinds (national, sexual, etc.). The quest for diversity at Smith in the past decade was marred by vehement and traumatic conflicts and turmoil over race, class, nationality, religion, sexual orientation, and gender identity, which were healed only by prolonged and painstaking soul-searching and profound policy changes. Also, as I will show at the end of this chapter, the preservation of the diversity cause has been a course of ongoing struggle, especially between the old culture of Smith as a salon to elevate the tastes of young women from wealthy families and its new identity as a progressive and responsible agency to nurture the talents of all women.

4.1.3.1 The turmoil

A series of dramatic incidents which helped sharpen the need for greater diversity at Smith came right before the inauguration of Carol Christ as the tenth president of this college. On Sept 11, 2001, Smithies, like many other Americans, were petrified by the destruction and deaths at the World Trade Center in New York. In the aftermath of the catastrophe, some students came to project their pain and terror to the Muslim students living around them, and an anti-Arab sentiment built up on campus. In the following months, the tension on campus became heightened by several incidents that involved racism and homophobia. Incidents of this kind happened in a number of residential houses, where what started as personal grievances or differences between individual students were mistakenly channeled toward hatred of people of different ethnicity or sexual orientation. A call for "Brown-outs," activities by students of color and allies to show solidarity and support to the victim, recounted the conflicts in the Gillett House:

> Repeated incidents of harassment (racism, homophobia) have been committed against Ms. C [real name concealed] which recently led to false claims of jeopardized house safety issues in which students conspired to call public safety for unfounded and contrived reasons. One of these students involved in this incent is named Ms. R [real name concealed] (the orchestrator), an ADA in Gillett House, who physically assaulted Ms. C in early December of last semester. Judiciary action was taken as per judicial board of Smith College, however, to date, no formal apology has been given to Ms. C and furthermore Ms. R still lives in Gillett house, an obvious statement that she was not punished for her violence. The college's allowance of this atrocious behavior to go

> unanswered has resulted in two semesters of blatant harassment and blatant racial profiling. (Khan 2002)

A series of anonymous and threatening messages of racism and homophobia appeared in the Gardiner House in April 2002, which threw the campus "awash in confusion and bewilderment—attempting to both discern the actual events and remedy a longstanding problem."[42] The series of incidents started on April 5.

> On Friday, April 5 a first-year student found a physically threatening and homophobic message on the dry erase board outside her door when she returned to her room from the bathroom in Gardiner House.
>
> …
>
> [T]wo more threatening and homophobic messages were found in Gardiner on Saturday night. One was found in the second floor bathroom and another in the fourth floor bathroom. (Elizabeth Whiston. "Homophobic incidents shock campus." *The Sophian*, April 11, 2002)[43]

The extreme messages seemed to indicate more extensive and subtle problems related to racial and sexual intolerance on Smith campus. After the incidents in Gardiner House, one student commented race had not been sufficiently talked about "until a blatant obvious incident occurs to make people talk about it. It's misrepresentative because the prevalent racism here is more subtle and less obvious."[44] Some students were also "frustrated with the absence of communication from our Residence Life administrators with regards to recent acts of racism for which the Residence Life system has come under fire."[45]

On the same day (April 5) the first homophobic slur was reported, a number of Smithies who were concerned about racism, classism and homophobia on campus mobilized to form The Student Grassroots Organizing Group (SGOG). SGOG played an active role in organizing events in response to racial and sexual hatred as well as in

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[42] Staff Editorial. "Campus must respond strongly to homophobic infractions in the community." *The Sophian*, April 11, 2002.
[43] The message found on April 5 reads "Die, Dyke, Die" ("Fact sheet." The Student Grassroots Organizing Group File, Smith College Archives).
[44] Sarbani Hazra. "Instances of racism spark outrage, debate in multiple community forums." *The Sophian*, April 11, 2002.
[45] "Students in Res Life announce dissatisfaction with handling of recent racist incidents on campus." *The Sophian*, April 11, 2002.

negotiating with the college administration for policy changes toward a more diverse campus. Among the SGOG-organized events was a campus anti-discrimination rally on April 16, attended by hundreds of Smith students, faculty, and staff, including the Acting President John Connolly, incoming President Carol Christ, Student Government Association President Anna Franker, and other senior administrators. Many attendees of the rally agreed that to break the silence and to talk about racism and homophobia were the best strategy for the college to counteract them: “For years, opinions have remained underground—never quite palpable, but always with an air of imminent hostility. We have a problem with each other’s differences, and now we are forced with the task of figuring out how to repair damages done and heal as a community.”[46]

However, the efforts to heal the community were again disrupted by the appearance of racist and homophobic slurs one week after the rally.

> I am writing to let all of you know the details regarding an incident which occurred at Gardiner House today (Tuesday, April 23rd).
>
> In the fourth floor bathroom, “beware dykes” and “die nigger die” were written. Residence Life staff, as well as Public Safety were contacted immediately. Public Safety has already begun an investigation. (Lafavor 2002)

That very night (April 23, 2002), students responded to the hate crime with a candlelight vigil and a march on campus. A demonstration, which took place the next day, was documented in the local newspaper:

> This morning in College Hall, students sat silently at first, then began to sing songs like “We Shall Overcome” and “This Little Light of Mine.” During the soft rendition of “Amazing Grace,” several students wept. They then chanted loudly, “Stop the hate, stop the fear.”
>
> One student asked Connolly to join them sitting on the floor of the lobby. The president complied, sitting with Maureen Mahoney, dean of the college, and Brenda A. Allen, director of institutional diversity, under the portrait of founder Sophia Smith. (“Sit-in at Smith protests latest on-campus slurs” *Daily Hampshire Gazette*, April 24, 2002)

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[46] Staff Editorial. “Visiting prospectives will get glimpse of campus at its worst.” *The Sophian*, April 18, 2002

SGOG met with members of the Smith administrations for several times between April 17 and April 29 to express students' concerns about the racist and homophobic incidents on campus and to discuss actions. Prior to their first meeting, SGOG presented a five-page list of demands to the college administration, calling for personnel, policy, infrastructure, and curricular changes to enhance diversity of Smith student body and faculty.[47] After discussions, a list of actions agreed upon by SGOG and the college administration was published in a document named "Repairing the Community." The preamble of the document written by the Acting President John Connolly and President-Elect Carol Christ also promises "a thorough review of our policies and programs in support of institutional diversity."[48] The changes listed in "Repairing the Community" included hiring of people with multicultural competence to positions in the Office of Institutional Diversity, residence life staff, health and counselling service, mandatory training on diversity issues to all college employees and new students, recruitment of underrepresented minorities in faculty and increased programs to recruit lower-income students, conversation to prioritize multiculturalism in curriculum, among other things.[49]

4.1.3.2 Impacts of the diversity campaign

It is difficult to pinpoint the impacts of Smith's quest for diversity on the teaching and learning of engineering according to my short stay on campus, yet I heard stories of individual engineering students to whose lives Smith's inclusive admission and support made a big difference. During my observations of Engineers for a Sustainable World Smith Chapter (ESW@Smith), I was greatly impressed by one of the student members: Ms. P5, a Picker sophomore, who displayed excellent organizational and leading skills. When I complimented Ms. P5's leadership skills and asked whether she had had prior leadership experiences. To my surprise, she said "none." Ms. P5 is a first-generation college student and comes from a low-income, single-parent family. When Ms. P5 was in high school, her mother had to work and couldn't drive her to school or pick her up. Instead, Ms. P5 rode the bus for two hours to school every day and had to catch the bus

[47] "Students issue list of demands." *Daily Hampshire Gazette*, April 17, 2002.
[48] See "Repairing the Community" (Smith College 2002).
[49] The curricular change proposed in the document was not implemented (personal communication).

immediately after classes, which prevented her from doing any extra-curricular activities or playing sports in after school. Ms. P5 felt she was "lucky" to be accepted by Smith. In college she found enormous opportunities for learning and for student activities so she "took jump on" everything. Besides contributing to ESW@Smith, Ms. P5 also helped with several college outreach activities and mentored younger engineering students.

4.2 Engineering learning

4.2.1 Diversity via accessibility

Over the past few decades, engineering educators have been alarmed by prospective students' declining interest in studying engineering and the rate of students who drop out from engineering programs (Bakos 1992; Seymour and Hewitt 1997). Significant efforts have been made to foster engagement of young people, from kindling student interest in engineering in K-12 education to retaining engineering students in colleges. An interesting, and perhaps very "engineering" fact about the efforts to retain engineering students is an excessive emphasis on the "retention rate": the ratio of students who complete an engineering degree as compared to those who enroll in engineering programs at the beginning. As native hobbyists of numbers, engineering educators hang up on the "retention rate" as the proper measurement of the "efficiency" of the campaign to engage students.[50] As a result of the focus on the "rate," the absolute number of students who drop out of engineering becomes less important. In many cases, educators only start to calculate retention rate after students have taken a "weed out" course, and the retention rate is defined as the ratio between the number of degree earners and that of students who have passed the "weed out" course.[51] It seems a little counterintuitive that while engineering educators painstakingly seek to attract more students to engineering, a

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[50] Engineering educators are not alone in focusing on the "rate" rather than the actual educational experiences of the students (especially underrepresented groups) who are the target of retention. Discussions of "retention rate" appear in higher education policy frequently (Astin 1996, Thomas 2002).

[51] Studies have found that the "weed-out" system is not effective in retaining students who are academically more prepared for engineering; moreover, the "weed-out" system impacts women students disproportionately (Tonso 1996). In contrast, studies have found academically competitive women students without a strong background in science, technology, engineering, and mathematics could have successful and satisfying engineering education with proper support (McLoughlin 2009).

make or break course is intentionally designed to weed out many who might have succeeded if given proper encouragement.[52]

Several measures might be helpful to expand the pool of interested students to engineering, especially those considered non-traditional (female, ethnic minority, international, etc.); e.g., more inclusive admission policies, appropriate financial packages, and academic intervention programs (May and Chubin 2003). On occasion, the literature on engineering education has recommended changes to how engineering is presented and taught, especially curricular and pedagogical changes that make engineering more accessible to students with diverse educational backgrounds (Ellis, Rudnitzky, and Scordilis 2005). Some faculty in the Picker Engineering Program, inspired by a new paradigm of "holistic engineering education," designed the curriculum and teaching methods to accommodate incoming students' educational preparation (Grasso and Burkins 2010). Some engineering faculty in Picker also make efforts to create course content relevant to students' experiences and expectations. Such efforts, I would argue, do not water down the quality of engineering education but enhance students' intellectual and moral sophistication.

An entry level engineering course in the Picker program introduces students to the broad terrain of engineering as well as a number of quantitative and qualitative methods for formulating, analyzing, and solving engineering problems. The problems introduced in the course are often contextualized; work in the course is primarily group based; the deliverables require extensive hands-on experiences as well as oral, written, and multimedia communication.

The introductory course explores a variety of topics: history of engineering, AutoCAD, engineering labs, design process, statistics, modelling, engineering drawing, engineering economics, ethics, the Grand Challenges, and so forth. The scope of inquiry includes contextual matters, procedure knowledge, as well as various techniques to represent, analyze, solve, and communicate problems that fall into a broadly conceived

[52] Students also reported a "weed-out" course in the engineering curriculum at Smith.

field of engineering. The breadth of topics is consistent with Picker's choice of educating "general engineers" and making engineering accessible for everyone.

According to my observation, this entry level engineering course was taught in a style that accommodates students' diverse academic preparations in their K-12 education. For example, instead of throwing abstract questions to students and requiring starchy analysis or calculation, most problems in the course were presented with rich contextual information, which channel students from real world experiences to more formalized thinking in engineering. Consider the example of a lab assignment on environmental engineering, which asks students to do conceptual design for a hog waste disposal system. The assignment starts with a "background" section as the following:

> Currently, most swine waste is treated as a liquid in earthen containment structures called lagoons, in which bacteria break down the waste aerobically. The treated effluent from the lagoons is then sprayed onto field crops that use the nutrients contained in the effluent. The N.C. Department of Environment and Natural Resources estimates that the state's 2,400 hog farms use 4,000 active lagoons.
>
> Treatment of livestock waste is a controversial subject in North Carolina and several other states. Waste from large hog and poultry farms has been blamed for polluting surface waters, contaminating wells, creating noxious odors, and discharging ammonia into the air. Treatment and disposal of the waste costs farmers tens of millions of dollars each year.[53]

The above assignment embodies a philosophy of engineering education: engineering learning starts not with abstract theoretical inference or calculation but with what engineers face when they begin to work: the context and the objectives. It is up to the engineers to represent the context in more formalized terms and to utilize tools of formal reasoning. The assignment also invites reflection by asking students first to elaborate the "assumptions" underlying their design processes.

Although upper division engineering courses in the Picker program contain more sophisticated methods and contents, the accessible style of teaching is retained. Classes are small, which allows instructors to address the needs of individual students.

[53] From "Environmentally Safe Hog Waste Disposal Methods."

Professors are also available outside class time to advise and collaborate with students. The students react differently to this "friendly" style of teaching (as compared with the demanding and challenging style we often see in traditional, especially elite engineering programs). Whereas the accessible teaching proves a key for some students to choose and to stay in engineering, some students who have been used to different educational styles worry Picker's over-friendly engineering education might fail to sufficiently prepare them for solving technically challenging problems.

4.2.1.1 Questioning accessibility

During an interview with me, Ms. P3 recalled that she found the teaching at Smith very different from what she had been used to in (an Asian country), where she had studied until the end of high school. Back home, teachers' main responsibility was lecturing, and students were left on their own to figure out how the lessons taught in lectures could be applied to new problems. The contents of learning were mathematically demanding and technically challenging, and teachers usually did not help students outside class time. Ms. P3 benefitted from the intensive high school education. When she started college at Smith, she was able to transfer almost a full year of course credits, which gave her the latitude to study on two exchange programs, in University A (a well-known American university) and University B (a technical university oversea). Unlike other Picker students who usually take non-engineering courses on an exchange program, Ms. P3 took a number of engineering courses in both universities, for she had been worried about not having enough technical training at Smith.

As compared to Picker, Ms. P3 found engineering in University A and University B "harder," "more technical," and "more independent." Engineering students in the latter two universities, Ms. P3 commented, knew more math and software than she did, although she noticed she was better at evaluating how the outcomes of engineering projects would impact people, as a result of the engineering education at Smith. Ms. P3 experienced a "cultural shock" when she studied at University A. The courses there were very difficult, and professors were not there to help. She also had difficulty getting help from fellow students, in part because the harsh grading policy at University A helped create a very competitive culture. It was a very hard time but she managed to get through and gained a lot of confidence as a result. When she returned to Smith, at first she was disappointed. She felt professors at Smith going too far setting things up for students and providing guidelines, but the excessive support might undermine students' preparation for the profession, because in the engineering profession, "nobody sets things up for you." Later Ms. P3 changed her attitude and came to appreciate the Smith approach of engineering education. I will discuss that change in the next section.

4.2.2 (Sustainable) Application

The emphasis on applying engineering knowledge to the real world is shared by many courses at Picker. The program also emphasizes sustainability as one of its core educational objectives, "global citizenship as engineers of a sustainable future."[54] This statement signifies Picker educators' understanding of a fundamental aspect of engineering: "Sustainability is not optional; it is essential."[55] These visions are enacted in a number of engineering courses, which examine issues of nature, energy, and other realms of sustainability concerns.

According to the College's policy, Picker holds an engineering advising meeting every semester before students electe courses for the upcoming semester. At the meeting every instructor gives a brief introduction of the courses s/he is going to teach. I attended an engineering advising meeting in April 2013. All the Picker students and available professors gathered in the auditorium in the Ford Hall. The director of the Picker program first explained a few curricular changes and generic rules for course registration (e.g., prerequisites for certain courses). After that every instructor for the upcoming semester stood up in turn and gave an "elevator pitch" to the students. Most of the professors stressed the application components when introducing their courses: control theory and its application in issues concerning economy and population; privacy issues

[54] From "Engineering at Smith: Vision."
[55] From "Engineering at Smith."

with wireless sensors; meeting human health challenges via engineering; cooling of engines; the moving of water in natural environment; designing photovoltaic system for garages and buildings on campus; complex data systems in finance.

The emphasis on applications in the course introductions implies that it is a priority of the program and a preference of the students. However, my participant observation at Picker was confined to a few courses. Because I did not observe Picker's more conventional engineering courses, I am not able to assess the way in which "lots of applications" are implemented in the day-to-day teaching and learning. However, interviews with Picker students suggested that the "applications" in most engineering classes are taught in the form of "problem solving," similar to engineering programs elsewhere. Recalling her experience shortly before graduating, Ms. P4 said that with the exception of one engineering design course, instructors in most engineering courses simply lectured, while students did homework and labs, not unlike other standard engineering programs. Ms. P4 considered the various application exercises in most engineering classes "fake projects," as they did not involve "real life" problems or data and the results of such exercises were not applied to important issues in the real world.

Picker students' engagement with sustainability was exemplified in one class exercise on "Design for Sustainability" (D4S). Before the framework of D4S was introduced, students were asked to recall previous courses in which they had talked or thought about sustainability. The course names and numbers were written down on the whiteboard, which was filled in a few seconds.

> 100 (Engineering to Everyone); 260/110 (Fundamental Engineering Principles); 388 (Photovoltaic and Fuel Cell System Design); 290 (Engineering Thermodynamics); 374 (Fluid Mechanics); 390 (Advanced Topics in Engineering); 363 (Mass and Heat Transfer); Hydrology; 325 (Electric Power Systems); 410/422 (Design Clinic)...[56]

Suddenly a student asked "why only engineering courses?" Soon other courses were named: Chinese Literature, Outdoor Design, CEEDS (Center for the Environment,

[56] The course titles were added by the author.

Ecological Design & Sustainability), Design for Architect, ESW (Engineers for a Sustainable World).

Not everyone welcomes the inclusion of sustainability in the engineering learning. Some students, who came with different sets of expectations, expressed discomfort with the program's overwhelming emphasis on sustainability. Ms. P1 thought the program had exhibited an aggressive focus on environmental engineering during the first two years she was there. She had not been interested in environmental issues, and the way environmental problems were presented in classes made her feel it was entirely the engineers' job to fix global warming. Being away from home for the first time, Ms. P1 was overwhelmed by that mission and did not appreciate it. As time went by, however, Ms. P1 came to understand sustainability represents not only a particular topic but also a broad approach to engineering thinking, one applicable to other realms of engineering endeavor. Environmental problems exemplify the need to "apply engineering to systems outside the engineering world," said Ms. P1, "because you are part of a larger world, not just engineering." The need to look at broader systems where engineering plays a part was the primary reason why Ms. P1 had chosen to study in a liberal arts college.

4.3 Holistic engineering education

4.3.1 An ESW "think tank" meeting

The Smith Chapter of Engineers for a Sustainable World (ESW@Smith) holds monthly "Think Tank" meetings, where everyone who has interest in the organization (regardless of membership) can come to learn about its work and contribute ideas to its future plans. I went to one of these "Think Tank" meetings. The meeting provided a window into the impacts of Smith's diverse campus culture and the broad liberal education on students' approaches to engineering. The meeting focused upon plans for building a garden in an elementary school to educate children about sustainability. The participants drew from intellectual resources in a variety of fields, such as design skills from environmental fairness outreach, teaching techniques from education courses, and political economic knowledge about food industry. Students at the meeting also paid serious attention to the users of their engineering project—the children in the elementary school. They discussed the cognitive and physical needs of the children. Some of them were also sensitive to the power dynamics between the Smith engineers and the children.

Following the announcement on the ESW@Smith website, I found the group in the Ford Hall Atrium. Eight Smithies were sitting on four couches that formed a rectangle. The moderator provided two possible topics for the meeting. The first topic invited theoretical contemplation on the relation between engineering and the liberal arts and how they could be connected to sustainability. The second one was a practical project proposed by a professor from the Picker program. The project involved building a garden for the Smith College Campus School—a local elementary school—to help the kids learn about engineering and sustainability. If ESW@Smith decided to do this project, its board members would meet with teachers from the Campus School to negotiate concrete plans. Everyone at the meeting seemed to be excited by the garden project and decided to discuss its possibilities.

At first, the group examined the capacities and resources of ESW@Smith for undertaking the project. One participant was designing a website to promote environmental fairness. The website would educate people about sustainability topics, such as the environmental impacts of building a house to one's neighbor, or how artificial intelligence technologies could be used to enhance sustainability. The designer envisioned the website to be a platform for storytelling about sustainability. Another student chimed in and suggested she had read a book about "imaginative learning," which provided ideas for encouraging students to make up their own stories. "Story is the project!" someone in the group exclaimed.

The moderator asked the group to propose some core issues through which they could teach the kids about sustainability.

"Food." popped out from a student immediately.

"Why?" The moderator inquired in an approval-suggesting tone.

Several participants shared their reasons.

“Everyone eats.”

“A lot of pesticides and chemicals are used in growing food.”

“Right now it’s cheaper to buy food from China and ship it here than growing food locally.”

“What makes food cheap or expensive?” asked someone.

Then a list was composed collectively:

- Labor cost.
- Class issues.
- Governmental subsidy. Most subsidy goes to industrialized agriculture, thus small scale farming is further disadvantaged.
- The supply-demand relation. For example, corn is prioritized than other crops in the U.S. Almost everything we eat has corn.

The group concluded that “food might be our best shot, because everyone eats.” Bringing the mission of ESW home to the group, a student suggested they explore the role of engineering in this chain of reasoning. She had observed a fruitful discussion of the political issues with food, but she had not heard much about engineering there. Hence her question: “Where do food justice and engineering intersect?”

Inspired by this question, someone in the group pointed to the importance of design in food industry, e.g., the design of genetically modified food. Another one followed the thread of design, noting that the food pyramid was designed to support the meat industry (at a previous lunch meeting for the ESW@Smith board members, I noticed very few board members picked any meat from the lunch bar). One student raised a caution about the danger of simply introducing engineering solutions to social justice issues. “We should introduce engineering as a system.” This suggestion brought the first topic proposed by the moderator into the conversation: how could ESW@Smith introduce liberal arts ideas about of sustainability to elementary school children?

The group agreed they should first figure out the kids’ learning needs and their capacity for understanding. It was estimated the kids’ ages ranged from five to eleven. The attendants felt a focus on fostering curiosity and critical thinking would be more effective than knowledge acquisition for kids in this age group. The students started brainstorming action plans, and multiple tools and methods were proposed: Permaculture, a concept of designing sustainable ecological systems; hydroponics, growing stuff in water. One student suggested they break down the options and let the kids "choose your own adventure." Another one suggested a role play game that let the kids choose to play farmers, president, engineers, etc. Someone asked "do farmers have unions?" Nobody knew for sure. They guessed farmers might have some union-like associations, but not exactly like the workers unions.

The moderator pointed out most kids in the Campus School came from privileged families, and she didn't mean to stop the outreach of ESW@Smith with the Campus School. She envisioned the project at Campus School as a model for building sustainability projects at other community schools. The group agreed they shouldn't be narrow-mindedly building a garden only; instead, they should think broadly about education and supplement the kids' formal schooling with hands-on learning experiences. "Are we teaching?" asked someone. "Maybe not," another student replied. But ESW@Smith might present at the kids' lab sessions. They were aware that an eight year old might not have much background in sustainability, so if they were to teach, it had to focus upon "little things." The student who designed the environmental fairness website shared her experience of talking to middle school student and explaining the concept of artificial intelligence using a simple language. Another attendant was taking a course on Education in Science and Engineering and recalled a lesson from the instructor: kids are used to holistic learning, but their classroom subjects are often compartmentalized into specific, limited units. Someone suggested that perhaps they might try "concept maps" (an educational tool some professors were promoting in the Picker program).

One student encouraged the group to think beyond the project and to act as the kids' advocates; she suggested they find out what the kids feel most strongly about. A survey of the kids' interests was suggested. Another student reminded the group that some kids might have allergy to certain plants and that there might be kids with disabilities. They wanted to design a project in which everyone could participate. One person in the discussion offered to call her eight year old brother to ask about his interests. The group also decided to contact some parents.

Before concluding the Think Tank meeting, the moderator asked those present what they personally wanted the project to achieve. Among the answers were these:

> We want the kids to walk away with a good sense about how food plays a role in their lives, and food involves bigger culture: politics, sustainability, engineering… all of which are parts of a system.
>
> We want to communicate engineering (design) to the kids in a broad sense, and ethics are involved ("can't forget ethics" one nodded).
>
> We want to give the kids more questions. Opinions matter.
>
> We want a model we can transfer to other schools.
>
> We want the kids to feel advocacy from us. We can facilitate their learning.
>
> We want the kids to feel nothing is too crazy (The moderator suggested they could encourage the kids to raise fund on Kickstarters for sustainability initiatives).

One student noticed many kids think of engineering as making cars; she wanted them to know engineering is much broader than that.

"Let them know we are engineers," a student said excitedly.

"We don't want to define it. Let them figure out," said another one.

4.3.2 The Latin Honors and the "stand-alone" model of liberal arts education

To guarantee that every engineering student gets decent exposure to the liberal arts, the Picker program requires every student pursuing a B.S. degree in engineering to complete either the Latin Honors or a minor in an area outside engineering and science. The Latin Honors are awarded to Smithies who take at least one course in each of the seven fields: the arts, foreign language, historical studies, literature, natural science, mathematics and analytic philosophy, and social science.[57] Similar to Harvey Mudd, the liberal education for engineering students at Smith is largely "delegated" to the liberal arts departments. However, the HSA department at HMC focuses on service teaching for science and engineering students, and the HSA curriculum at Mudd is planned and coordinated at the college level, with representatives from all departments. In contrast, the liberal arts education for engineers at Smith is presented in a more "laissez-faire" style. According to my interviews and informal conversations with engineering faculty, the Picker program has little interaction with the liberal arts departments with regard to the role of humanities, social sciences, and arts education in facilitating engineering students' intellectual and professional development. With rare exceptions made by concerned individual faculty members, no institutional efforts is made to help students synthesize their learning in engineering and in the liberal arts. In spite of the lack of "holistic" and integrative pedagogies, a significant proportion of engineering students come to draw insights from their learning in the humanities, social sciences, and arts to see engineering in a much broader light. My observations convinced me that Smith's diverse intellectual and interpersonal environment, vibrant campus culture, and its dedication to community engagement help students see their learning in a more sophisticated picture.

The experience of Ms. P3 is a clear example. During her first few years at Smith she felt uneasy with the lack of technical depth in the engineering program and worried about her professional competence. Eventually her worries vanished and she came to appreciate the strengths of engineering education at Smith. Ms. P3 attributed the change of mind to her experiences in the liberal arts courses and the strong social justice orientation on campus. She named two courses—one in social sciences and one in engineering—that especially inspired her to reassess engineering education. One of them is a course on macroeconomics, which helped her understand how the financial system works and how global economy causes poverty. The other course was taught by a faculty in the Picker program known for grappling with the social and political

[57] Besides the distribution of courses, the Latin Honors also requires "a minimum of 48 graded credits that have been taken after the first year" and a minimum GPA (Smith College Course Registration). The engineering program requires students to complete the breadth requirement, but not every engineering student actually graduates with the Latin Honors.

implications of engineering. The course revealed to Ms. P3 the intricate social dynamics of engineering in the developing world. In that class Ms. P3 read about water projects in Bolivia, which succeeded technically but caused constant suffering for the poor. It dawned on Ms. P3 that political factors, such as access to water, had more crucial impacts to many people than features of technical design. Ms. P3 took this lesson to heart and started to "take more of a social science approach to engineering."

4.3.3 The living learning experience

The "social education" offered at Smith is by no means confined to classrooms. As a residential college, dorm buildings served as another important site for Smithies to learn about diversity, tolerance, and other issues about people, organization, and social life. Ms. P3 had been a residential assistant (RA) for a couple of years at Smith. As an RA, she received plenty of training on issues of social justice and diversity.[58] As part of her RA responsibilities, Ms. P3 organized a number of initiatives for social justice causes in her residential community.

There are times when social realities are revealed to Smithies in unexpected, rather unsettling ways. Ms. P1 learned a memorable lesson about classism in the dorm her first year at Smith. Ms. P1's parents were unemployed at the time, and she found class differences becoming real when she lived among people who came from disparate financial backgrounds. Ms. P1 often heard students and a few professors sharing stories of self-discovery with no acknowledgement of their privileged family background, and it was difficult for her to find relevance in stories of this kind. Arriving fresh at the college and attempting to find fields of common interests, many students excitedly exchanged the places they had been to, especially places of interests in Europe. Ms. P1 found these conversations inconsiderate for students like herself, who had not been to other countries. One day Ms. P1's roommate returned to the dorm and made a comment that shocked her. Bored by the excessive gossiping about Europe, her roommate complained,

[58] The training of RA was mandated as part of an agreement between the Student Grassroots Organizing Group and the college after the racist and homophobic incidents in spring 2002.

"Oh it's so stupid how these girls think it's so special because they have been to Europe. Come on, everyone has been to Europe." Ms. P1 felt "broken down" as she was surrounded by people who came from more privileged families. However, experiences like this made her aware of the presence of social class differences in the collective life of Smith College. Living among people with diverse background proved an opportunity for learning, whether pleasant or not.

4.3.4 "Drifting away" from engineering

I first noticed Ms. P7 during a class session on corporate ethics. In that class students watched two video episodes from Lockheed Martin's Ethic Awareness Training.[59] The first episode showed an African-American male supervisor bullying an Asian female subordinate to cover up a potential problem revealed by her inspection of a manufactured part. The female employee reported the supervisor's harassment to an officer, and the man was reprimanded. In the second episode, a white female employee was discovered accepting gifts from some clients of the company and lost her job. In the follow-up discussion, most students brainstormed strategies for the scenarios depicted in the videos. How would they respond to such incidents in their future careers? In contrast, Ms. P7 took an entirely different angle on the situations depicted. She noted that in the first video the person who eventually corrected the mistake was a white woman, while an Asian woman was the victim of a black man's wrongdoing. In the second case, a white man discovered and fired the wrongdoer, a white woman. Ms. P7 asked whether women and people of color were misrepresented in the videos.

Ms. P7's parents had immigrated to the U.S. from another country, and she self-identifies as a person of color. Ms. P7 had enjoyed math in high school and had intended to study environmental engineering with a focus on environmental issues in Latin America. Ms. P7 deliberately chose an engineering program in a women's college, where she could avoid being minority twice, both in ethnicity and gender.

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[59] "Ethics Awareness Training Resources: Voicing Our Values."

The contents of engineering at Smith and the teamwork experience brought much fun to Ms. P7. She had a good time studying engineering and applying it to design projects. Although the contents of engineering are engaging, the personal environment in the Picker program disheartened and persuaded her to give up the idea of becoming an engineer. Ms. P7 explained that she never felt welcome in the program because of what she represented: a first generation college student and a person of color. There were no faculty of color in the engineering program, and Ms. P7 knew no more than two faculty who had overt commitments to social justice and diversity. One of these was her advisor. Except for some international students, there were very few U.S. origin people of color in Ms. P7's class. A less explicit but more influential factor was the "support system" in the engineering program, which is often referred to as the "engineering family." This informal support system plays an important role in shaping the program culture and students' relationship with professors. Ms. P7 found the "engineering family" not universally accessible: "A lot of people talk about the engineering family and how we are all in this together. The people who are dominantly a part of the family are white U.S. people, not international, not people of color from the U.S."

While she was having difficulty relating to the engineering community, Ms. P7 found her own support system within her residential house and a group of Latino students and professors. During her junior year, Ms. P7 joined an exchange program and studied for a semester oversea. There she did a project for an independent study course using social scientific methods, which illuminated a number of social problems for her. The project fascinated her so much that "my heart felt really good in a way I never felt in engineering."[60] She planned to find a job in areas for which she had real passion: urban planning, affordable housing, or teaching.

[60] Ms. P7's remark suggests a widely existing limitation of the engineering culture, which discourages students from engaging social values in their learning (Cech 2014).

4.3.5 Epistemological "black box," micro-ethics, and the limits of "holistic engineering education"

Individual students' experiences raise questions about how a well-intended engineering program should attend to the needs and perceptions of students who come from more diverse economic and ethnic backgrounds. The "nontraditional" engineering students' feeling of "not belonging" implies a need for educators to reflect on their own privileges. This challenge, I would argue, also points to a limitation of the widely held epistemological principles in the engineering discipline. As I will indicate in the rest of this section, the dominant vision of engineering shared widely in the engineering profession as well as in a program that pursues more holistic ways of educating engineers, reflects traditional dualist assumptions that separate technology and society. In the case of a program that tries to integrate engineering with the mission of a liberal arts college, the dominant vision of engineering is tilted with a reminder of benign applications, yet it does not appear to strongly challenge the traditional ways engineers approach their jobs and to open up for scrutiny the prevalent epistemological "black box" within professions of engineering.[61] What I observed in this case reflects a tendency among engineering educators at large to subscribe to a vision of engineering and society that is widely embraced by the engineering professions: Engineers tend to favor a simplified world running within a dominant technical order, where politics, values, interests, and other social parameters are reduced to simple variables that can be optimized according to technical rationale. According to this vision, the social factors irreducible to technical terms ought to be eliminated as barriers (Nieusma and Tang 2012).

As one of its indications, this "engineering" way of engaging social parameters is enacted in codes of ethics published by professional societies and reinforced among young engineers through the teaching of "engineering ethics."[62] Inspired by the "codes,"

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[61] I use the "black box" here NOT to refer to the technical mechanisms that are usually screened from the users; the latter are examined by the social construction of technology theory (Bijker, Hughes, and Pinch 1987). I am referring to "black-box" of a different kind: the taken-for-granted and "fixed"/embedded ways of thinking that refuse reflection. The epistemological black-box is also different from the "black-box method" introduced in the E4 class at HMC (see page 44).
[62] Mitcham (2009) examines the historical evolution of professional engineering codes of ethics.

ethics teaching of this kind often falls into what Herkert (2005) calls "micro-ethics," which centers on individual integrity, observance of laws and professional codes, and emphasizes heroic "whistleblowers".[63] Issues of concern to the "macro-ethics"—the collective social responsibility of the engineering profession—is addressed in ethics education of this kind only to the extent required by professional societies, and consequently, is often confined to general statements of public good. It lacks adequate reflection on professional ethics as an embodiment of the commitments and limitations of the engineering professions (Little, Barney, and Hink 2008).

According to my observation, ethics teaching in this educational initiative did not always emphasize the difference between "what is accepted by the Code of Ethics" and what a more reflective ethical inquiry would entail. Although the message was communicated that the Code represents one element of the profession, a way in which the field helps to uphold its reputation. That is, the students were reminded the ethical codes are enacted by a few "professions;" the rules are "codified" by groups with particular interests. A rich opportunity not fully taken advantage of was to help students examine how the ethical codes reflect the norms, assumptions, ambitions, and constraints of the professions, and question where the interests of the professions and those of the public coincide or conflict.

The methods of ethics teaching I observed also resembled a fairly widely adopted model among engineering programs, which follows a process like this: introduce a Code of Ethics, read a case, find applicable codes, arrive at conclusions according to the codes. As an example, one ethics case study published by the National Society of Professional Engineers (NSPE) Ethics Contest was used in an engineering class.

The contest took the form of a questionnaire. The first paragraph in the questionnaire stated the "FACTS":

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[63] One upper level engineering elective, Science, Technology, and Ethics, was offered for a few semesters in Picker, which took a macro-ethics approach and utilized pedagogies of liberation (Riley 2008).

> A developer retains a contractor to design and build a residential subdivision near several high voltage power lines. Engineer A, an electrical engineer employed by the contractor, recommends to the contractor and developer to include a protective steel mesh in the homes to be built to mitigate occupants' exposure to interior levels of low-frequency electromagnetic fields (EMF). While Engineer A understands that in the United States there are no widely-accepted health and safety standards limiting occupational or residential exposure to 60-Hz EMF, he is aware of and concerned about certain scientific research concerning possible causal links between childhood leukemia and exposure to low-frequency EMF from power lines. Because of the added cost associated with the recommendation, the developer refuses to approve the recommendation. Contractor directs Engineer A to proceed in accordance with the developer's decision. (NSPE 2009)

After the statement of facts, the contest posed a "QUESTION": "What are Engineer A's ethical obligations under the circumstances?" (NSPE 2009) The next section asked the contestants to cite the relevant "NSPE CODE REFERENCES" that govern the situation. Following that, application of the proper codes was to be elaborated in the "DISCUSSION," based on which the contestants should arrive at their "CONCLUSION."

Students in the class identified three relevant facts in this case: 1. scientific research suggests possible harmful effects of exposure to low-frequency EMF; 2. there's no relevant regulation in the U.S.; 3. the action has possible connection with severe consequences (childhood leukemia). Collectively, the students suggested the following codes that might be applicable to this case:

> I 1 "Engineers, … shall: Hold paramount the safety, health, and welfare of the public." This was taken by many students to be the dominant code in said case.
>
> II 1.4 "Engineers shall not permit the use of their name or associate in business ventures with any person or firm that they believe is engaged in fraudulent or dishonest enterprise." A student questioned whether the proceeding of the project without proper protection for the residents was fraudulent.
>
> II 2.2 "Engineers shall not affix their signatures to any plans or documents dealing with subject matter in which they lack competence, nor to any plan or document not prepared under their direction and

> control." A student suggested this decision was not under the control of the engineer's but the contractor's.
>
> II 4 "Engineers shall act for each employer or client as faithful agents or trustees." A student thought Engineer A was responsible for the contractor.
>
> III 2.2 "Engineers shall not complete, sign, or seal plans and/or specifications that are not in conformity with applicable engineering standards. If the client or employer insists on such unprofessional conduct, they shall notify the proper authorities and withdraw from further service on the project." In the case presented in the contest, students expected relevant standards might be made in the future, but the best knowledge at the time being was no present standard. (NSPE 2014)

The students were divided by two types of analysis: The first analysis centered on engineers' paramount responsibility for public welfare and safety and concluded Engineer A should refuse to sign the document. The second analysis stressed engineers' loyalty to their employers and sided with the contractor, considering there was no obvious violation of existing regulations. After deliberation, the students were presented with the winning entry for the contest, which was officially considered by NSPE an appropriate solution to the said ethical challenge. The "official" answer cited three codes: I 1, II 1.2, and II 4. Code II 1.2 had not been suggested by the students; it states "Engineers shall approve only those engineering documents that are in conformity with applicable standards" (J. Carson and G. Carson 2009). After citing a few previous cases ruled by the Board of Ethical Review, the winning entry articulated its logic of decision:

> Engineer A has concerns about possible health effects of residential exposure to 60 Hz EMF. They may prove prescient, but they may be dispelled too. He cannot justify his additional design by a relevant US building standard or even by widespread practice. Clearly, it would add to the cost of the homes.
>
> While it was appropriate for Engineer A, given his knowledge of this controversial topic, to make the additional design recommendation, the developer has rejected it as too costly. Since there is an insufficient objective basis for Engineer A to claim the additional design is necessary to protect public health and safety, he should accept the developer's direction and complete his project. (Ibid)

Based on this reasoning, the winning entry concluded,

> Under the circumstances, it was ethically permissible for Engineer A to recommend the protective steel mesh. Since there is no widely-accepted, let alone controlling, standard for 60-Hz EMF radiation in US, the developer was justified in rejecting it. Engineer A is ethically obligated to comply with the developer's direction and complete the design." (Ibid).

The case of engineering ethics was hence concluded. How could we make this case study more productive to open-ended ethical inquiry? A few points about the winning solution might worth reflecting on. First, the contestants cited Code I 1 as one rationale for its decision, and the code states engineers shall "hold paramount the safety, health, and welfare of the public." In this case, however, the contestants apparently prioritized the developer's interest in lowering cost over reducing the health risk of the public. Second, code I 1 does not indicate any preconditions; it does not suggest engineers should only be responsible for the public when laws and regulations so require, nor does it imply that such responsibility is contingent on unquestionable scientific proof. However, when Engineer A's recommendation was denied for "insufficient objective basis," the contestants put the burden of proof on the part of the public, not on corporations that initiated the hazardous move (Woodhouse 1987). It also troubled me that the conclusion recommended by the winners of the NSPE Ethics Contest was considered "ethical," rather than "professionally acceptable," "free of obligation," or "legal." What "ethical" meant in this case was grounded on economy and undefined "objective basis." Such principles, while all-too-often dominating decisions and practices in engineering, are highly questionable according to numerous ethical standards (Nussbaum 2000). With proper guidance, the students might be able to use this case study as a rich example to scrutinize and unpack the assumptions undergirding the engineering professions' commitment to ethical practice. They might also use the insights generated from the reflection to challenge the ethical boundaries of the professions.

4.3.5.1 The ethics curriculum conflict

The scope of ethical inquiry embodied by the NSPE example seems different from the program founders' vision of making ethics "an integral part of an engineering education"

(Riley, Ellis, and Howe 2004). This contrast, according to Prof. PB, reflects a “drift away” of the program from its original vision of integrating engineering and the liberal arts at epistemological and moral levels. Prof. PB was one of the founding faculty who helped lay out a cross-curriculum ethics education, according to which ethical components are included in three levels of engineering courses—introductory, technical specialty, and senior design—in a progressive manner. In the introductory course, students would read an article with ethical components; the purpose is to communicate to students that ethics is part of the engineering profession. A second semester core engineering course, which Prof. PB used to teach, includes a unit to teach ethical case analysis. This unit is crucial according to the original design of the ethics education, for it would enable students to do ethical analysis of cases related to different contents in following technical courses. When an incoming faculty member succeeded Prof. PB to teach the core engineering course, she decided not to teach ethics and skipped the ethical case analysis without notification. In the following year, when Prof. PB assigned the students to do an ethical case analysis in her course for engineering sophomores, the students had no idea how to do it and expressed frustration at Prof. PB.

Prof. PB’s adoption of liberative pedagogies in a core engineering course, meant to facilitate students’ critical thinking and reflective learning, also met oppositions from some colleagues. For example, in addition to teaching the mathematical relationships in thermodynamics and their application in usual engineering disciplines, Prof. PB also taught historical and cultural contexts of thermodynamic knowledge and critiques on Western science to help students ponder on the limitations of engineering epistemology. These efforts, especially the questioning of the scientific objectivity, were considered inappropriate by some engineering educators who worried the essence of engineering methods was compromised. Such worry calls my attention to the power of a “black box” mentality which seems to be the core of the majority vision about how engineering and progressive educational and social philosophies should be integrated. This mentality welcomes changes in the inputs and outputs of engineering (education). On the inputs side, it encourages more women to join engineering; on the side of outputs, it promotes socially and environmentally responsible application of engineering. However, the transformation of engineering education is welcomed as far as it leaves intact what is in the black box and is taken to be the core of engineering—the analysis grounded on mathematical and technical principles. In contrast, the way Prof. PB taught engineering indicated the possibility of making transparent the black box, tinkering it, substituting some parts inside the box with non-technical components, or questioning the validity of the black box approaches of problem-solving. The attempt to transform the very "black box" of engineering hence created tension between Prof. PB and some engineers who feel more comfortable calculating the right answer than challenging the way questions were posed in engineering.[64]

The literature in engineering studies points out a sole emphasis on "benign application" implies a dualist understanding of the technical and social dimensions of engineering.[65] By dividing engineering learning into "mastering the technical skills" and "minding its proper use," the "technical" and the "social" are separated instead of unified. The "two cultures," though both recognized, are placed into two compartments in students' minds (Snow 1959). Dualism of this kind can be counterproductive to the spirit of integrating engineering and the liberal arts. Moreover, a technical/social dualism prevents engineers from holistic problem definition and solution (Downey 2009). Similar to the "social impact" model that dominates engineering students' ethical imagination at HMC, limiting students' involvement with the social dimensions of engineering problems to the "application" phase diverts their attention from the sociotechnical arrangements that often cause the problems (e.g., ownership to water as the cause for water shortage). Severing the engineering analysis from its application also shades questions such as: What kinds of social changes are necessary for engineering solutions to be effective?[66]

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64 The majority vision of engineering education reform presented here reminds me of the old school of thought characterized as "technology neutrality," which holds technology itself is politically and morally neutral, and it is the users of technology who determine its benevolent or malevolent application (Winner 1977). The logical and empirical deficiencies of the neutrality claims of technology have been exposed by STS literature (Sclove 1995).

65 See Page 13-14 for a review of literature on "technical/social dualism."

66 STS research has yielded powerful examples to demonstrate that truly effective engineers design not only devices but also the corresponding social systems (Winner 1986, Callon 1987).

A similar way of thinking is often used by those who attempt to divide engineering into a technical black box and its proper application. Within this framework definitions of desirable application are delegated to politicians, economists, etc., while the job of engineers becomes that of finding the proper technology to put in the black box. For example, in a class about Design for Sustainability, a guest speaker was invited to share her experience with sustainable design via Skype. Her presentation was essentially a survey of green technologies: condensing boilers, ultrasonic humidification and building automation system, and magnetic levitation compressor. She introduced the latter as "highly efficient" and "a pretty cool technology." A striking contrast appeared to me between the extensive engagement of sustainability throughout the curriculum and the discussion of it that centered on the technological aspects, with less emphasis on the numerous political, social, and economic factors as well as the multiple stakeholders involved.

The tension between the ideal of a holistic engineering education and the emphasis on the technical dimensions draws my attention to a structural factor with attempts to transform engineering into a liberal art at large. As with many other engineering programs, most faculty members of the Picker program have been trained in traditional engineering programs.[67] Although the faculty in general share Picker's commitment to dedicated teaching, empowerment of women, and socially responsible engineering, in the meantime they conduct research and publish in traditional engineering journals and socialize with colleagues from traditional engineering programs in professional societies. It is likely they have not been sufficiently encouraged to challenge the traditional ways of formulating engineering problems. Neither has there been at Smith explicit institutional design nor incentivizing structure for engineering faculty to collaborate with colleagues from other disciplines to create blended epistemological and methodological frameworks.

[67] There are a few exceptions. One professor received her PhD from a program on engineering and public policy and another has a Master's degree from a technology and policy program.

4.4 Women engineers

During my observations at Smith College I did not hear mention of anything like "feminist engineers" in the Picker program, yet the identity of Picker as an engineering program for women is deeply ingrained in the faculty and students (Beddoes 2012). Some of the Picker students I interviewed deliberately chose to study engineering in a women's college. Many of the rest of them, ones who had chosen Smith for different reasons, recognized Smith's empowering influences on women over the years.[68] Although I did not perceive from the Picker program a systematic and explicit critique of the gender dynamics in the engineering professions, there were frequent discussions about the challenges confronting women engineers. The program also provides extensive strategies for women to steer their engineering careers toward success.

From what I observed, Picker seems to cultivate in its young women engineers a dual attitude (relation) toward a career in engineering. On the one hand, the program actively seeks to prepare and socialize its students as excellent members of the professions who understand and play by the rules of the game. On the other hand, the students are reminded of women's disadvantageous positions within the engineering professions and advised to strategically challenge the professional world they would soon enter in order to minimize any disadvantages they might encounter.

4.4.1 Socializing professionals

One way of leveraging women's positions in the engineering professions often emphasized in the program is networking. According to my observation, students were encouraged and at many times channeled to the network of Smith or Picker alumnae. The common message was that Smith graduates are easy to reach and they are often happy to help young Smithies.

[68] Cech et al. (2011) find that "professional role confidence" is a crucial factor for women's decisions to stay or leave engineering.

Most students in the program have at least one class session dedicated to networking and informational interviews, guest lectured by a specialist in marketing, socializing, and public relations. During one of such sessions I observed, the lecturer opened the class with a question: “How long should one continue to seek informational interview and networking?” The students had apparently read the appropriate answer from the hand-out distributed before the class, for they immediately shouted out “Forever!” The lecture elaborated upon the process of informational interview: what it is, how to initiate it, how to prepare for it, how to behave properly during an interview, how to follow up, and the like. The speaker gave students another hand-out which contains over a hundred questions one could ask during an informational interview. After explaining the purposes of informational interviews, the lecturer asked the students to think of three people they might contact for an informational interview and then gave students a five-minute exercise: to write the open paragraph for a letter requesting an informational interview.

The lecturer also advised students on “proper professional behaviors.” The students were advised to arrive early and to appear “punctual” at the interviews. They were reminded “as soon as your vehicle or feet touch the property [of the company], you are being observed.” In particular, they were told to behave carefully in front of the administrative assistants, who would “observe you” and report their impressions to the administrators. During the Q&A following the lecture, one student asked if the professional contacts addressed themselves by their first names in email correspondence, whether she should also call them by their first names. The lecturer suggested they stay on the safer side, for they were still students.

The lecture was an eye opener for me. It introduced the significance and procedure of professional networking in a practical, interactive, and operative way. The honest and informative lecture relieved many of my previous impressions of such activities as opportunist and pretentious. Although the lecture convinced me of the necessity of networking and its value for the students, it struck me how the rules and tips for networking were communicated mainly in one direction: from the lecturer to the students. Students were told what they should or should not do according to the rules of the professional world, whereas the underlying assumptions, cultural history, and the pros and cons of these rules were not examined. While "technological determinists" often hold that social and cultural arrangements can and should be changed to accommodate objective, rational, and rigid technical necessities, what I saw in professional education of this kind was an amusing reversal of this logic: the open-ended and holistic design philosophy reminds the students that technological choices are flexible and contingent to stakeholders and the context of design problems, yet some social aspects of engineering—e.g., professional ethics, behavioral norms, and courtesy—are taught as given, strongly prescribed, with no space for reflection and critique.[69] It occurred to me that the social variables might also be "black boxed" when the students are involved in the technical design, as if the ethics and culture could not be objects of "design" or intervention by the young engineers.

4.4.2 Strategic engagement and challenge

While the professional socialization of engineering students in the Picker program stresses good professional citizenship, it also explicitly addresses the predicaments women confront in the engineering professions. Initiatives are organized in the program where women engineers' disadvantages in the professions are frankly discussed and strategies to overcome them are recommended. Role models, such as professional women engineers or Picker alumnae, are invited to share their professional experiences with the students. Moreover, the Picker program creates space for the students to bring women's visions and perspectives into engineering learning.

Most engineering students in their senior years take two class sessions on negotiation, which were meant to help the students negotiate their benefits with the employers. During one of such sessions, students were recommended to read the book *Women Don't Ask: Negotiation and the Gender Divide* (Babcock and Laschever 2003).

[69] Technological determinism is a school of thought which holds that "that changes in technology exerts a greater influence on societies and their processes than any other factor" (Smith and Marx 1994, 2). Technological determinism has been systematically critiqued in STS (Winner 1977, Bijker, Hughes, and Pinch 1987, Bijker and Law 1994, Latour 1996).

The book points out women tend not to negotiate their benefits. One statistic from the book was highlighted, which reports a woman engineer is paid a starting salary averagely 10% to 20% less than her male peers. To visualize the loss, students were shown a math example. Two engineering graduates, a woman and a man, were both offered a starting salary of $25,000 a year. The woman accepted it and the man negotiated his salary to $30,000 a year. With a same annual raise of 3% per year, when they reached the age of sixty, the man would be paid $92,000 a year, while the woman would get $76,000. If the man had put the extra he got every year in a bank with a 3% interest rate, by the time they reached sixty, he would have had an extra saving of $568,000. The numbers powerfully explained the difference that skilled negotiation can achieve.

4.4.3 Work-life balance

At Smith, concerns about balancing one's work and life have been recognized institutionally with the establishment of a Center for Work and Life. In spring 2013, a featured article in *Smith Alumnae Quarterly* told a few Smith alumnae's stories about "start over, give up, let go or turn around to find a better, more satisfying path" (Sergent 2013). The relationship between work and life is also explored in the engineering program. During one class session I observed, three women engineers were invited to join a panel on issues in work-life balance.

Two of the panelists had had novel, rather complicated career trajectories. Engineer A had a bachelor's degree in music and started her career in a music instrument factory. As her work in the factory leaned increasingly toward the engineering side, she went to graduate school to get a master's degree in engineering. After working several engineering jobs, Engineer A moved to Europe with her husband and spent a number of years, first as a stay-home mom and later a part-time worker, raising two kids. She had returned to a full time managerial position recently, after her kids had grown up. Engineer B started her career with a chemistry degree from a pharmaceutical school. Later she completed a master's degree in mass communication and worked for a long time on traffic safety issues, for which she went back to graduate school and got a master's degree in human factor engineering. Engineer B had run safety research groups for a number of years; she had recently relocated and started working from home. The third panelist, Engineer C, was a recent graduate from Smith. She had worked in several engineering jobs and recently moved to an engineering firm in a nearby state.

The students seemed very curious after hearing the panelists' diverse trajectories. They greeted the panelists with a broad range of questions: relocation, making friends at/outside workplace, informal vs. formal work relations, negotiating work hours, the feeling of women engineers, time to start a family, and so forth. The panelists gave frank and often contrasting answers. For example, Engineer C gave up going back to her home state after college because she liked her current job in the East, though she thought eventually she would be able to move back. Engineer A, in contrast, prioritized family life in job choices, because "you only got one family. Jobs come and go." Both Engineer A and Engineer B worked in male-dominated industries. At the beginning of the panel, Engineer A recognized it was her first time to see so many women engineers in one room. Engineer A also noticed that women tend to interact with people at work differently from men: While men were observed to interact more "hierarchically," Engineer A felt women often tried to "level the playing field" and to balance their roles as managers and co-workers. With regard to the gender dynamics at work, Engineer A noticed she had never been discriminated against for her gender, but she reminded the students of age discrimination. Engineer B also agreed that as long as she ensured quality work and remained productive, gender was not a hurdle. Like the two senior panelists, Engineer C did not recall any experience of discrimination during her short career.

I wondered what the students made of the panelists' messages about gender discrimination at work. I had heard similar comments at another panel organized by the College. The general message seemed to be this: if you do the best quality work and do not think about your gender identity, you won't feel any difference.[70] This message might well indicate a generally gender-neutral work culture in engineering, but I wondered how it might impact the students who weren't so lucky. If a student who works in the engineering professions did encounter gender discrimination, would she question her quality of work or her sensitivity to issues of gender identity? I posed this question to some Picker faculty, who told me gender discrimination in engineering was indeed perceived and reported on other occasions. The Picker program once had an initiative that let students shadow professional woman engineers. Participants of the initiative returned to campus and reported instances of gender discrimination they had observed at workplace.

4.5 Conclusion: Peer influence as a maneuverable variable

I have been cautioned by colleagues not to underestimate the "external factors"—geographical, institutional, and personal, etc.—that might have influenced the growth of Smith engineers more than the educators' attempt to integrate engineering and liberal education. After all, an engineering program at Smith College may be by default different from those at MIT or Purdue or Ohio State, not least because Northampton has a different character from Cambridge or West Lafayette or Columbus. Besides, it is reasonable to assume a women's liberal arts college attracts engineering students of a different kind from those who apply to famous, giant research universities. More importantly, one could hardly ignore the influences of the peers—the artists, the political activists, the community organizers, and so on, who live on the same campus with the engineering students for four good years. If college is defined more by the experience of living among a community of same-aged peers than the knowledge and skills learned from professors, one would have the ground to argue that the intellectual and political sophistication demonstrated by Smith engineers should be largely attributed to the

[70] Studies have found that "spotlighting" women students by gender in engineering education could also cause discomfort, even when it is done with good intentions (McLoughlin 2005).

college's diverse student body and active campus culture. [71] In sum, if the political engagement, the interdisciplinary inquiries, and the inclusive conception of engineering I saw from Picker students were mostly outcomes of an esoteric breed of students (who chose engineering in a liberal arts college) and the peer influence in a progressive women's liberal arts college, what lessons can we learn other than encouraging liberal arts colleges to create more engineering programs?[72]

My case studies included no "control variables," and I do not intend to hide the "bias" in my sample. Yes, an engineering program in a women's liberal arts college might well attract students of a different type than those who go to big research universities. In fact some of my interviewees confirmed this bias: they deliberately looked for alternative institutions for engineering education and decided that Piker was a good match for them. Meanwhile, I also met in the Picker program students who had cared little about Smith being a women's liberal arts college, who could have gone to MIT or Princeton but chose Smith for more contingent reasons, such as a generous financial aid package. However, when reflecting on their college experiences, these students all highlighted the value of Smith's inclusive culture, holistic teaching, and its championship of women, which influenced their engineering trajectories in unique ways. Ms. P3, who had been used to a more traditional, technical-oriented style of education in high school, came to appreciate the more comprehensive approach to engineering education at Smith. Ms. P2, whose characteristic initiative had encouraged her to pursue her interest in engineering regardless of the gender dynamics, also acknowledged how her horizons had expanded thanks to the empowerment she felt at Smith. Admittedly, such examples add support to arguments that stress the role of institutional and peer influences. Surrounded by intellectually curious, politically sensitive, and broadly thinking peers, one is bound to be more like them, right? It is regrettable that this kind of

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[71] This assumption has its merits, considering the knowledge taught in college is available from other venues (e.g., libraries, books, MOOCs, and so on). Also research in higher education has stressed peer influence (Winston and Zimmerman 2004).

[72] Picker does set a positive exemplar for engineering education in liberal arts colleges. Other leaders of liberal education have also called for the embracement of engineering and other professional education (Shulman 2005). However, the prospect (affordability) for liberal arts colleges in the U.S. is not optimistic (noted by President Christ at a meeting with Smithies, personal communication.)

peer influence, one that widens a student's perspectives and sensitivity, has become increasingly rare outside the small liberal arts colleges. What can engineering educators do in large universities, where students come ready to "fit the mold" and do no more than what is required to obtain a degree and find a job?

But wait a moment. Perhaps the beauty of Smith's story lies in the revelation that peer influence is not a completely independent variable in the equation of reforming education. Although Smith has long been known as a progressive institution, as most women's liberal arts college are thought to be, the economic, national, and racial diversity of the student body is increased as a result of difficult, persistent, and contested efforts. As Section 4.1.3.1 shows, the college's aggressive campaign to diversify the student body in the recent decade was in part ignited by a series of traumatic conflicts and turmoil brought on by bigotry, homophobia, and racial hatred. Even after consensus on increasing social justice and diversity was formally reached within the college, such values were not pursued without opposition. In 2012, Anne Spurzem, an alumna of Smith College and President of the Smith Club of Westchester County, questioned President Christ's campaign to increase diversity in a letter to the editor of *Sophian*, the student-run newspaper at Smith College. Ms. Spurzem suggested the diversity campaign would impact the donors' interests in supporting the college, because the increase of students from non-traditional background was considered to lower the academic standards of Smith and to alienate the most resourceful students and donors—women from wealthy families.

Ms. Spurzem characterized the demographic changes of Smithies in the following paragraph:

> "The people who are attending Smith these days are A) lesbians or B) international students who get financial aid or C) low-income women of color who are the first generation in their family to go to college and will go to any school that gives them enough money. Carol emphasizes that this is one of her goals, and so that's why the school needs more money for scholarships or D) white heterosexual girls who can't get into Ivy League schools." (Quoted in North 2012).

Ms. Spurzem claimed Smith no longer looked at students' SAT scores because "Low-income black and Hispanic students generally have lower SATs than whites or Asians of any income bracket. This is an acknowledged fact because they don't have access to expensive prep classes or private tutors." As a result of these changes, "the days of white, wealthy, upper-class students from prep schools in cashmere coats and pearls who marry Amherst men are over," and Ms. Spurzem thought it "unfortunate because it is this demographic that puts their name on buildings, donates great art and subsidizes scholarships" (Ibid).

The letter incurred strongly critical responses. President Christ wrote an open letter to the Smith community expressing "shock" and "dismay" (Christ 2012). The students at Smith responded to the offensive and discriminating messages with more creativity. They created a blog named "Pearls and Cashmere," where students, some of whom put on their pearls and (fake) cashmere sweaters, shared how the diversity at Smith had strengthened them both academically and personally and rejected the unfair stereotyping in Ms. Spurzem's letter.[73]

The Picker program at Smith College provides a powerful, positive, fruitful argument for increasing underrepresented population in engineering education. Not only will the expansion of underrepresented students increase the total number of engineering personnel, an outcome eagerly anticipated by policy makers, political, industrial, and educational leaders, but in addition a more diverse student body also enriches the perspectives in engineering learning and connects engineering students to broader social realities. The inclusion of minority students in the Picker program results in part from a college-wide campaign and a series of institutional policies negotiated between the administrators and the students. In the meantime, the engineering program accommodates the inclusive efforts with alternative teaching methods and contents of learning. These steps make engineering more accessible to students with varying educational preparation and more meaningful to those who seek to understand the social and humanitarian significance of technology.

[73] Pearls and Cashmere.

5. PDI

5.1 The puzzling encounter

At its beginning, “Product Design and Innovation” (PDI) was organized as a dual-degree program that awarded a B.S. degree in Engineering Science and another B.S. degree in Science and Technology Studies. In 2006, the program was approved by the New York State Department of Education to offer a B.S. degree in Design, Innovation, and Society (DIS). As a result, DIS replaced PDI as the initial of the program’s official name. However, the program is still better known as “PDI” among its educators, students, and alums. “PDI” also survives in the program description in a special way: as students who major in DIS can choose to pursue a second degree in a number of majors—e.g., mechanical engineering, management, computer science, communication, “[t]he dual major options are referred to as the ‘Interdisciplinary Programs in Design and Innovation’ (also known as ‘PDI’).”[74] Following the tradition of the “insiders” of the program, in this dissertation I continue to refer to the program as “PDI.”

In theory, PDI is first of all a program that teaches social analysis of design, yet it is usually considered an interdisciplinary design program involving engineering, arts, and critical social studies. There are two reasons to see PDI as an experiment of engineering education reform. First the program was created with the joint efforts of faculty from the Schools of Engineering, Architecture, and Humanities, Arts, and Social Sciences. Second, the majority of PDI students are mechanical engineering and DIS dual majors. The program states the integration of different disciplines as its hallmark: “integrating STS with design; integrating technical and social analysis with creative synthesis; and integrating students from engineering, management, and the creative arts in the same program” (Ibid).

Unlike the engineering programs at Harvey Mudd and Smith, PDI students receive most of their regular engineering education not from the design program but from the engineering departments on campus. PDI also distinguishes itself from HMC and Picker

[74] See RPI (2014).

in that the liberal arts education is not implemented in a stand-alone manner: although the DIS degree requires twelve course credits in the humanities and social sciences and another twelve credits in STS, the core of PDI is a series of design studio courses, where engineering, social sciences, and arts are synthesized in identifying needs, generating concepts, visualizing ideas, making prototypes, presenting and critiquing design projects. The sequence of the design studios have changed several times over the years, the latest sequence includes seven regular and one optional studios for most students (See table 5.1).

Table 5.1 Sequence of PDI design studios[75]

Studio	**Skill Sets**		
Focus Area	**Design**	**Technical**	**Social**
Studio One Interdisciplinary Design	creativity, conceptual design, design iteration, presentation boards, note-books, modeling, portfolios	representational drawing, PowerPoint, Photoshop, Illustrator, Flash, Excel	needs finding & assessment, design research, gender & equity, design critique
Studio Two Product Development	design process, problem definition, concept evaluation, product testing	concept representation/CAD, manufacturing feasibility & prototyping, engineering analysis	interviewing, user observation, object history, social values analysis
Studio Three Industrial Design	form & aesthetics, professional design reports, design presentation boards	Rhino solid modeling, rapid prototyping, environmental impact assessment	market & product research, social and consumer trends, usability analysis

[75] Ibid.

Studio Four[76] Intro to Engineering Design	engineering design process, product development cycle, scheduling, teamwork	engineering analysis, prototyping & modeling, technical communications	professional audience analysis, presentations, needs analysis
Studio Five User-centered Design	participatory design, cognitive interface, cultural design	electronic hardware & software, advanced prototyping	ethnographic research, cultural probes, evaluation design, social justice & user identity.
Studio Six Design Entrepreneurship	moving idea from concept to market, advertising design, sustainable design	new product / production economics, distribution planning, financial modeling	predicting social effects, risks & safety, market potential, consumer trends analysis
Studio Seven Capstone Design	design integration, systems design	engineering analysis for real-world problems	designer-client relations, adv. technical presentations
Studio Eight (Optional) Inventors Studio	advanced creativity, iteration	engineering analysis, patenting	legal dimensions/IP, technical presentations

Readers will notice in this chapter a glaring shortage of introduction and comments on the institutional context of PDI. I intentionally left out a more extensive discussion of its home institution—Rensselaer Polytechnic Institute, the earliest civil engineering

[76] Studio Four is required for students who are pursuing a dual degree in engineering.

school in the U.S. This choice was not due to a lack of connection between the specific educational experiment and the characters and culture of its home institution. As I present the story of the design program, readers might be able to identify threads of influence coming from the visions, history, institutional policy and culture of this centuries-old institute. I, however, set aside a focused, detailed discussion of the institute, for it would not be possible to recount even the recent history of this institute without writing a greater length than I can manage here. By "recent" I mean the time between the making and remaking of the "Rensselaer Plan," a blueprint for this almost two hundred years old technical institute in the twenty-first century (RPI 2007). I would simply point out that the "Rensselaer Plan" and its "2.0 version"[77] represent one vision, among others, of moving the college beyond the identity of a technical institute as it had been recognized over the past two centuries, to become a fully developed university. This attempted identity shift overlapped with the trajectory of an interdisciplinary design program in a number of ways, but much of the plan deals with issues that belong to a different volume that comprehensively examines the structural changes of technical education in the twenty-first century U.S.

My relationship to PDI differs significantly from mine to the other two case studies. Because PDI is institutionally hosted in the department in which I am conducting my graduate study, I am connected to this program in a number of ways. Many of my colleagues, myself included, have taught in the program. Hence "data" for this case study was collected not only from using formal research methods—archival, interviews, and participant observations—but also from my memories of anecdotes, casual conversations with students and instructors, and my own experiences teaching in the studios.[78]

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[77] "The Rensselaer Plan 2024."

[78] This chapter draws mostly from my participant observation of two PDI studios—Studio One and Studio Five—in the fall semester of 2013. Therefore, the representation of the program here is selective; students' educational experiences in other studios and in the non-studio based courses required by the DIS major are not fully examined in this chapter.

PDI left me with mixed and sometimes conflicting impressions. When I introduced the features of PDI to engineering educators outside RPI, they were often impressed that the various educational components—hands-on work, team-based projects, co-teaching, involvement of end users, etc.—that they strived to partially include in their teaching could be implemented in a full-blown educational program. However, the impression of some colleagues in my department, who taught PDI students outside the design studio courses, suggested that PDI students are far less enlightened by the systematic social science thinking than an education in Science and Technology Studies (STS) aspires to achieve. Occasionally I was also puzzled by the PDI students. Some of them thought in ways not appreciably different from the profession-oriented, job-hungry engineering students elsewhere on the Rensselaer campus. In fact, several of the students I came to know reminded me of the uncritically minded technological enthusiasts depicted in science fiction films or in public relation campaigns. However, sometimes PDI students intrigued me with profound critique of the dominant and problematic technological order of our time; very often they amazed me with thoughtful and original solutions to challenging technosocial problems. In addition, a good many PDI students seemed a happy breed. In the studio they played music, passed around snacks, exchanged jokes and gossips, while keeping their hands busy sketching, making paper prototypes, or building circuits. They seemed thoroughly at home in the studio. Keeping students happy is a challenge that, in my view, higher education, and engineering education in particular, fail to meet overall. My own experience of studying engineering as an undergraduate was so unpleasant that the discovery that learning could be fun seemed to be an outcome totally outside the purposes of both one's education and one's eventual career. Joy in inquiry and in mastery of the practice of engineering? Don't be frivolous!

My contact with PDI started before it caught my research interest as an educational experiment. I taught PDI students as a teaching assistant for Science, Technology, and Society, a 1000-level social science elective for all RPI students. The course encourages students to critically examine the social implications of modern technoscience and to envision alternative ways of organizing and steering tehcnoscientific innovations. At first I considered the PDI students in the classroom colleagues of mine because they were studying for an STS degree. Both the PDI students and I thought they had been more at home with STS point of view than the rest in the class, yet the perspectives they presented, which they thought were in line with the teaching of STS, sometimes appeared to me as shockingly misconceived. For example, many PDI students tended to understand problematic sociotechnical arrangements as “bad design.” They held that if only consumers were better informed to realign their consuming habits and technoscientists paid more attention to user needs, problems would be solved. Issues like uneven distribution of profits and costs, distorted power dynamics in decision making, tension between democratic governance and individual liberty, and other issues covered in the class, did not exist in their vocabulary. There also appeared a popular mentality among the PDI students, which Langdon Winner calls “techno-triumphalism,” the hope that we could solve any problem with the creation of the next revolutionary technology or consumer good, like iPhone or Google (Winner, 2011). Thus, my first encounters with the attitudes of first and second year students seemed to correspond to faculty critics of PDI, who consider the program of little success in educating social analysts of design or well-rounded engineers who would base their technical intervention on careful and comprehensive social analysis. After all, STS has drawn attention to stories of sociologist engineers, sometimes called “heterogeneous engineers,” who could both read the social dynamic in technological creation and utilize their technical expertise to materialize social visions within material artifacts (Winner 1986, Law 1987, Callon 1987).

However, these early perceptions and judgments were called into question as I became more directly involved with the program, especially the core of PDI—its studio courses. In the spring semester of 2010, I informally sat in one of the PDI studios, Studio Two. It soon became clear that the class was unlike any engineering or STS classes I had known about. Three instructors co-taught Studio Two, one from STS, one from mechanical engineering, and one from the business school. Every class usually began with a mini-lecture given by one of the instructors, while the other two frequently chimed in. It was quite an experience to watch the instructors debating with each other in front of all the students. Much of the class was dedicated to “open studio time” when students sat around broad workstation tables and worked on their design projects with their teammates: brainstorming ideas, sketching, making posters, building prototypes, etc. The major course project that semester was to design something to help solve a world problem defined by the students. I followed a group who sought to change the barren support for creativity in education. The group struggled for a long time narrowing down the general educational challenge into a solvable design problem. They tried round after round of brainstorming and other techniques of generating design concepts. When the time almost ran out, the group gave up the challenge of cultivating creativity and designed a toy meant to increase interaction in classroom teaching. I was impressed by the original ambitious objective of the project, but I felt a little disappointed at the final outcome.

In the following semester (fall 2010) I was surprised to find myself assigned as a teaching assistant to Studio Three, teaching the same class of students I had met in Studio Two. Studio Three was taught by Prof. DA, a former engineer who went on to get a PhD in STS and became a professor in RPI's STS department. Prof. DA had been involved with the creation of PDI as a graduate student and TA. After he joined the STS faculty at RPI, he became the backbone of PDI, serving as the program director and STS advisor for all PDI students. Studio Three focuses upon usability, manufacturability, and aesthetics. Students in the class complete three major design projects: a poster, a device to be used in the design studio, and a consumer product of students' own choice. Besides the design projects students read three books on the theory, methods, and culture of design and wrote five reflection papers. I graded and commented on all the reflection papers, co-led discussion of readings, and provided feedback to students' design. My first formal involvement with PDI felt like stepping into a neighbor's home for the first time. I had "known" the program and some of its students through "Science, Technology, and Society" and Studio Two, so I thought I had made acquaintance with this neighbor. However, I quickly discovered how "foreign" I was in a space occupied by some thirty designers.

The design studio has a different culture than the STS courses I had been used to. PDI students are passionate about "sleek" designs: original ideas, elegant aesthetics, fine details, and so forth. In their view, the social significance of design is but one concern among many design objectives. Prof. DA's prominent design thinking as well as his knowledge about particular design tools and techniques make him a favorite among students, who frequently consult him on design ideas, choice of materials, mechanical and other resources available on campus.

I had but a vague idea about conversations of this kind, despite having an undergraduate degree in engineering. In the meantime, I had a hard time finding the "proper" space to have conversations about STS concepts and theories in the class. Discussions of readings are open-ended; students are welcomed to share their responses to the readings in any direction they found relevant. I also came to discover attempts to steer discussions toward any specific direction would do no more than confusing the students and discouraging their participation. The writing assignments are also open-ended. Students wrote five reflection papers over the semester. The first assignment asks them to explain their definitions of and criteria for beauty; the second paper is a life-cycle analysis of the product they were designing for their final project; and the third assignment asks students to reflect on visual thinking. Because of the openness of the papers, I commented on students' logic and style of presentation more than their qualities of social analysis.

Feeling anxious about my role as an STS TA in the class, I discussed with Prof. DA about the degree of STS intervention in the studio teaching; I also questioned whether we had been too "lenient" in pushing students to critically examine the assumptions they held about design. I was especially alarmed by the tendency of "tech-fix" in students' design thinking when one group proposed to address energy waste by designing an appealing switch, which would encourage people to turn off the lights when they leave an empty room (Morozov 2013). Prof. DA is aware of the limits of STS education in the design studio, but he is also careful not to impose STS contents on students in simplistic ways that disempower students. Instead, he seeks to create a power dynamic in the studio different from what students are used to in engineering classes. It is a trade-off between mandating students to do more critical analysis and creating an educational experience of which students can take ownership.

I was even more surprised when I heard students in Studio Three complaining about the social analysis they had to deal with. What I considered a too scarce STS education was deemed by many a student in the studio as overwhelming and irrelevant. Over that semester, students were required to read three books: *Design: A Very Short Introduction* (Heskett 2005), *Universal Principles of Design* (Lidwel, Holden, and Butler 2010), and *Where Stuff Comes From* (Molotch 2005), a book written by sociologist Harvey Molotch about the cultural, professional, and organizational contexts of products. During a reflective discussion at the end of the semester, a student said he enjoyed the *Very Short Introduction* and the *Universal Principles*, but he couldn't understand why they had to read and discuss the *Stuff* book, which seemed to offer no connection to what they did for the rest of the time in the studio: working on their design projects. It was hard to answer him because from a particular point of view he was right: discussions about the sociological and cultural meanings of design find little resonance in the actual ways students "do" design.

I met this student in fall 2013 after I came back from fieldwork in Claremont, CA. Most of his cohorts had graduated the previous summer. He had spent a semester as an intern at a prominent toy producing company and had just come back to finish his last semester. We talked about his working experience. He had done well in the company and had been given a job offer. It was good news and a proof that he was capable of doing professional design work. However, he said, it was "scary" to think that what he designed—toys—would be played by thousands of children. I was curious about the cause for his scare, and he didn't know for sure. He said it was because of something he had learned from those STS classes. At the time he was doing his undergraduate thesis on the technical-social divide in design thinking.

5.2 Teaching in PDI: The development of design expertise

5.2.1 Support and challenge

As an interdisciplinary program, PDI brings together instructors from different backgrounds, carrying with them disparate educational philosophies and visions of design learning. For example, while instructors like Prof. DA seeks to encourage and support students to explore their own trajectory of design learning, others more intently challenge students' habitual ways of thinking in order to achieve the shift in mentality regarded as helpful for today's designers. Instructors' different approaches are sometimes revealed to students in a single studio course, such as the debates between the co-teaching instructors in Studio Two. Yet it is more common to find visible embodiments of different visions across different design studio courses, as every studio is usually heavily influenced by the instructors' personal styles. During my interviews and informal conversations, PDI students frequently referred to two instructors as especially profound sources of influence. One of them was Prof. DA, who serves as the main instructor for two studio courses (Studios Three and Six), the director of the program, and the STS advisor for all PDI students. The dual-majored PDI students have one advisor from the STS department and one from their other institutional home, usually in the mechanical engineering department. Most PDI students hardly know their engineering advisors; they unanimously turn to Prof. DA for advices on course registration (in STS and engineering), internship decisions, career planning, etc. Most students I spoke with agreed that the program would stop functioning without Prof. DA. As I point out above, Prof. DA's own interdisciplinary training and his educational philosophy contribute to a pedagogical style that encourages students to develop less discipline-bounded, hybrid expertise. He is not keen to imprint a specific design approach or a school of thought on students' minds; instead, his teaching focuses on cultivating students' ability to reflect on their education and to establish their own identities as designers.

The other most frequently mentioned instructor was Prof. DB, who influenced PDI students in a radically different way. Prof. DB completed his undergraduate study in mechanical engineering in the 1950s. He joined RPI's Department of Mechanical, Aerospace, and Nuclear Engineering as a senior lecturer after retiring from his business career, having founded four companies and owned fifteen patents. Prof. DB appears a faithful and enthusiastic disciple of technological and entrepreneurial innovations. The central message from his teaching stresses that PDI students could make great accomplishments by challenging the limits they had set for themselves and constantly striving for the most important and radical innovations. Prof. DB has little patience for design ideas aiming at incremental improvement of the world. He expects "win-win-win" solutions, groundbreaking innovations that meet simultaneously the multiple objectives of people, planet, and profit. Students' receptions of Prof. DB are highly polarized. Many students find his excessively high expectations intimidating, especially when they have just left home and entered college. Some students are also suspicious about his all-too-positive attitudes toward technology and innovation and the lack of critical analysis. However, students who share Prof. DB's visions consider him an unparalleled source of inspiration.

The difference between Prof. DA and Prof. DB in a way represents the typical approaches taken by the STS and engineering faculty to the program. The STS instructors tend to acknowledge that students' understandings of the social dimensions of design have been partly shaped by the environment they grow up and the influences from their engineering departments; they are also more willing to negotiate with the students with the attempt to exemplify an alternative power relation in the studio.[79] The engineering instructors, though a minority in the number, push forward their visions of proper design more assertively.

In the fall semester of 2012, Prof. DA taught in the first hour of every Studio One class for the first seven class days. He intended to use this extended orientation to help students transit from high school to college; in the meantime, he guided students to launch the journey of exploring their own, unique identities as designers. The seven mini-lectures were organized around reading and discussion of a textbook, *Product*

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[79] Most of the STS instructors in PDI have read or indicated approval for Paulo Freire's (2000) critical pedagogy.

Design (Rodgers and Milton 2011). Prof. DA acknowledged in class that the textbook introduces “the traditional way of design,” adding that the choice of the book “horrified” Prof. DB, the main instructor of Studio One, who seeks to teach PDI students non-traditional ways of design. The rationale for choosing the book, Prof. DA explained, was to expose students to the orthodoxy so that they would understand how PDI is different. In the discussions, Prof. DA frequently reminded students of the program’s unprecedented institutional structure and the unique identities of PDI students in the world of design. He spoke proudly of the program as the world’s only design program hosted in a social sciences department, which provides PDI students with unparalleled advantages in concept design, because leaning in social analysis will help them formulate, articulate, and critique design concepts. In particular, Prof. DA stressed PDI’s integrative pedagogy, which contributes to students’ excellence in concept design by consistently integrating broad social contexts into the various components of design: from identifying design needs amid sophisticated political, economic, and social variables, to choosing socially and technically robust design approaches, and critically reflecting on the social, economic, and environmental significances of design products.

With Prof. DA’s encouragement, the students in Studio One not only commented on the contents of the book but also critiqued its style of presentation. Much of the time was spent discussing philosophical questions about design thinking. One day students debated an idea promoted in the textbook: “it’s not what the designer wants but what the consumer like about a product.” Many students recognized the central role of user needs in design thinking, but they also explored various ways designers could express their personal styles and artistic ideals while meeting user needs. Prof. DA also called students’ attention to the authors’ tendency to separate engineering from design by creating a category “engineering designers,” a tendency that echoed a popular misconception that designers come only from artistic fields and are primarily concerned with matters of form and appearance. He encouraged students to renegotiate the boundary between engineering and design so as to identify themselves as both engineers and designers, not “engineering designers” or simply “more creative engineers.”

During the discussions Prof. DA tried various methods to encourage participation from all the students. He tried to convey to the students that they played a part in constructing their own learning experience. Meanwhile, Prof. DA very tactically avoided forcing students into speaking. To avoid students from feeling picked, he played a number of games that randomly chose students to express their thoughts. The class always sat in a circle, so everyone was facing each other. Through his effort to encourage participation, Prof DA attempted to signal to students a different relationship between themselves and their learning. Before the last class hour ended, Prof. DA pointed out the students were in the room because they had been very successful at "being good students," that is, they had been used to obeying orders and memorizing what was taught to them. Prof. DA suggested college is a different game: in college they should no longer be content with just being good students; they have to own their education and to love it. He asked the class whether they had been familiar with the term "plug and chug" in engineering. After hearing a few "yes," he asked students not to play "plug and chug" in PDI. He reminded "you won't love everything and every instructor here, but you've got to own it."

In seven hours, Prof. DA established a personal connection with the students. At the beginnings of the first two or three classes, he challenged himself to remember every student's name; by the end of the seventh class he had known all their names. Students freely chatted and joked with him in classes and during class breaks. After he said his temporary farewell (he would not teach them until Studio Three), the class gave him a cordial round of applause.

As Prof. DA was leaving, Prof. DB entered the studio. He brought with him three undergraduate teaching assistants (TAs). Prof. DB had chosen them from his students in another class, the Inventor's Studio. Two of the TAs were senior PDI students. The TAs handed out blank paper to students and told everyone to write their names on a piece of paper and placed it in front of them as index cards. Prof. DB opened his lecture by asking students to take notes. During the following class time, he stopped his lecture several times to check if students were taking notes on what he had said.

Prof. DB noticed Prof. DA's efforts to help students develop their design identities. Prof. DB thought being designers was fine, but not enough: he wanted every student to be "an innovator" and to "make significant difference in the world;" he wanted them to be "all leaders in the future." Then Prof. DB asked everyone in the class to visit the website of Ecovative Design, a company founded by two PDI graduates. Prof. DB said Eben Bayer, a co-founder of Ecovative, was not only "a designer" but "really an inventor and innovator." Prof. DB did not elaborate the differences between a designer and an innovator. Instead, he paused his lecture and urged students to take notes. He told the class the "smartest and most successful people" he had known in his career took notes, "If you take notes and draw something, you own it." One of the TAs was illustrating note-taking: He projected his real-time notes on the screen as Prof. DB continued the story about Ecovative, in whose creation he played an essential role.

In 2007, Eben Bayer, a senior in PDI and mechanical engineering, developed a rigid, molded material from mushroom. While Bayer was wondering about the potential application of this discovery, Prof. DB paired him up with another student in the Inventor's Studio, Gavin McIntyre. Bayer and McIntyre took the material to a national testing center in Texas and proved that the new material had characteristics equal to or better than Styrofoam. With Prof. DB's encouragement and subsidy, Bayer and McIntyre founded their own company—Ecovative Design—to develop an environmental friendly replacement for plastic foams. Over the past few years, Ecovative had won numerous awards and grants. Prof. DB especially emphasized the winning of the 2008 PICNIC Green Challenge Prize (500,000 Euros), and the 2012 "Screw Business as Usual Award" given by Virgin Unite.

Prof. DB told the students they should watch Ecovative's award reception presentation on their website. Then he started to point at the students one by one: "You, you, you, and you can do something incredible! Not just a designer." He announced that "we are building a culture of innovation. Take notes please!" Prof. DB explained the road toward a culture of innovation: students have been used to doing what they are told to, but from that moment on, he wanted them to give up that habit; he wanted them to find problems by themselves. Prof. DB also asked the students to start using Google Alerts and to add "Ecovative Design" in their Google Alerts.

5.2.2 T-shaped concept of knowledge

Although each studio personifies its instructors' individual preferences and philosophies, most PDI instructors share some fundamental understandings about the program and design education. Some core values were agreed on at the time when the program was created; these values served as an informal contract for instructors who joined the program later on. The core values are communicated to students both through the official presentation of the program and through their recurring appearances in the day-to-day teaching and learning. Although the interpretations of these values are partly up to individual instructors, all the studios in general emphasize diverse skillsets, comprehensive approaches to problem identification and solution, iterative design process, and reflective learning.

PDI instructors are champions of diverse and multidisciplinary skillsets. Prof. DB often emphasize in his teaching the concept of "T-Shaped knowledge," which he has learned from IDEO, the pioneer company in design and innovation consulting. The metaphor of the "T-Shape" emphasizes the importance of both breadth and depth of one's knowledge and skills.

> The vertical stroke of the "T" is a depth of skill that allows them to contribute to the creative process.
>
> …
>
> The horizontal stroke of the "T" is the disposition for collaboration across disciplines. It is composed of two things. First, empathy. It's important because it allows people to imagine the problem from another perspective- to stand in somebody else's shoes. Second, they tend to get very enthusiastic about other people's disciplines, to the point that they may actually start to practice them. (Hansen 2011)

Learning a broad range of design skills is partly made possible by the interdisciplinary background of PDI instructors. For example, in fall 2012, Studio One was staffed with one engineering professor, one professor in graphic design, and a graduate TA from the STS department (besides the visit of Prof. DA). Students in Studio One learn at least three bodies of skills: First, through readings, discussions, and design exercises, they gain knowledge and experiences in concept design. Second, they learn and practice a series of artistic and visualization skills under the guidance of a graphic design professor: sketching, making posters, using Photoshop and Illustrator, and prototyping with simple materials. Third, the instructors introduce a number of project management tools, such as mind-mapping. In Studio Two, students are formally introduced to a design process spelled out in a widely used textbook on engineering design. They are given opportunities to utilize various design tools in their projects; they also learn tools to analyze and evaluate design, such as lifecycle analysis. Students in Studio Five learn to use Arduino, an open-source platform for electronic prototyping. Studio Five also teaches Flash, smartphone app development, and qualitative research methods, such as ethnography.

Nevertheless, PDI students' scope of learning is not confined to their instructors' expertise. Instructors more often act like advisors/coaches and point students to resources of learning available on campus or on the web. Students routinely bring their mechanical, electrical, and other knowledge they have learned in their majors to bear on their design projects. More importantly, PDI supports a culture of self-driven and self-guided learning. Many PDI students are eager to expand their knowledge bases and skillsets by teaching themselves or learning from each other. For example, when I worked as a TA in Studio Five, many students who did not major in electrical engineering encountered electronics for the first time when they were introduced to Arduino. During the first class some students needed my help to install the programing environment on their computers, for they had had no background knowledge of Arduino. Although both the course instructor and I have background related to electrical engineering (the instructor has a master's degree in cybernetics and I have a bachelor's degree in automation), no extensive instructions on programing were given to the students. Instead, students were recommended to visit an online forum for examples and excerpts of codes. However, many of the non-electrical engineering students soon surpassed me in their knowledge of Arduino. One student, Ms. D5, noted the difference between her classmates in PDI and mechanical engineering in their attitudes toward active learning. When she took “Introduction to Engineering Design” with other mechanical engineering students, one of her teammates refused a task involving electronics because “I’m not an electrical engineer.” PDI students, Ms. D5 recalled, are not used to saying “Oh I can’t do that.” On the contrary, they often intentionally switch their roles in projects so that people could work on something they are not so good at. Peer-teaching is common in the studios. Ms. D7 had been a quite accomplished graphic designer when she came to RPI. She taught a number of people how to use Illustrator and other image-processing software in her design teams.

5.2.3 Iterative design process: Learning by making and correcting mistakes

Of course, design is not like making soup: One doesn’t simply throw various knowledge and skills into a pot and call it a design project. PDI instructors make every effort to communicate to students the generic process of design as a non-linear, iterative process. Teaching the design process is a central educational objective in virtually all the design courses I have studied or visited. However, in most engineering programs, students only get to experience the extensive design process in one major course project, which usually runs for the good part of a semester (or a year, if the course runs that long). At PDI, students’ experiences of the design process are reinforced through completing one or several design projects every semester for seven or eight semesters. Starting from Studio Two, students in each design studio have to complete at least one project for which they go through the whole process, from concept generation to the delivery and presentation of a prototype.

In fact, instructors in Studio One already start to establish the mindset of process-focused design, although in a particular, somewhat dramatic manner. In the early years of PDI, Studio One was offered as the first studio course for both PDI and architecture students. The architecture instructors’ way of teaching, said a PDI instructor, was sometimes intentionally “abusive.” The rationale was to help students get used to failure and criticism. As a result, architecture instructors often told the students bluntly "this doesn't work" or "this is wrong." Although PDI Studio One eventually departed from the architects' disruptive style, the philosophy of challenging students and getting them used to critique is retained, with arguably less stylized "abuse." The confrontational style of teaching is partly meant to dismantle students' mythical misconception that a designer goes from problems directly to concepts, sketches, models, prototypes, and final products. Carrying this myth, the newcomers in the design studios are often reluctant to proceed in the design process before they get everything right for the step immediately at hand. The instructors try to break this mentality and to rebuild in students the conception of design as an iterative process; that a designer goes back and forth, revising and refining her design; that it's better to "fail earlier in order to succeed sooner."

While Prof. DA carefully avoids imposing his ideas on students, he also emphasizes the importance of iteration. When concluding his lectures in Studio One, he suggested students create a portfolio to document their work: "If you are not assembling your portfolio, document your work, keep your sketches, design books, take photos." Prof. DA explained that records of their design were not meant to be clean or polished, because it was not their glossy final products but their design process that mattered. He added that when they looked for jobs, employers would be interested in their abilities to iterate an idea.

5.2.4 Problem definition

Problem solving has been widely considered the defining feature of engineering. Yet more people have in recent years come to realize the limits of the "problem solving" model and have recommended a paradigm shift toward what Downey (2009) calls "problem definition and solution." In fact, those who are content with the education of "problem solvers" might change their minds after learning what "problem solving" means in many engineering programs. Unlike the literary meaning of "problem solving," which implies omnipotent expertise in solving any problems we have, my interviews with engineering students indicate that when they speak about "problem solving," they usually mean answering the narrowly defined questions in textbooks, homework, or exams. The limits of problem solving oriented engineering education are emphasized in educational reformers' debate about the differences between "Problem Based Learning" and "Project Based Learning." Though a number of educational experiments can be considered both problem and project based; some educators point out a crucial difference: problem based learning does not exclude repetition of the "problem-solving in homework and exam" model (Akera and Tang, forthcoming).

Teaching of engineering design in all my three case studies unanimously emphasizes students' ability to define problems in one way or another. However, different educational objectives drive students to focus on different aspects of the problems. In the Introduction to Engineering Design course at HMC, for example, students started the first design project by rewriting a given problem statement. The purpose of the rewriting was to help students recognize and correct the errors, biases, and implied solutions in the client's problem statement. In the Engineering Clinic I observed, every team spent a significant amount of time discussing the scope and nature of their projects. The focus here, however, was to negotiate a set of objectives and deliverables that the team and their liaisons could agree on, objectives that were both feasible given the time and team capacity and valuable for the liaisons, whose company sponsored the Clinic projects.

In PDI's vision statement, one of the "supporting objectives" of the program seeks to educate students to "understand design as a multidisciplinary enterprise that includes *problem analysis* (emphasis added), problem solving, design research, articulating alternatives, *exploring social problems* that have significant technical content, and developing design solutions that take into account the values statement" (RPI 2014). Formally, "problem definition" is included as a design skill that Studio Two focuses on. In reality, problem definition is one of the key experiences that are repeated in every studio, although the approaches students take to find problems vary from course to course.

Prof. DB was interviewed in CNBC's "One Good Idea" once to discuss the steps of teaching innovation. He appeared on screen wearing a red baseball cap. The front and back of the cap were both patched with a piece of paper, which wrote respectively "How" and "What." Prof. DB explained that the first and the big step of innovation was "problem-finding," which was "harder than problem-solving." In order to support unconstrained problem-finding, Prof. DB suggested separating "what's needed" from "how we are gonna do it," for he found people often give up user needs or ideals for products because they do not know how to achieve them. Prof. DB suggested everyone turn the hat around, placing "What" in front of "How."

Prof. DB faithfully prioritizes problem-finding in his own teaching, creating numerous opportunities for students to question existing products and to envision ideal ones. The first project Prof. DB assigned in Studio One was to identify problems with plastic bags. He advised students to start with the existing product and ask questions about its performance, cost, user interface, environment impacts, product history, and its relation to people, society, and culture. Prof. DB foresaw many people would look for incremental, obvious solutions. But "we are not going to do that," said him. He wanted the students to explore not biodegradable plastic or better reusable bags but something radical. He wanted them to strive for not incremental but disruptive innovations. With his encouragement, some students proposed to look for possibilities of not using bags at all. "Eliminate the need for bags! I love it!" Prof. DB praised the proposal, but he also cautioned the students not to create other problems with their solutions.

The aforementioned project of "solving a world problem" in Studio Two also started with problem definition (see page 132). At the beginning of the said project, the instructors handed out a paper card to every student and asked them to write down the major world problems they wished to tackle. After the writing, students were asked to pin their paper cards on a side wall of the studio. After every student had read the problems on the wall, they rearranged the cards according to common problems: transportation, food, education, etc. Project teams were thus formulated by students who targeted at a similar problem, whose cards were grouped in the same category.

5.2.5 Critique

Design critique is another essential skill PDI tries to teach. Formally, design critique is listed as an object of teaching for Studio One. In reality it is emphasized across the studios, and different aspects of design critique are emphasized by different instructors. Almost every design project in the studios ends with a presentation, during which instructors and other students would provide oral feedback to the designers. In their face to face evaluation of students' work, the instructors exemplify the practice of design critique. In the meantime, students are given plenty of opportunities to learn and to practice the art of critique.

In Studio One, Prof. DB introduced design critique as a tool for problem finding. For example, he asked students to do a "paper clip criticism" exercise. After giving every student a paper clip, Prof. DB asked them to question the paper clip in every possible direction, for example, why do people use paper clips? And what are some unintended uses of them? Every student was asked to come up with fifty criticisms of the paper clip by the next class. Students brainstormed some quick criticisms in class: It breaks. You can't eat it. It leaves marks on paper. It's not tight…. Prof. DB reiterated he wanted the students to be expert criticizers. Mr. DD, the STS graduate TA, encouraged the students to think about the life cycle of a paper clip. Prof. DB also illustrated asking questions about the product's life cycle: Where does the metal come from? Where does it end? What's wrong with the container for clips?

While Prof. B recognizes the intellectual value of design critique, he also sets a limit for its use in Studio One. He is convinced that people with really great ideas are often suffocated by peers who are not as much visionary and courageous as the radical innovators. Hence he is very keen to remove any constraints on students and to create an environment for boundless thinking. To protect students' imagination, Prof. DB attempts to create a culture of support in Studio One by discouraging critical comments on peer students' design ideas. In his own words, students should play not "the devil's advocate" but "the angel's advocate."

Unlike Prof. DB's protective stance, Prof. DA makes an effort to cultivate a healthy culture of critique in Studio Three. I witnessed this strategy while working as a TA in the studio. Before the students undertook their first project—a poster design, Prof. DA asked them to arrange their seats in a semi-circle facing the side wall on which posters designed by previous classes were pinned. Prof. DA explained the purpose of the exercise was to develop students' ability to conduct design critique at all levels: from high-up, conceptual level to details of implementation. Prof. DA pointed out design critique was a critical skill for professional designers. Under his guidance, students critiqued various aspects of the posters: size, font, color, consistence between texts and images. At first most critiques were directed to visual details. Prof. DA patiently clarified students' perspectives and encouraged them to also look at higher-level issues, such as the logic of presentation. A few weeks after the warm-up exercise, students were invited to critique each other's work after they finished their own posters. Prof. DA reiterated the logic of design critique and reminded students of critiquing design ideas professionally. He asked the authors to take the critical comments and suggestions they had received as resources for design thinking, not as criticisms to them personally.

Besides refining students' design thinking, the STS instructors in PDI also use critique as a pedagogical tool to provoke reflections on the social and cultural implications of design and to question students' assumptions underlying their design choices, ways of thinking, and the use of language. Although the STS instructors in the studios do not usually advocate particular design approaches, they are often sensitive to the implicit political and cultural connotations embedded in students' ideas and take action to help students articulate and reexamine these ideas. After students had learned the visualization skills in Studio One, they were asked to design a device that helps mitigate the world food crisis. Students were required to define the problem, sketch design ideas, and prepare a poster for their design using the graphic processing software they had learned. A design review was held at the end of the project. All the posters were pinned on a wall; every student went up to give a brief presentation about her design, including the specific problem she chose to address and her proposed solution. A number of students targeted the shortage of clean water in the world and designed devices to generate or transport clean water. However, a number of students who worked on water projects imagined African countries as their primary users and presented their problem statements somewhat similar to "I designed … that can be used in African countries where people have difficulty accessing clean water." After hearing such statements for several times, Mr. DD, the STS graduate TA, interrupted a student when "African countries" appeared in the presentation once again. Mr. DD pointed out the lack of clean water was not unique to Africa, nor were all African countries short of water. He told students some African countries actually had a quite high GDP. In order to avoid stereotyping Africa; Mr. DD suggested students use "some developing countries and regions" to represent their potential users.

When I worked as a TA in Studio Three and Studio Five, I did not receive clear guidance on facilitating students' exploration of the societal aspects of design. My "STSish" intervention was often impromptu. On a number of occasions I was commended by the STS instructors after I had called into questioned the potentially problematic assumptions reflected in students' design or comment in class. In Studio Three, the first project asked students' to make a poster that communicates the lessons for good poster design. It was an exercise of iterative thinking, which Prof. DA liked to have students do. Three of the final posters included human figures. One poster mocked up the cover of the Life Magazine and used Prof. DA's face to represent a competent designer. The second poster showed a white male college student whose head spouts ideas about poster design. The third poster displayed a black person wearing a tight suit; the message was a poster has to "fit." The poster did not show the face of the person, but the body shape and dressing style implied a black male. After the class had critiqued the clarity, visual appeal, and other technical aspects of every poster, I raised my questions: Why was there no female figures in the posters? What assumptions about design were implied in the absence of female figures? I especially highlighted a comment that had been made by the authors of the second poster, who had explained the male figure in the poster as a representation of "a typical college student."

5.2.6 Design in context

PDI students are often encouraged to start problem finding by studying and analyzing the context of their design. In Studio One, Prof. DB insists on students studying the users and their lives. In the exercise of designing a solution to the use of plastic bags, Prof. DB sent students to grocery stores to observe and interview the consumers to find out their shopping habits. Students reported their findings in a later class. One student went to shop in Rite Aid herself and reported she was given two plastic bags for three cans, which could fit perfectly in one bag. Another student noticed in a bookstore that no matter what one bought, the cashier indiscriminately asked the customers whether they needed a bag. A student in Walmart found the cashiers just gave people bags without even asking. When students presented their design solutions, Prof. DB asked a series of questions in search for detailed information about the users: What are their genders? How old are they? Do they have kids? Where do they work? Where do they live? How often do they shopping? What do they buy? Students started their presentations by introducing scenarios in this general manner: "My targeted user is a thirty year old single lady called Jennifer. She lives in a city and works in a shopping mall five days a week for long hours, so she only goes to the grocery by the subway once a week. As a female, she has difficulty carrying too much grocery home by subway all at once, so instead of designing a substitute for plastic bags, I plan to design a grocery delivery system. With this system, Jennifer can do her grocery shopping online, and the store will deliver the goods to a communal center near her home. She can pick them up when she is free." The solution proposed in this presentation diverted from a substitute for plastic bags. Such diversions were encouraged, as Mr. DD once told the students: "You are not talking about plastic bags unless it is a way into food, nutrition, and other things."

Every studio course includes regular readings and discussions at the beginning of each class session (usually during the first hour of the three-hour class meeting). Reading and discussion provide opportunities for students to explore and reflect on the broad political, cultural, and historical contexts of design. Prof. DB required every student to spend twenty minutes every day reading news. He also illustrated how he found inspirations from reading the *New York Times* and listening to NPR, and how learning about people's struggling cultivated his empathy. He cited IDEO's executive that empathy was an essential character for designers. In other studios, students' read books and articles about the historical, political, and organizational contexts of design.[80]

5.3 Technosocial integration

5.3.1 Synthesis in design

As an interdisciplinary program, PDI differs from HMC and Picker in an important way as regards the integration of engineering and liberal learning: in PDI, students learn the technical, social, and artistic knowledge and skills simultaneously, rather than through parallel engineering and liberal arts curricula. The design projects in the studios entail the synthesis of various knowledge, techniques, and methods. To be sure, students tend to emphasize particular technical, social, or artistic features of their design according to their personal styles. To meet the required design objectives, however, students often have to integrate diverse ways of thinking and making.

In the fall semester of 2012, the major project in Studio Five was to design an educational product for a group of fifth and sixth graders in a local community charter school. The project illustrated the central philosophy of PDI education: multi-level integration. The course taught knowledge, techniques, and ways of inquiry from a variety of disciplines. The scope of the project included user needs analysis, concept design, testing design iterations, visual and physical presentation; it also included reflection on the social and political implications of design work. Throughout the project students interacted with different "stakeholders:" guest lecturers, elementary school teachers, and the end users—the children in the community charter school.

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[80] Readings in Studio Three have been discussed on Page 134, and readings in Studio Five will be introduced on Page 151. "Design, Culture and Society," a required STS course to the DIS majors, is also geared to raising broader questions about design. In one version of the course, for example, the instructor emphasizes the ways in which nineteenth and early twentieth century designers either resisted or welcomed the coming of "The Machine."

Many of the children came from families with lower socioeconomic status; the majority of them were ethnically African Americans or Latinos. Design for this user group posed unique opportunities and challenges for PDI students to grapple with the politics of design and broad questions of economic and educational inequality. Direct contact with the children also revealed to PDI students the importance of cultural sensitivity, communication and observation skills, and the subtle implications of design choices, such as the racial and gender representations in design.

The course consisted of readings and discussions, sociological and technical lectures, field trips to the charter school, open studio time, and in-class presentations. The course began with reading and discussing articles on racism in science, educational inequality, and methods for educational research. The first reading assignment examined how racism influenced biological and psychological research on Intelligence Quotient in history. Following that reading, the instructor Prof. DC gave a lecture on the history of and problems with biological determinism in science. In the following discussions, students commented on the biases and ignorance in science. One student also called into question the narrow definition of intelligence in scientific research, which excluded other important wisdoms, such as surviving skills. Prof. DC introduced the concept of "social construction of science" to students during the discussion.

Students also learned a number of technologies in Studio Five. Guest speakers were invited to give lecture about Flash, MIT Inventor Studio (a free program to write Android smartphone apps), open source software licenses, and so on. Prof. DC also introduced the use of Arduino. Many students had not heard of these techniques before, but they quickly learned and applied them to their projects. Four of the eight final projects used Arduino; one team used Flash; another team wrote an IPad app.

In order to help students think about the relevance of mathematical and scientific knowledge to different national and ethnic cultures, Prof. DC asked them to use the Culturally Situated Design Tools (CSDT), a series of "web-based software applications that allow students to create simulations of cultural arts—Native American beadwork, African American cornrow hairstyles, urban graffiti, and so forth," using mathematical principles that are situated in various cultural contexts (Eglash et al. 2006). Students were divided into groups. Each group studied one CSDT and prepared a mock-up presentation to introduce the tool, its cultural context, and the mathematical knowledge to elementary students.

The educational objectives for Studio Five include teaching students methods of participatory design. That is, students are supposed to include the end users—the children in the charter school—within the whole process of design: from concept generation to the construction and testing of prototypes. For this purpose, the class made several field trips to the charter school, where PDI students studied their users' learning needs, documented the children's responses to and comments on their design iterations, and during the last field trip, evaluated the effectiveness of their products. Preparations for the field trips included reading design literature on user participation and basic training in ethnography. Before the first field trip, Prof. DC gave a mini-lecture about ethnography and other qualitative social research methods. Prior to the lecture, students had read a handout on "Qualitative Social Science Methods in Design" and a one page mock up entitled "What is Ethnography" written by a former graduate student in the STS department. Prof. DC explained ethnography to students as "deep hanging out." He gave a number of examples of how qualitative social research was used in design work, especially in identifying user needs. After each field trip to the charter school, students were required to write ethnographic field notes, in which they summarized what they had learned about and from their users.

5.3.2 Technocracy: A game of power

Before I conducted careful study of the teaching and learning in PDI, I had been often taken aback by PDI students' views of technology, which were at odds with the kind of sophisticated, reflective assessment endorsed by STS education. In the discussion sessions of "Science, Technology, and Society," some PDI students appeared personally offended, at times more so than the other majors, when critical examination was suggested toward technological totems such as Google or Apple. Observing in PDI studios and talking to PDI students outside classrooms provided me with more clues to understand their relation to the concept of technology. These experiences also taught me not to take for granted PDI students' identities as STS-majors but to reexamine their self-identification in their own terms.

I will discuss PDI students' self-identification more extensively in the next section. Here I merely want to point out most students identify themselves as "designers," an identity that is often distinct from the "social analysts of design" envisioned by STS faculty. Presumably most PDI students are aware of their differences from the industrial designers, yet they share with the latter in their pursuits of ambitious, idiosyncratic (artistic) visions/ideals of design (Woodham 1997). The primary distinction between PDI students and the idealist industrial designers in this regard is probably the latter focus more upon the form of design (the shapes of useful objects), whereas PDI students' visions of design are articulated at more diverse levels: aesthetic as well as technical and functional features. In every studio, there are some students who march toward actualizing their personal design visions without accommodating the users or the context in which their products will be used.

My understanding of technocracy was renewed by observations of those PDI students who persistently pursued their own visions of design at the expense of other concerns. I am not suggesting that PDI students appear more "technocratic" than engineering students in general. Arguably PDI students show more sophisticated understanding of technology than typical engineering students; they are also more willing to engage the social context in their approach to problems. However, the co-presence of the "technical," "social," "artistic," "creative" threads of education in PDI provides a unique opportunity to examine the dynamics between these educational approaches. In PDI studios (as well as my other case studies), technocracy appeared less as the dominance of a particular (set of) technology than as a system to organize power. By automatically giving privileges to particular ways of thinking over their alternatives, the technocratic viewpoint limits the scope of inquiry and accelerates its closure. In other words, I perceived technocracy less a conscious calculation of (technological) rationality or efficiency but more a system of distributing ideological power. For example, in the process of solving design problems, students' choices between more technology-centered and more comprehensive approaches depend not so much on the efficacy of an approach to solve the problem as on which approach is "empowered."

An important source of empowerment or the lack of comes from the instructors, especially the more "charismatic" ones. In Studio One, Prof. DB acted as a great source of inspiration to some students and a significant constraint to others, depending on the design philosophy one chose. Prof. DB embraces a vision of design that blends progressive social values, conscious but limited engagement of context, benign entrepreneurship, and flamboyant rhetoric of the glory and omnipotence of technological invention. He cordially encourages (using) the power of technological creation and goodwill entrepreneurship to improve society and the environment, with his often repeated motto "putting people and planet ahead of profit." His own educational and industrial experiences have revealed to him the important role of the users; hence he always insists on starting the problem analysis by understanding users and their lives. However, his engagement of context does not go very far beyond economic impacts, trends in technological industry, and in some cases, the environment effects. Political, cultural, and even macro-economic mechanisms that contribute to the creation or persistence of the problems confronting designers rarely appear in Prof. DB's lexicon. The examples of great innovations Prof. DB gives concentrate on revolutionary products, but he hardly urges students to examine how a great product garners support or how the inventors sometimes seek to rearrange necessary social conditions for their products to take effect. The legend of Ecovative Design, which Prof. DB told time after time in Studio One, focuses on the co-founders' personal initiative: their pursuit of novel ideas for product development and their smart marketing strategies. Suffice for a designer who wants to create the next award-winning green product, I suppose. But for the purpose of educating innovators who could identify crucial environmental challenges and create positive, effective, and enduring solutions, the absence of any attention to the political and economic conflicts on climate change or to viable business models for the spreading of high quality but little known product struck me as alarmingly inadequate. Prof. DB's vision reminds me of the technocrats in the Progressive Era who wished to transcend political and economic struggles by creating technologies whose superior qualities would satisfy all parties and silence all petty political debates and quarrels (Layton 1986, Akin 1977).

Prof. DB also promotes the image of heroic, ahead-of-time individuals who bring about great social advancements with their genius. He encourages students to be radical innovators and takes pains to eliminate any limits on their thinking. In Studio One, courageous thinking, even not grounded on technical and social realities, was cordially welcomed and praised. In a conversation with me, Prof. DB expressed his opposition against teamwork at the early stage of design learning. Here is his reason: before the spirit of fearless and resolute pursuit of innovation has been firmly established on students, individual students with great and radical ideas might be too often turned down by their uninitiated teammates. Therefore, Prof. B discouraged students from questioning and criticizing each other's design ideas in Studio One. It might not have occurred to him a "techno-triumphalist" ethos was clearly empowered in Studio One, whereas critical examination seemed "regressive" and became disempowered.

5.3.2.1 Technology as an omnipotent black box

In PDI studios I also developed a compelling feeling about the way many students thought about technology. It occurred to me that students often did not "enroll" concrete technologies in their thinking about design problems; instead, they conceived technology as an omnipotent black box that could be inserted into a situation to achieve desirable outcomes without further reflection or analysis.[81] The inclusion of what amounts to a magical black box technology in design thinking was encouraged in Studio One. Students were not required to know how the proposed technology actually works, and

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[81] The philosophy behind this approach implies ignorance of "constraints" in design thinking. This is very different from the engineering design education at HMC, where "constraints" are an essential factor emphasized throughout the class. The first design project especially highlighted the constraints by asking students to work in a survival scenario.

often times the functions designated to the "black box" could not be met by existing technologies. In this way, students were freed from the burden of mastering the numerous technical details (a burden that could have paralyzed the freshmen) and were enabled to focus on designing a system or device with few if any encumbrances.[82] One might expect this teaching philosophy to direct students' attention away from the technical details to the contexts, users, and the functions and systemic features of design. It worked that way partially. However, an unintended consequence stood out: it encouraged among students a tendency to ignore technical (as well as its relevant social) realities and constraints. The teaching philosophy meant to free students from mental blocks in the end contributed to the rise of groundless triumphalism among many students, who thought they could solve any problem with their bold (but naive) ideas because technological advancements would sooner or later achieve what they envisioned. Consumed by such wishful thinking, they often forgot to consider how the non-technical factors might be mobilized to accommodate the technical advancements they hoped to realize or to anticipate both opportunities for and barriers to such advancements that a broader vision might provide. The question becomes: Is it good to indulge such expectations at the very beginning of PDI education, expectations that are already part of the mythology of immaculate creativity that has long been central to American understandings of technology or design? Or would it be preferable to begin teaching the contexts and complexities of design and engineering that have been revealed during the past several decades of research and theory in STS?

Moreover, many students' utopian visions of technological future, the outcomes of their free imagination, turned out to be very narrow. Students in PDI studios often leaned some imaginary, mythical smartphone (tablet) apps as the panacea design solution. Watching students strip the complicated social, natural, and technological factors from their design problems to fit them to answers of imaginary apps (most likely apps that collect "big data") reminded me of an ironic fact: even after their were freed from

[82] This educational choice in part reflects an iterative design process in which divergence and convergence happen alternatively. In Studio One the focus is to help students "diverge" their thinking, so that they can "converge" in later studios.

constraints placed by the instructors, their imaginations were still largely informed by and, more importantly, limited by a few "trendy" technologies fed to their minds via everyday lives and popular media.[83] At some level these dreams and fantasies are helpful in students' motivations and sense of self-identity. At the same time it is true that a good education in design and engineering must seek to reveal other crucial dimensions of what such work involves.

On December 6, 2012 students in Studio One presented their final design projects. The final project started with a series of class excises to identify and solve problems within the American educational system. Toward the end of the semester students were given the liberty to continue their design for the educational system or to divert to any problems they deemed important. Students were required to present the problems they tried to tackle and their proposed solutions. Prototypes and sketches were encouraged, but no actualization of the design ideas was required. Twenty-five individuals and groups of students gave presentations; twelve of them proposed a smartphone or tablet app, accessory, or a computer program to solve a broad range of problems: teaching critical thinking, monitoring health data, visualizing lectures, monitoring student learning, cancer detection, diabetes treatment, enhancing professional skills, releasing pressure, among other things.

The first group of presenters targeted the lack of critical thinking in American public education. Their solution was a tablet app that teaches critical thinking by having students watch videos or TV shows and answer questions. When the audience asked what type of critical thinking questions would be included, the presenters fumbled a little and suggested they would look like SAT. Another student designed a health data monitoring app for people in small business, hoping it would provide low cost healthcare to less affluent clients. One from the audience pointed out that the designer had assumed less affluent people could all afford iPhones. Prof. DB interrupted the comment and

[83] Again, these are likely brought with them from expectations common in American culture (and perhaps other cultures) in which technological "innovation" and clever design "apps" are regarded as the great wonders of this historical period.

reminded "we are doing plus here, not critical." Another student, with a little mocking tone, suggested the first audience ask his question in a "plus" way, so he did: "this (idea) is so good. How can we make more people have it?" The presenter admitted he was basing his design mainly on the U.S. context, where most adults have access to smart phones. Prof. DB praised the designer for boldly challenging the status quo; he thought the design fantastic and asked the class to "recognize it first and support it."

5.3.2.2 The struggle to push forward technocratic visions

There were occasions when PDI students who attempted to pursue their design ideas regardless of contexts, constraints, and other stakeholders encountered push-back. In Studio Five I observed two students' failed attempts to impose their own vision of learning upon the users through designing an educational product. The process highlighted the designers' constant struggle to gain power over their users in defining the proper meaning and functions of the product. From the very beginning, Mr. D9 and Mr. D10 were determined to pass their own enthusiasm toward math and science to the children in the charter school. Mr. D10 was a technically savvy student. In the studio, he often gave advices to other classmates when they encountered technical challenges. During the first field trip to the charter school, most teams planned "kids friendly" group activities to interact with their users. Mr. D9 and Mr. D10, however, each brought their own "prompt devices." Mr. D9 showed the children a collection of mineral rocks to start their conversation. Reflecting on the experience afterwards, Mr. D9 reported the children got too excited by the colorful rocks and did not pay much attention to him. Thus he recognized the importance of establishing himself as an authority figure in order to gain control: "The first of all lessons to learn was to know how to grab the students' attention if there was an objective at hand. If a *sense of authority* (emphasis added) was not established at the start, you were treated as another student, with nowhere near enough respect for the students to listen properly."[84] Mr. D10 was the only PDI student who brought Arduino to the charter school during the first field trip (others brought devices more common for the users' age group: play dough, color pencils, etc.). Mr. D10 wanted

[84] Unpublished student reflection paper.

to see how children react to a technological device. He demonstrated to the children how to control LED lights using Arduino, from which he found the children curious about the device and his project.

During the second field trip, Mr. D9 and Mr. D10 brought some circuits to the charter school. This time they found the children were interested in the circuits, but not the math game the two of them had designed: "We learned that how much info we require the students to learn depends on how interesting the subject is, and math was not interesting enough." In the meantime, "[e]stablishing authority and creating order was not an issue, but keeping attention up after the subject was introduced was the next issue to be resolved" (Ibid). In their ethnographic writing, Mr. D9 and Mr. D10 reported their painstaking efforts to make sure the children actually used the resistance to build circuits instead of "goofing." Mr. D9 was especially frustrated when the children did not build circuits as they had planned. In their proposal for the final design, Mr. D9 and Mr. D10 planned to use electric resistance to help the children understand the idea of electrical circuits. Instead of including a heavy dose of math in their device, Mr. D9 and Mr. D10 proposed to build pipes and use the metaphor of water flow to visualize how resistance works. Following the proposal, Mr. D9 and Mr. D10 made slight changes to their plan in order to create more context for the circuits presented to the children.

For the next field trip, Mr. D9 and Mr. D10 brought to the charter school a big paper box they had made for the children. On one facade of the paper box were placed various poles. The children could make circuits by connecting wires and resistances between the poles, but the circuits were hidden beneath the façade. I asked Mr. D10 whether the children understood the concept of dividing electricity with resistance. He told me it was not their main focus; they focused on observing which formats of connection were preferred by the children. The children seemed more interested in playing with the connections, but a somewhat peculiar pattern emerged. Mr. D10 was teaching some children how to connect the circuits while Mr. D9 took notes for their ethnography. Two girls in the group were sitting at the far corners of the table and were not paying attention to the circuit box: one of them was reading from a piece of paper filled with handwriting; the other girl walked to and fro the table. After a while, another girl who sat next to the box showed interest in what was going on inside the box, where the circuits were installed. Mr. D10 was delighted and showed the interior of the box to her, but she lost her interest quickly. Eventually the girls sitting at the far end showed interest to the box and kept staring at it, but it was out of their reach. I wondered what would have happened had Mr. D10 moved the box closer to them.

Overall, the third field trip seemed a vote of confidence to Mr. D9 and Mr. D10's more accessible design: "After seeing how the math portion of education can be devastating to keeping the students' attention, we aimed for a more intuitive device, only requiring that wires be connected, no math necessary." Mr. D9 and Mr. D10 were encouraged by their users' cordial reception, but they were not ready to give up their initial vision: "The students were having fun and learning at the same time, but we questioned if they could be learning more. At some points it seemed as though the students were just randomly plugging in wires without thinking, which is not necessarily bad, but displays a major lack in any analytical thinking which should be part of the education process (using both hemispheres of the brain, thinking creatively and analytically, for a truly intuitive experience)." In the end they decided "math needed to make a comeback through a simpler medium" (Ibid).

In a presentation following the third field trip, Mr. D9 and Mr. D10 proposed a significant change in their design philosophy. They planned to develop their final product as a tool for experiential learning, which would help the children experience everything and see how circuits work visually. The proposed product was a "circuit city" with houses, speakers, and a ferris wheel. The new device was envisioned as a gaming platform, and the children would be in charge of powering a section of the city. I was very impressed by this change and asked how they made the transition from a math-focused to a more accessible design. Mr. D9 said they found during earlier field trips that the children didn't want to or weren't quite able to do the math, so he and Mr. D10 sought to preserve the educational value while making the device more accessible to the children and giving them more options. It was a moment when I seemed to perceive the power of participatory design.

Their final product, however, took a sharp turn toward math challenges. It was a model city with power plugs. Connections between plugs were marked with fraction numbers, and one had to calculate the fractions in order to light up a building or turn on a motor. To help the children with the calculation, Mr. D9 and Mr. D10 gave everyone a worksheet. After hearing the instructions, one kid immediately said, "That's very difficult." From what I saw, the children just tried different connections randomly without doing the math. In their final presentation, Mr. D9 and Mr. D10 explained the change. They had learned from the teachers at the charter school that teaching fractions was the most difficult challenge, so they tried to undertake that challenge in their design. Mr. D9 and Mr. D10 were confident that their device could be used to teach "anything." The core of their device was built around Arduino, which "can speak the language of math." With the support of Arduino, they had thought one only needed to put any object of teaching at the facade of the device. During the field trip, however, Mr. D9 and Mr. D10 found the children "intimidated" by the math challenge, and few of them used the worksheets. The biggest issue with their design, thought Mr. D9 and Mr. D10, was that it fell out of the children's "zone of proximal development," a concept reiterated in the studio class (Vygotsky 1978). Thus the emphasis of Mr. D9 and Mr. D10 upon math challenges did not actually engage the children in the classroom. What approach might have been more successful is a question that the two PDI students would need to ponder.

5.4 Designer: A distinct identity

Critics of PDI argue that the students do not learn enough social analysis. The STS faculty who have taught in the studios often come to realize the need to negotiate their identities as STS scholars. Those who encountered PDI students outside the studios, for example, in "Science, Technology, and Society," or in the STS "Senior Project," are sometimes struck by the lack of apparent traces of STS education on them. As I suggest above, the impression about PDI students' lukewarm engagement with STS as an academic field of study is by and large accurate. A critique of the STS education in PDI, however, has to face the challenge of relevance to what the program currently stands for. Through interacting with PDI students in classes, informal conversations, and interviews, I find the primary identity PDI students develop is not social analysts or design critics but of practicing designers. From the students' point of view, they are not very likely to become the kind of people who write *Where Stuff Comes From* (Molotch 2005) or *Twentieth-Century Design* (Woodham 1997); it's more likely they become the people written about in books of that kind.

The image of a designer shared by PDI students is quite unique to this program. Unlike the industrial designers who care primarily about the aesthetic or formal dimensions or the engineering designers who focus on the technical mechanisms of functionality, PDI students engage design at multiple levels: they are artists who enhance the physical grace and beauty of products, engineers who work out and integrate various technical systems, anthropologists who read the culture of users and consumers, managers who coordinate the operation of project teams; but above all, they generate ideas and actualize them in the finding and solution of practical problems. Most students play all of these roles in the studios, although everyone accentuates different aspects: some highlight artistic skills; others demonstrate extensive technical knowledge; some are master coordinators; others excel at initiating new ideas.

In PDI studios knowledge and insights from the scholarly field of STS is often translated as part of a body of design knowledge. For example, study of a product's social history is taught as a research method and is often utilized in initiating design projects. Ethnography is introduced and practiced as a way to identify user preferences and to collect user feedback. Readings and discussions of STS theories and analyses, while media to provoke critical analysis, also help improve students' communication and other professional skills.

The students who have a dual major in engineering also seem to maintain a clear distinction between their identities as designers and engineers. When engineering learning is brought into discussion within the studios, it is often presented as a contrast to design learning. While a lot of students credit their engineering learning for providing the technical expertise that is applied to design projects, students seem to see few impacts of their design learning on the way they approach engineering. While most students are used to the open-ended design inquiries, such experiences do little to loosen or challenge their faith in the conventional view of engineering as rigorous, black-and-white problem solving. As I discuss more extensively in the next chapter, when PDI students reflect on their knowledge acquisition in college, they often attribute the professional skills to learning in PDI and the technical knowledge to engineering learning.

5.4.1 Placement and recognition

Despite their intensive experiences of studio and project based design learning, the presentation of PDI students to employers focus primarily upon their professional savvy. After all, with a few high-profile exceptions, most PDI students find jobs in traditional industries, where they stand out with their skills of communication, presentation, and time management, but according to the interviews I conducted with PDI students who had had intern experiences, they were given little space to apply their design expertise. In fact, interviews with students suggest to me employers are not very concerned about their design expertise.[85] Students also reported employers are sometimes confused by the DIS degree, a social science degree in design.

5.4.2 Solidarity

In contrast, the design identity is widely accepted inside the program; this shared identity also helps establish a strong bounding community among the PDI students. A strong sense of solidarity is fostered among the PDI students who take classes and work on

[85] Although some PDI students did not work on design projects during their internships, the experience of working on open-ended and team-based design projects in PDI help them in other critical ways at work, such as “read” the context at work and take initiatives. The value of PDI for students’ professional preparation is more extensively examined in Chapter 6.

projects together in the same room for four years; some of them identify more strongly with PDI than with their other majors. Because the studio room is shared by all PDI classes and students not infrequently take a studio course with a different cohort, different cohorts are well mixed. Hence the solidarity is not confined to a single class but bounds the entire program.

A number of students who are emotionally invested in PDI feel it under-recognized outside the program. Hence the students made several attempts to promote the program to prospective students and to colleagues in design education. On December 7, 2012, students in Studio Three presented their final design. The students did not leave immediately after the presentations finished. Two senior PDI students came in the studio to make an announcement. Mr. D11 and Ms. D12 told the presenters they had developed a Design Contest to encourage high school students to study design. The contest grew out of a course project in Studio Six, where the students were required to design an entrepreneurial initiative to promote PDI. Mr. D11 and Ms. D12 felt PDI was underappreciated by college applicants, so they envisioned a design contest to boost PDI recruitment. Every year the contest would present a design challenge to interested high school students, and the winners would be provided with a scholarship to visit PDI.

Having finished the course project, Mr. D11 and Ms. D12 took the idea into action. They set up a website for the contest and created the challenge for the coming year: redesign a public water fountain to solve its sanitation issues. They had also contacted PDI alums for donation. As both of them were graduating the next year, they came to recruit PDI volunteers who would continue the contest for the following years. They also asked the students to promote this contest in their high schools when they went home for the winter recession.

5.4.3 Ungrounded designers

From my experiences teaching and observing in the design studios, I perceived a peculiar mentality among many a PDI student. For lack of a better term, I call it a mentality of “ungrounded design.” It is embodied in students’ imagination of their design expertise as omnipotent and universal. This imagination might have been partly empowered by the consistent support from the instructors, who encourage students to undertake unknown challenges by self-guided learning. It might also have been fueled by a politically driven design philosophy reiterated in the studios, which holds design should be universal so that no user groups would be excluded. Yet I detected a more problematic undercurrent that assumes a designer could utilize the same set of design skills to tackle any problem without developing proper domain expertise or deeply engaging the local situation; as if a designer could walk into an unfamiliar field, applying problem finding and solving skills (e.g., identifying user need, optimize function, etc.), and walk away with admirable achievements.

There were numerous demonstrations of the “ungrounded design” mentality in the studios. The students who designed the “critical thinking app” focused upon a “neutral” medium and failed to question the meaning of “critical thinking” or the pedagogical tools to teach it. The fact that the designers chose “answering questions” or “SAT style tests” as the formats to teach critical thinking suggests they might not themselves have had very effective education in critical thinking. Similarly, the all-too-often proposals to improve healthcare with a health data monitoring app repeats an unexamined faith in a popular and generic solution, a tech fix, without serious attempts to study medical knowledge or the social, economic and organizational challenges of healthcare.

Mr. D9 and Mr. D10’s attempt to undertake a difficult educational challenge—teaching fraction to children—was also based on the versatility of an electronic device (Arduino) and a groundless belief that their product could be used to “teach anything.” Their design vision implied a mechanical model of learning: knowledge could be mounted at one end of a learning device and transmitted to students at the other end. Had they studied more learning sciences and educational theory, the flaws with the mechanical model might have been more salient to them. The problem they encountered and were not able to solve was how to engage students in a kind of learning that the students (for whatever reason) were not ready to embrace.

5.5 Conclusion: Tensions for integration

Unlike HMC and Picker, where liberal arts education is implemented through a "stand-alone" curriculum with little connection to students' engineering learning, PDI synthesizes engineering, arts, and critical social studies in design learning.[86] While the engineering and the liberal arts work together in the design studios to forge a body of hybrid design expertise, a series of limits and tensions arise from the simultaneous presence of different disciplines, pedagogies, and design philosophies. An examination of these limits and tensions might be illuminating for educators who attempt to bring together engineering and the liberal arts in more direct contact.

5.5.1 Limited context and ungrounded design

Earlier in this chapter I have suggested that PDI students' engagement with broad contextual factors of their design problems is limited from an STS point of view. Analysis of the "context" in studios often concentrates on the direct "users" of the designed products and scenarios of their usage; students seldom go beyond to scrutinize the social mechanisms that contribute to the formation of problems or to envision the necessary social arrangements required for their products to take effect.

Some of my STS colleagues attribute PDI students' limited understanding of context to the inadequacy of social sciences education in the studios.[87] Indeed, PDI's reputation as a successful design program has at times overshadowed its identity as a program for the social studies of design; social analysis in the program is often translated into an instrument for design research and its critical perspective is underemphasized. For example, the way most PDI students conceptualize the "users" gives little thought to the notion of users as equal co-constructors of design as STS scholarship has suggested

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[86] At HMC, the curricula are coordinated by engineering and HSA faculty at the college level, but the actual teaching of HSA courses resonates little with students' engineering learning partly due to the HSA department's decision to teach "authentic" liberal arts. Picker primarily delegates the liberal arts education to the non-engineering departments. While HMC arguably has more coordination of engineering and the liberal arts, neither institute has much integration of the two branches of learning at the pedagogical level.

[87] PDI students are required to take the same credits in STS courses as in the design studios. It is therefore worth questioning how well the STS courses help PDI students develop coherent social understanding of design.

(Jasanoff 2004). Instead, the "users" are often treated as data sources, from which students could mine information in order to set design objectives and product features. On the rare occasions when students confront their users directly, such as the ethnography exercises in Studio Five, a few students come to reflect on the power dynamics between the designers and the users. In most cases, however, students are given neither the structured space nor the social scientific language (e.g., reflexivity) to carry out reflection of this kind.

Instead of becoming critical social analysts of design, as the vision of a DIS degree suggests, the image of "ungrounded designer" seems to play a more dominant role in students' self-identity. This identity is partly based on a belief in the omnipotence of universal (and in many cases, the technological aspect of) design expertise and the confidence that PDI students could solve problems in any field without appropriate domain expertise or profound engagement with the local situation.

The limits in students' contextual thinking are partly related to the structure of the program. To begin with, PDI focuses on teaching a generic and iterative design process. Within seven studio courses, there is neither the teaching resource (none of the faculty were professional designers) nor the time to cultivate profound domain expertise without compromising what is currently highlighted: knowledge about the diverse aspects of design and the multiple technical, social, and artistic skills. Secondly, due to the limit of time, cost, staff, etc., in most projects students work for imaginary rather than real users. The presence of few visible users weakens the challenge to designers' assumptions.[88]

5.5.2 Philosophical tensions

It is possible, perhaps even likely, that the multiple educational objectives PDI strives to achieve may be in conflict with each other. In particular, some of the central philosophies undergirding PDI's design education seem to undermine the objective of

[88] In Studio Five the students did encounter real users and were challenged by them, although some design students assumed superiority over the children. The users, due to their ages, lacked the ability to challenge the designers in articulate ways. They expressed themselves more through their reactions to the designers.

educating more contextualized and reflective learners (Baxter Magolda 1992, King and Kitchener 1994). Most faculty and students appreciate the "openness" of PDI education. With rare exceptions, PDI students define their own projects instead of being told what to do. This open philosophy benefits the program in a number of ways. For one thing, it encourages students to take initiatives in their learning and provides a radical alternative to the conventional style of engineering teaching. The latitude given by this open educational philosophy also help remove the "mental blocks" students often uphold and facilitate their transition from a linear model of learning, which is common in engineering programs, to a process focused, reiterative model of design learning. However, the "openness" of PDI also poses challenges for "STS intervention" in design education. As I discuss above, the need to identify the appropriate domain of expertise relevant to particular situations and issues seems at odds with an open and limitless design philosophy.

The focus on the design process also implicitly prioritizes a culture of "doing/acting" over "thinking/analyzing." I shall point out that because PDI represents a minor, alternative paradigm of education, it perhaps takes every effort to rid the students of the hesitations and taboos they have inherited from traditional teaching and to embolden them to proceed in the design process. As a result, not finishing the design projects (e.g., not delivering the prototype) is almost always considered a salient failure in the studios. It becomes increasingly clear to the students that less thoughtful design could be improved afterwards, whereas overthinking would definitely kill a design project. The tension between "doing" and "thinking" in a way reflects the different approaches emphasized in engineering and social sciences. The orientation towards action seems inherent in the engineering culture/mentality. The rhetoric and discourses of the engineering profession indicate engineers' zeal for visible and material changes, which are deemed embodiments of engineering intervention. In other words, the engineering mentality assumes that changing, and, accordingly, *improving the material aspects* of the status quo is the ultimate goal of one's work. Social analysis, in contrast, often starts with *improving our understanding of* the status quo and assessing the possibilities, benefits, costs, and risks of proposals for change.

5.5.3 Structural tensions: Engineering vs. STS

The structure of PDI adds another layer to the philosophical differences between the engineering and the social scientific approaches in the program. Earlier in this chapter I suggested that the engineering faculty in the program very assertively press for their visions, eagerly transferring to students the "right" conceptions of design: disruptive innovation, solid functionality, etc. The STS faculty, on the other hand, focus more on developing students' own agency of critical and reflective thinking, not only on design but also on their learning experiences. For that matter, the STS faculty in PDI teach in a more invitational manner, carefully avoiding imposing their ideas on students. The different pedagogical approaches taken by the engineering and the STS faculties creates an asymmetrical power relation in the design studios: students receive a loud and clear message about the engineering vision of design, while the STS vision is more sinuous, suggestive and often seemingly indifferent.

Beyond that, the asymmetrical power relation between the engineering and the STS visions in the studios does little to offset the mainstream thinking prevalent in the engineering departments and the college at large. At RPI, a well-known engineering school, the meaning of engineering, or rather, the conventional, "engineering" interpretation of engineering seems straightforward. Sports teams are nicknamed "the Engineers." The college bookstore is filled with mugs, Hoodies, and sweatpants with bolded prints "Engineers." Some PDI faculty from the engineering departments suggest design is essentially an engineering issue. As an educational model that integrates engineering and the liberal arts, PDI presents a minority (alternative) vision of engineering education and design learning. It would be reasonable to assume the success of a minority vision calls for special strategies of self-empowerment in order to destabilize the dominant, conventional, and overarching vision. In other words, the minority vision PDI aspires to promote needs extra power to compete with the mainstream understanding of engineering education on campus. However, the STS faculty in PDI undertake the double-task of establishing an alternative/minority paradigm while at the same time creating a more equal power-relation between themselves and the students. The basic rationale is this: as students are liberated (empowered) from the doctrines and values spoon-fed to them, they would be able to make decisions for themselves and be drawn to a freer mode of education. In practice, however, the intellectual space created by the more accessible STS approach was often (and very quickly) seized and filled by the more powerful and dominant one, which further reinforces its impacts on students. The STS faculty's predicament provides a concrete example of the dilemma facing critical/liberation pedagogy: in a context where the dominant (oppressive) and alternative (liberating) visions co-exist, presenting the alternative vision in an accessible, non-oppressive manner might pale when confronted relentless assertions of the dominant vision. Here we see a clash of cultures—social scientific aspirations to reform the education of technical professionals faced with the deeply rooted traditions of engineering.

5.5.4 The way forward: The "trading zone" hypothesis

Amid a recent initiative to review PDI, serious concerns were raised about the quality of STS education in the program. Borrowing Galison's (1999) notion of a "trading zone," one STS faculty recommended a more fluent understanding of STS in PDI. My communication with PDI students suggests the "trading zone" a more promising and relevant conceptualization of PDI at its current stage. As I will indicate in the next chapter, PDI students do embody significant differences from their engineering peers with regard to the breadth of their understanding of education, their ability to reflect on their learning experiences, and professional skills (communication, teamwork, etc.).

However, if the STS educators were determined to further enhance PDI students' social analytic skills and political savvy in the long term, several changes might be worth trying. One of my findings is many PDI students cared little about the social science components when they chose to join the program. They were attracted to PDI by the creative and artistic aspects of design, the hands-on experiences, or a sense of companionship more than by a social or ethical concern about design. Therefore, more effective changes might come from "tweaking" the demography of the student body. The example of Smith College's aggressive embracement of diversity in its student body is illuminating. As I try to show in the previous chapter, although education in the Picker program by and large repeats the epistemological assumptions dominant in the profession, Smith's institutional culture and a diverse student body become powerful sources of influence upon the experience of engineering students.

I can foresee the difficulty of changing the student demography at the program level without a similar policy college wide. Yet some changes might be achieved by revising the presentation of the program. The way PDI is presented currently highlights its values in the context of the traditional professional culture. The language used in the program description also subscribes to the business-loaded innovation discourse (Winner 2009). Promoting a more socially progressive identity might make the program more congenial to students with different orientations.

6. Student Reflections

This chapter pays close attention to the students in the three programs introduced in Chapters 3 to 5, for they ultimately represent the effects of integrating engineering and liberal education. It is my contention that many engineering educators too readily celebrate what I call the "existential value" of reforms. That is, they hastily praise the idea of implementing, rather than the outcomes, of new ways to educate engineers. For example, nowadays we hear talks of "flipped classrooms" in virtually every conference on engineering education.[89] Alas, very few of these enthusiastic judgments care to explain how students react to the "flipping." In many cases the cheerful priests of the flipped classrooms seem oblivious to the need of understanding students' actual learning experiences with "innovation" of this kind. While I have no intent of fetishizing outcome assessment in engineering education, I believe those who sincerely wish to improve this field ought to seriously and meaningfully engage students—the end users of such endeavors—in conversations about and serious evaluations of their learning needs and experiences.[90]

What I present in this chapter only begins to meet the goal I set above. Although my interviews with students probed various aspects of their learning in college—e.g., choices of major, favored and disfavored courses, homework, projects, internship, etc., I focused on a specific set of (epistemological) questions: What would their ideal college education look like? What do they expect from studying engineering in a liberal arts setting? How do they understand the nature of engineering knowledge? How do they delineate the technical and non-technical dimensions of engineering? In what ways do they see college learning connected to their future?

Engineering students' epistemological stances may shed light on a broad range of questions about the professional development of young engineers. By epistemological stances, I refer to one's beliefs about the nature of knowledge and learning. Engineering

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[89] This educational model is in fact not new; personalized system of instruction gained considerable attention in the 1960s and 1970s (Akera 2014).
[90] Riley (2014) critiques the limitations of outcome/evidence-based engineering education.

students' epistemological stances embody what they consider legitimate engineering knowledge and their objectives of college learning. Scholarship in STS, and especially in engineering studies, reminds us the epistemological frameworks that guide scientists and engineers' professional practice also strongly affect their beliefs about truth, views of proper theory and data, cultural imaginations, collegial relations, and moral views (Layton 1986; Forsythe 1993; Knorr Cetina 1999; Faulkner 2009; Cech and Waidzunas 2011). The literature on engineering epistemology argues that the engineering profession is bound together by a shared body of knowledge (Vincenti 1990). The literature on professional socialization also suggests that an important component in the development of professional identity is the learning and internalization of professional knowledge (Grusec and Hastings 2008; Keltikangas and Martinsuo 2009). Inspired by these findings, I intend—through studying engineering students' epistemological views—to understand the interconnection between their conceptions of engineering knowledge and their formation of the identity of engineering as a profession and, indeed, a way of life (Downey and Lucena 2004; Tonso 2006a).

A bolder thesis, one not yet fully articulated here, concerns the relation between engineering students' epistemological stances and their political and ethical viewpoints. Political scientists suggest the meaning of truth should take into account sociopolitical conditions (Shomali 2010). History of engineering also teaches engineers' epistemological views are shaped by, and in turn reflect, the macro political-ethical discourse they live in. From the vogue of technocratic thinking in the Progressive Era to the revolt against the military-industry complex in the 1970s, answers to epistemological questions—What is engineering? And what counts as engineering expertise?—are always grounded in the political, economic, and ethical landscapes where the social significance of engineering is derived (Layton 1986; Wisnioski 2012). Historians like Alder (1997) and Noble (1979) also provide vivid accounts of how engineering educators translate political and economic imperatives into mundane curricula and pedagogies for training young engineers. Such historical accounts, however, do not fully elaborate the mechanism through which the political-economic-educational complex affects engineering students' formation and change of epistemological stances (e.g., how does consumerism affect students' preference for "tech fix?"). To complete this jigsaw puzzle, we first need to elicit engineering students' epistemological stances, such as their conceptions of legitimate engineering knowledge and ideals of professional education. Then we can examine at a micro level the link between students' epistemological stances and how they are influenced by the structured educational experiences (curricula, pedagogy, etc.).

In order to understand engineering students' epistemological stances, I borrow tools from educational psychologists who study college students' epistemological development. A group of psychologists, pioneered by William Perry, have developed systematic methods to elicit students' epistemological views (Perry 1970; Belenky et al. 1986; Baxter Magolda 1992; King and Kitchener 1994). Some of their work (e.g., Perry 1970) also indicates threads of convergence between students' epistemological and ethical stances. Section 6.1.1 elaborates how I adapted the psychological tools for studying engineering students' epistemological stances and in what important respects my work differs from the psychological literature on college education. Here I merely want to note that, in the main, this body of literature focuses on mapping and categorizing students' epistemological views without dedicated inquiries into the educational components which take part in students' formulation or change of epistemological stances. For example, Perry and his colleagues' classic longitudinal study of Harvard undergraduate students' intellectual development relied on students' self-reporting and retrospection on their college experiences; it contained no observation of the interviewees' actual learning experiences (in classes, assignments, exams, etc.), nor did the researchers deliberately seek to establish connections between students' epistemological views (and changes) and specific components in their learning experiences. Perry (1970) concludes that a generic change (toward maturity and sophistication) takes place among most students over their college years, what he calls "intellectual development," and attributes the development to the overall college experience (or "growth").[91,92]

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[91] Belenky et al. (1986) do discuss the power dynamics that affect women's epistemological frameworks, but its focus is not on schooling or methods of teaching.

Indeed, I have witnessed many college students who display increasingly sophisticated understandings of themselves and their learning as they enter further into adulthood. Yet the specific trajectory each of them underwent during this transition is too complex to characterize in a linear model of development.[93] As I report in Section 6.1.1, students tend to use different frameworks to understand the nature of knowledge in different disciplines (which highlights the need to study students' "engineering epistemology"). Therefore, my interviews focused on eliciting students' epistemological views in their own terms, especially with regard to the relationship between engineering knowledge and its social contexts. My purpose was to capture the diverse perspectives through which students make sense of their engineering learning, not to rank their epistemological stances according to a precise linear scheme of development.

I would propose a further step to forward the study I describe above, one that might be called a "micro-sociology" of engineering students' epistemology. This project will focus on the connection between the formulation and transition of students' epistemological views and the main structure and components of their educational experiences, e.g., widely-adopted methods of instruction, organization of learning environment, the power dynamics between teachers and students, etc. The scope of work in this chapter is narrower than this far more ambitious sociological project. The focus of the current work is on understanding and presenting engineering students' diverse epistemological views. Only on rare occasions have I allowed myself to speculate—based on the occasional clues I collected (which I am reluctant to call "evidence")—on the relevant educational experiences which might have affected the formulation or transition of students' epistemological views. However, careful examination and systematic reporting of students' epistemological views arguably lays the groundwork for a full-blown sociological study of engineering students' epistemological change. I hope that a seed of that kind will be planted by the speculations I offer in the following sections.

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[92] The psychological studies inspired by Perry (1970) for the most part repeat this linear view on "development;" they also stay content with reporting categories of epistemological views without connecting them to specific educational components.
[93] For a critique of the development model of learning, see Lave and Wenger (1991).

6.1 Methods

The research presented in this chapter uses different methods from the previous three chapters; in this section I explain my methods of collecting and analyzing the data.

6.1.1 Interview protocol

In the summer of 2012, I conducted a pilot study on the epistemological stances of five engineering students and six engineering/design dual majors at RPI (Tang 2013). The main purpose of the pilot study was to adapt the interview protocols used in psychological studies of college students' epistemological development. I intended to develop interview questions more appropriate for studying engineering students' understanding of engineering knowledge and its relevant social contexts. The design of the pilot study also sought to overcome two limitations in the psychological literature on epistemological development: first, the psychological studies do not investigate students' understandings of disciplinary-specific knowledge. Second, the psychologists do not ask students to articulate the meaning of the specific "context" of knowledge.

At the beginning of the pilot study, I developed an interview protocol based on the classic studies of Perry (1970). The protocol inquires into students' understandings of disciplinary knowledge and invites them to articulate the particular context of knowledge. The interview protocol was revised based on students' responses during the interviews. As a major revision, I added a request for students to draw a "knowledge map," which proved a helpful prompt for them to articulate their epistemological viewpoints.

I used the final iteration of the interview protocol in this dissertation research (See Table 6.1).

Table 6.1 Sample protocol for student interviews

CATEGORIES	QUESTIONS
Identity	Looking back the past academic year, what stood out for you?

	(Follow-up questions to invite elaboration of influential experiences.)
Learning style	How did you learn about XXX (the name of the program)? What were you thinking when you chose XXX? What do you think about XXX now? (What advice would you give to a freshman who is thinking of choosing XXX?) What (parts of) courses do you find most difficult? Why? What (parts of) courses do you find easiest? Why? What is your most effective way of learning? What types of knowledge is this style especially helpful at learning? What would be more difficult to learn using this style? Why? How do you make up for that?
Epistemology	Can you draw a map of the knowledge you would have learned by the time you graduate from XXX? Have you and others ever disagreed on academic issues? When you and others disagree, do you think someone is right and the other is wrong? How did you settle the disagreement? Can you give me an example? Have your professors ever disagreed with each other? Give me an example please. How do you choose when they disagree? Has their disagreement affected you in other ways (e.g., grades)?
Conclusion	What is your career goal? Is there something you wish you could have but didn't learn here? Are there any questions I should have asked you? Do you have any question for me?

6.1.2 Samples

A total number of thirty-one students were interviewed for my research here (including six PDI students interviewed in the pilot study). For the present chapter, I use data from twenty interviews. The selection of which samples to include in this chapter is mainly based on three criteria. First, in all three cases I interviewed both engineering and non-engineering students to get broad perspectives on the college, but in this chapter I only present the interviews with engineering students. Thus, at Smith College, seven out of the eight students who accepted my interview requests came from the Picker program; and all of these are included in this chapter. Second, with the exception of Picker, I sought to include interviews that represent both genders. Third, I made an effort to include students from different academic classes—freshmen to senior (Because HMC students usually do not declare majors until the end of the third semester, only five interviewees, all juniors and seniors, from HMC are declared engineering majors. These five interviewees are included in the present chapter.).

The demographic information (gender, majors, year in college) of the interviewees presented in this chapter is summarized in Table 6.2.

Table 6.2 Information of student interviewees

STUDENT	GENDER	COLLEGE	MAJOR(S)	YEAR IN COLLEGE
H1	F	HMC	Engineering	3
H2	M	HMC	Engineering	4
H3	F	HMC	Engineering	4
H4	M	HMC	Engineering/CS	3
H5	M	HMC	Engineering	3
P1	F	Smith	Engineering	4
P2	F	Smith	Engineering	4
P3	F	Smith	Engineering	4
P4	F	Smith	Engineering	4
P5	F	Smith	Engineering	2

P6	F	Smith	Engineering	3
P7	F	Smith	Engineering	4
D1	M	RPI	ME/DIS	2
D2	F	RPI	ME/DIS	1
D3	M	RPI	ME/DIS	1
D4	F	RPI	ME/DIS	2
D5	F	RPI	ME/DIS	2
D6	M	RPI	ME/DIS	4
D7	F	RPI	ME/DIS	3
D8	F	RPI	ME/DIS	4

6.1.3 Transcribing and coding

Most of the interviews were digitally recorded.[94] I did approximate transcriptions of the records with the software Transcriva. Then I coded the approximate transcripts. The quotations included in this thesis are ones transcribed word-for-word.

The interviews were coded through an iterative process. After an initial reading of all the approximate transcripts, I created five categories and several keywords within each category. I opened an individual text document for every keyword. Then I reread the transcripts and copied and pasted relevant excerpts to the corresponding documents. While I reread the transcripts, I also refined the categories and keywords to better capture the interviewees' responses. The final categories and keywords are as following:

1. Major choice
    a. Why engineering
    b. What was engineering
    c. Why this college
2. Concept of Engineering (& design)

[94] Two students—Ms. P3 and Ms. H3—requested not to be recorded, but they agreed my note-taking. Therefore, these two students are not quoted in this chapter; some of their views are paraphrased.

a. Math & science
b. What is engineering
c. Engineer
d. Make
e. Technical/social
f. Design

3. Professional engineer
    a. Intern experience
    b. Professional preparation
    c. Women engineer
4. Educational experiences
    a. Likes
    b. Dislikes
5. Career
    a. Goal
    b. Trajectory
    c. Immediate plan

After I had "mined" all the relevant interview excerpts and placed them in corresponding documents (entitled by the above keywords), I read through each document and color-coded the excerpts. For example, in "1.c-Why this college," five colors was used to highlight different reasons: "creative," "support," "small," "liberal arts," and "other." The excerpts that mention creativity were highlighted in green, and references to liberal arts education was highlighted in red, etc. After color-coding, I complied students' views within two spreadsheets. Sheet One displays every individual interviewee's responses to the questions indicated by the keywords (e.g., why did this person choose HMC?). Sheet Two summarizes all the interviewees' general views on these questions (e.g., what are the common and influential factors in my interviewees' choices of colleges?).

6.2 Results and explanations

Due to the "semi-structured" nature of my interviews, not all the questions listed in the interview protocol (see Table 6-1) were asked of every student, nor were the questions always asked in the same order. With rare exceptions, the viewpoints I present hereafter represent at least "a few" students instead of single individuals. While I sought to capture diverse perspectives, this chapter does not exhaust all of my interviewees' responses. Although the questions were not always asked in the same order, in most cases my conversations with students tracked their journeys from high school to life after college. The flows of these interviews thus coincide with my organization of students' responses within Sections 6.2.1 to 6.2.3. The three sections roughly overlap with students' pre-college, college, and post-college lives. These sections are not organized so as to match the order of the interviews or the chronology of the interviewees' life history. Instead they present students' reflections on three conceptual domains. Section 6.2.1, "Expectations," probes students' reasoning about college and major choices and examines their ideal conceptions of college life and engineering learning. These expectations mostly reflect students' "a priori" visions: normative presumptions about what engineering should be; legends passed down from family and friends; etc. It is important to note that my interviewees' thinking about "engineering" as a general concept concentrated in the "expecting" period. After they entered the college, reflections on engineering became more "ad hoc" and often related to specific learning experiences (e.g., a course or a project). Section 6.2.2, "Grasping engineering," inquires into students' broad learning experiences, with a focus on their understandings of the nature of engineering knowledge and the relation between engineering and its social contexts. Answers to the question "what is engineering (knowledge)?" were often implied in students' commentaries on pedagogical matters; e.g., which courses do or do not belong to engineering, what instructional methods are effective, whether a grading policy is appropriate, etc. Moving on, Section 6.2.3, "The world beyond college," explores students' imaginations about the future, especially about their career trajectories. While in college, a number of my interviewees had already been exposed to the professional world through internships, campus research, club activities, and likewise experiences. Hence, the interviewees shared their "ideals" about professional life, anticipating the future with the clues they were able to collect from college. At the same time some interviewees, drawing from their preliminary professional experiences, reviewed their college education in light of the rules and requirements they had received from their experiences in the professional world.

6.2.1 Expectations

Students' choices of colleges and majors are often shaped by complex factors, including their self-assessments (e.g., what they are good at), inputs from closely affiliated people (e.g. family members and high school advisors), and logistic matters (e.g., financial package, location), etc. For example, among the eighteen interviewees who explained their choices of studying engineering, six mentioned one or more family members who were engineers. Reflecting on such choices, my interviewees seemed to place considerable weight upon their own expectations about colleges and the programs of study. The expectations which significantly impacted their college and major choices reside mainly in three aspects: intellectual, practical, and experiential.

6.2.1.1 Intellectual

Contents of learning and styles of instruction are the main intellectual factors that affected my interviewees' choices of colleges and majors. Eleven out of eighteen interviewees chose engineering in part because they liked (and were usually good at) math and science in high school and expected to learn more of them in college.

> Ms. P6: I knew I was doing engineering from high school. It was kind of the only thing that appealed to me. I've always liked math and science.

> Ms. P4: I also felt that econ (economics), math, and engineering especially in the undergraduate level they are the same thing, why not go for the harder one? –It's all like logical thinking and math, that kind of thing—If you get one done, it wouldn't be hard for you to pick the other one.

It is worth noting that no interviewee from HMC mentioned math and science as a motivating factor in their choices of engineering. Whether this means they preferred a less math and science oriented view of engineering or their love of math and science is assumed in the choice of HMC cannot be fully determined from my interviews.

A significant proportion of my interviewees, especially those who went to HMC or PDI, were looking for opportunities in college to work with tools and to build artifacts. In Chapter 3 I note how engineering education at HMC includes extensive hands-on experiences. This philosophy is cordially welcomed by many Mudders.

> Ms. H1: In CS you work mostly with code and you work with really, really complicated kind of algorithms. So you have things that you have to think about a lot, and you don't have a lot of things where it is hand-on, where you can touch it and make sure it works. I am the hand-on kind of person. I like to make things and I like to see them work.

PDI's studio-based design learning grants students plenty of space to work with their hands and with tools. This was appreciated by most of the PDI students I interviewed, who considered themselves "hands-on persons" who like "moving," "making," or "building" things.

Two PDI students chose RPI and the PDI program as they were more "creative" than other engineering colleges and programs they had considered. However, neither of them elaborated in the interviews what "creative" meant to them at the time of choosing colleges. I am therefore left wondering to what extent their expectations for a creative college education had been affected by the self-presentation of the PDI program, which uses the word "creative" eight times and "create" four times in its program description webpage.[95]

6.2.1.2 Practical

My interviewees' practical considerations of choosing engineering major are mainly concerned with two matters. The job prospects played an influential role in the choice of engineering: six out of eighteen interviewees took into account the benefits of an

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[95] RPI (Rensselaer Polytechnic Institute). 2014. "BS in Design, Innovation, and Society (DIS)." Accessed from: http://www.sts.rpi.edu/pl/design-innovation-society-dis.

engineering education for their career advancement. Engineering was considered a helpful career leverage for its reliability as well as flexibility. Ms. P7 chose Picker because she thought "*engineering is one of the only majors I know of here that's very clear that's gonna go towards a career*." Similarly, MS. D7 believed engineering students' heavy training in math and science and their abilities to solve hard problems guarantee their employability. Therefore, although MS. D7 did not think herself best fit for the traditional engineering job for *"I knew that I was never gonna be the person hired to design an engine for an airplane. That's not gonna be me. You are gonna want somebody to check my numbers (laugh)*," she completed her degree in mechanical engineering as a backup plan "*because if I can't get a job that I want, I'll still have that to fall back on. It's your safety net*."

The reputation of engineering to provide a reliable career is occasionally called into question, especially at HMC, where in recent years computer science has taken the place of engineering as the most wanted major by employers. However, this tarnishes but little the image of engineering as a career-friendly major, as a number of students believe an education in engineering will equip them with flexible knowledge and skillsets and prepare them for a broad range of careers or advanced studies. Ms. H3 thought the engineering degree would make her qualify for a number of options: MBA, law school, graduate school, etc. Ms. P5 had intended to study physics when she first came to Smith, but she found the engineering major has a more intensive curriculum, which makes it easier to switch from engineering to other majors than the other way around. As a result she started with the engineering major to *"be on the safer side."*

Another major practical concern that drove some of my interviewees to engineering is its potential for common good, i.e., the capacity of engineering in helping other people or improving the environment. Seven interviewees expressed an explicit will to advance common good with their engineering skills.

> Ms. P5: I want to be an engineer because it allows me to combine my love of science and math for the benefit of humanity.

> Ms. P1: It (engineering) just feels like it matters. Building a bridge, or, my [an engineering class] project is to make a (?) device that will reduce chemotherapy (patients') hair loss, and that actually will do good to people whereas making business card? Nay. Not really. Didn't ever feel that was contributing to the greater good.

> Mr. D1: I said OK, so I really want to help people. That's right, I built wind mills and solar panels when I was in high school. I wanted to come here to do sustainability.

6.2.1.3 Experiential

When a student chooses a college, she chooses not only the intellectual contents she is going to learn but also the experience she is going to live for the next four years. Therefore, the college experience is an important parameter in students' decisions on colleges (this is especially true for my interviewees from Picker and HMC).

More than half of the interviewees from Picker and HMC admitted they consciously looked for a small college. The preference for "smallness" often indicates their expectations for higher teacher/student ratio, attentive professors, abundant opportunities for campus research, and the feel of a close and personalized community.

Most of my interviewees who looked for small colleges were also seeking a liberal arts education. Although liberal arts colleges tend to be small, expectations for a liberal arts college are somewhat different; they often stem from a need for a well-rounded education. In particular, some interviewees found a technocentric engineering education inadequate for their development as full persons.

> Ms. P1: Of course you need a liberal arts education. You need to understand the context of the field you are working in, and you can't do that if you only work in your field. You also need to talk with people outside your field...It's been obvious we're members of the world, not members of the engineering world.

Among the six Picker students who explained their choices of Smith, four referred to the various kinds of support Smith College offers to women and especially to students who come from non-traditional backgrounds (minority, international, low-income, LGBT, etc.).

> Ms. P7: the original reason why I wanted to come was where else in my life am I ever gonna be surrounded by women studying engineering? –I felt like in the U.S. society—realistically, I'm already a minority in so many other ways, so why have women being another minority?

> Ms. P1: People say that racism isn't a thing, classism isn't a thing, and sexism isn't a thing, but they are all real. And just because someone isn't really saying "you can't do this because you are a woman," or" you can't go there because you are black," or "you can't do that because there's no way you can afford it, so you don't deserve it." There are more subtle things that people do, that show that they don't believe in you. And if everyone around you does these subtle things, you can't help but not believing yourself. Whereas at Smith, it's all about empowering women. And before people come to Smith, they got the acknowledgement that sexism is real, women do not have—formally we have the same opportunity, but informally, people will not believe women are as capable as men. And that's a problem.

> Ms. P5: I'm a first generation college student, coming from a very low-class, low-income background, and I'm very lucky that Smith saw the potential in me and accepted me and was able to, like support me in college. The very beginning of my second semester here, I was called into the department chair's office and I was freaking out apparently I was chosen to receive a grant that covered half of my tuition.

6.2.2 Grasping engineering

Once the students have experienced the "nitty-gritty" of engineering learning, it becomes more difficult for them to define "engineering" or "engineering knowledge" as a generic concept. In many cases, the holistic conceptions of engineering they held before coming to college are replaced by fragmental and piecemeal experiences of particular courses, labs, and projects, each of which reveals a scale of the whole fish. The synthesis, if it can be articulated at all, often does not come until the capstone experience in the senior year. For example, Ms. D2 had taken engineering AP classes in high school and thought she knew what engineering is: "*a way to interact and improve the world.*" After studying mechanical engineering and design for three months in college, she no longer knew "*what engineering is now*." For similar reasons, the request for students to "define knowledge in your field/discipline," which was included in an earlier iteration of the interview protocol during the pilot study, received a lot of resistance, for students found it quite impossible to give a definition. These encounters taught me to ask about particular experiences, rather than pressing for the generic concept of engineering. Hence the categories of epistemological stances presented in section 6.2.2.1 should not be understood as determinant or mutually exclusive; they don't necessarily distinguish one student's epistemology from another: the same student's comprehensive image of engineering, which is inspired by an interdisciplinary instructor, might well be changed by another reductive lab assignment. My attention to students' particular educational experiences yielded another reward: on occasions, after elaborating their stances on an intellectual question, the interviewees would justify their views by recollecting their own experiences. Such justifications, though unsystematic, indicate some components of their education which are accountable for the formulation and change of their epistemological stances. A few cases of this kind are documented in section 6.2.2.2.

6.2.2.1 Mapping epistemological stances

The request for the interviewees to draw a "knowledge map" turned out to be a successful prompt to help them articulate in their own terms the various parts of engineering learning and how they relate to each other. In some cases the knowledge maps also clearly illustrate how their authors draw the boundary between "engineering" and "non-engineering." The following epistemological stances are derived from analyzing the interviewees' reflections on their learning experiences as well as their explanations of the knowledge maps. Two of such maps are presented here as examples.[96] Figure 6.1 shows the knowledge map drawn by Ms. D8, in which college learning is clearly broken down into two parts: engineering and design. According to this map, engineering learning includes the scientific, technical, and economic knowledge that are accountable for the proper functioning of a mechanical system. Design learning, in contrast, implies a diverse and heterogeneous set of knowledge and skills. Figure 6.2

[96] To protect the identities of the interviewees, these hand-drawn maps were reproduced using Microsoft PowerPoint.

displays Ms. P6's knowledge map. Ms. P6 is a dual major in engineering and a policy related field. This map shows a very sophisticated and inclusive concept of engineering, which encompasses technical principles, interpersonal skills, design, and ethics. The typology of the map also implies the author takes a very holistic approach to her college learning, as various parts of knowledge and learning activities are interconnected.

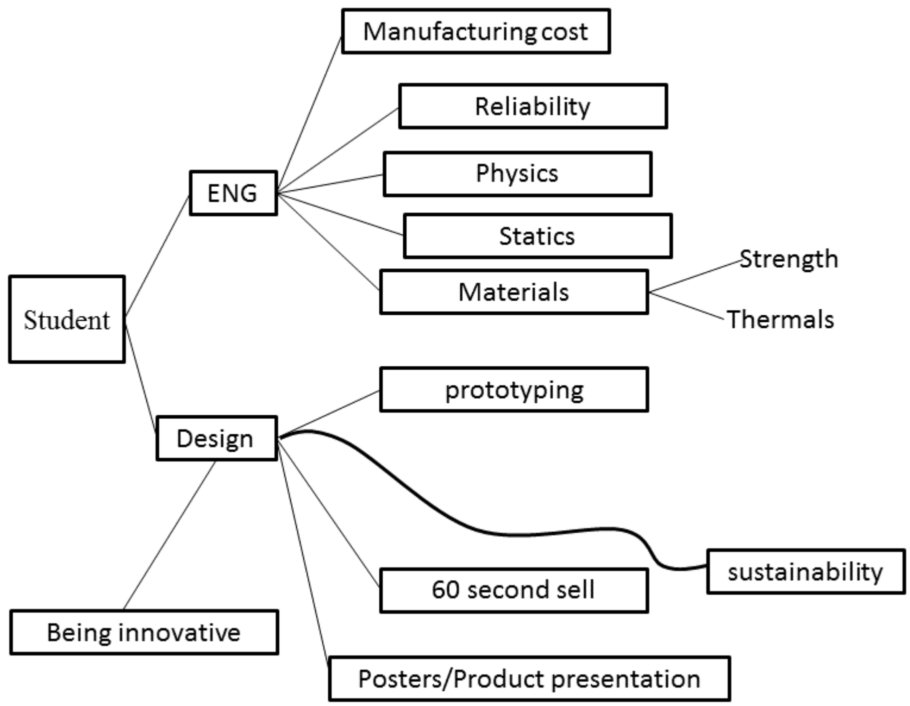

Figure 6.1 Knowledge map by Ms. D8

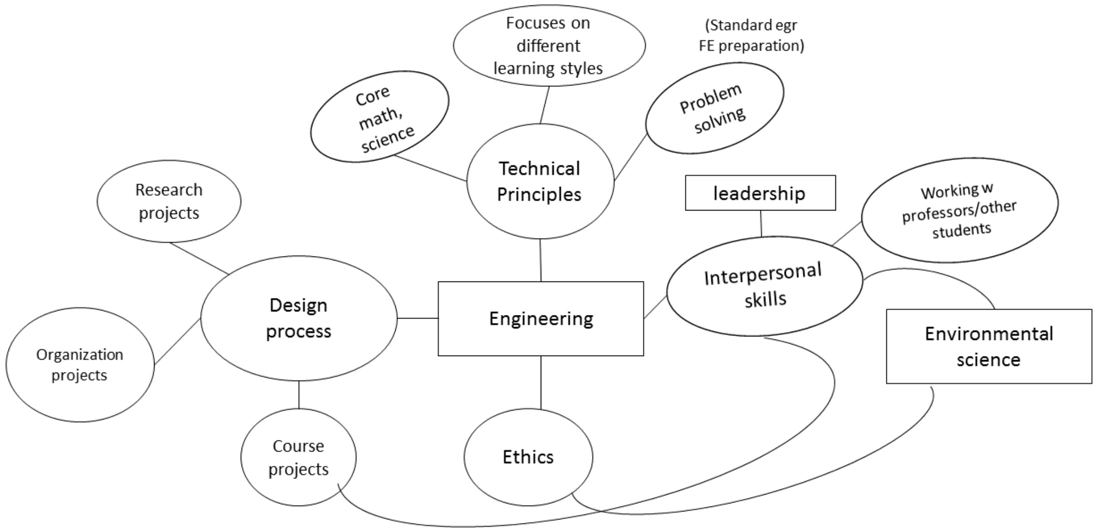

Figure 6.2 Knowledge map by Ms. P6

6.2.2.1.1 Math and science

Just as they had expected, my interviewees found engineering learning involves a lot of math and science. This appears to be especially true for the first two years in college, as I heard first and second year students more frequently use "computation" or "physical rules" to describe the contents of their learning. Among all the interviewees, math and science seem to be the least controversial part of engineering knowledge. When they suggested other components—such as teamwork or evaluating the social impacts—as engineering, they often felt the need to give justifications. This was not the case for math and science, which were comfortably accepted as an integral part of engineering.

Unlike the almost unanimous welcome of math and science in high school, my interviewees, while all recognizing the legitimate role of math and science, showed greater diversity in their reactions to their heavy presence in engineering education. Mr. D3, who had gone to a math and science high school, felt at home with the continuation of these subjects. Mr. D3 considered himself "*relate(s) better to math and science people than I do to English people.*" Mr. D1, however, discovered he had liked math and science in high school only because he was good at them then. Once he was surrounded by RPI students who are all good at solving mathematical and scientific problems and became no longer the best, he "*lost interest in them*." People like Ms. P5 were torn between their interests for math and science and for interacting with the social aspects of the world. Ms. P5's interests in the natural sciences were kindled as a child by her mother, who did not finish college but retained a passion for physics and passed it down to her daughter through numerous conversations about the laws of the physical world.

> Ms. P5: Public policy is an option, but I still like science and math so much, and I still want to be working with numbers, and I don't know. It's something I'm wrestling with.

Although most of my interviewees saw math and science as an integral part of engineering, almost none thought engineering includes only math and science. Each of them in their own ways recognized there are things in engineering that are beyond calculation and physical laws, such as communicating expectations and constraints for engineering projects, work in teams, etc. This finding might be of interest to engineering epistemologists (e.g., Vincenti 1990), who take pain to explore the boundary between science and technology/engineering and to distinguish engineering from "applied science."[97]

6.2.2.1.2 The contexts of engineering

How students understand the relation between the technical and non-technical dimensions of engineering, and how they delineate the technical work and the broader contexts of engineering, are at the heart of my study of students' epistemological stances. Through a close reading and analysis of students' reflections on courses, instructors, projects, and other matters regarding the proper contents and formats of education, three patterns emerge, which characterize the major ways in which students engage the contexts into their understandings of engineering. The first pattern, "decontextualized engineering," shows very little attention to the (non-technical) contexts of engineering. During the interviews, "decontextualized" views about

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[97] The term "applied science" was hardly mentioned by my interviewees.

engineering were only expressed on rare occasions. The second pattern highlights what I call the "microcontext" of engineering. The microcontextual views take into account the people (e.g., co-workers and clients) and relations (e.g., collaboration and negotiation) that are often present in educational and professional contexts, such as engineering classes, project teams, and engineering firms. The third pattern demonstrates what I call the "macrocontext" of engineering. The macrocontextual view exhibits a comprehensive understanding of engineering that engages the broad political, economic, cultural, and environmental contexts.

Decontextualized engineering

Very few of my interviewees saw engineering as purely technical and devoid of social contexts, or as mere technological endeavors that yield economic returns.

> Mr. D3: (engineering) putting out new ideas, things that haven't been done before, you know, create new technology and create new businesses which help the economy.

Regarding engineering learning, those who thought of engineering as pure technical development tended to emphasize the ability to solve mathematical and scientific problems. For example, Chapter 4 documents Ms. P3's anxiety about the lack of difficult technical challenges in the Picker program. In the meantime, a decontextualized view of engineering also led some interviewees to consider the non-technical courses—i.e., the humanities, social sciences, and arts—very easy. That is, they found the non-technical courses conceptually straightforward, despite the amount of reading and writing required in these courses.

When asked about the easiest classes in college, Ms. H3 pointed to the humanities classes, on which she managed to get satisfactory grades without much serious thinking. This impression was shared by a few other students at HMC, some of whom elected the HSA courses as "buffer" to balance out the stress of "technical courses."

> Mr. H4: I think it is both a nice break and a nice eye-opener to the rest of the world to take some of these classes (in humanities and social sciences).
>
> [...]

> I feel like overall the impression is that the humanities courses are easy, because there's less technical material and less pressure on a week to week basis. HSA courses they are like more—you are studying something, it's not you have a homework set due every single class meeting time—the workload is lighter but it's more open-ended. You still have a lot of reading to do, and in fact you'll have the same amount of time spent on it, but it's a lot lower stress.

Although some of these students appreciated the opportunities to take extensive courses in the liberal arts, they did not recognize and engage the specific epistemological rules in these disciplines. For them, besides honing their communication skills, studies of the humanities and social sciences were mainly meant to raise "awareness" about social issues.

> Mr. H4: The biggest point I take away from a lot of the humanities courses is not so much the knowledge of history as is the revelations that I see—the things I learned changed how I view the world. Whether it's as small as understanding investing or finances or as large as classical history. I think it's important to understand that—we are not studying to learn the facts; we are studying to be aware.

As Perry (1970) observes, students' perceptions of the grading policy also indicate their epistemological understandings of a field of study.

> Mr. D6: I think the way the professor grades those projects are by how deep or how many materials you have learned, not really what you learned. Because those are non-science based classes, there is no one absolute correct answer. Every answer is correct. So as long as you claim why you believe this. How you come up with the explanation to the case. And you have to show the depth, what materials you look up on the Internet, how many research you do, like that. If you do that kind of work, the professor will give you a higher grade. I guess PDI is similar to that.

These comments on the purposes and criteria of evaluation imply an unexamined view about the "non-science based" courses, that they stress reading and writing for their own sake (instead of as a medium toward reflection, critique, and systematic inquiry). It did not occur to the commentators that the disciplines in humanities, social sciences, and arts may operate under epistemological frameworks that are distinct from engineering, and learning in these fields requires thinking in different styles than in technical problem solving.

The microcontext of engineering

Most of my interviewees displayed at least some recognition of the microcontext of engineering. The microcontextual view of engineering admits technology, though a critical component, is not in itself adequate for completing real engineering work, either in a project-based course or at the workplace. Successful engineering work, according to this view, requires knowledge of the system, which involves people, organizations, materials, etc., as well as skills in communication, teamwork, and the ability to identify problems and to seek new solutions.

For example, the interviewees who had interned in the production sectors stressed knowing how the whole system functions; they often acquired such "tacit knowledge" by staying "on the line" and directly experiencing the context of the plants (Polanyi 1958). Ms. D7 had interned at the performance improvement department of a makeup company. She reported that her engineering training enabled a comprehensive understanding of the whole production line, which was necessary for her job.

> Ms. D7: I have to understand the whole process of, when we get stock from suppliers and when it's brought up to the production lines, and the section in between is where I focused. "How do we minimize the time it takes between it arriving at our door and it getting into the line; like why is there a delay, why is there a chance it's not gonna be the right component coming to the line." I have to understand all of that, which is where my engineering background came in.

While interning at an electronics company, Ms. D8 redesigned a human computer interface for colleague engineers who do simulation to optimize the production. Besides talking to the engineering and manufacturing staff, Ms. D8 also familiarized herself with the actual manufacturing process.

> Ms. D8: As an intern I think I preferred staying on the line because it helped me learn more about the product—how it worked. Sitting at the desk and not doing anything isn't going to be helpful.

A number of my interviewees also noted some non-technical professional skills, especially those related to communication and teamwork, are essential for engineers. Ms. P5 noted the importance of a forum for ESW members (many of whom are engineering students) to practice oral communication.

> Ms. P5: Communication is so vital to the field and so many engineers grow up not being able to communicate effectively. We don't know how to talk to each other. And I want to provide a forum for people to discuss, to bring their academic background, with their cultural background and all their other identities and be able to have a real discussion with their peers. Because we learn so much in the classes but it's not worth anything if we can't apply it. So I feel like having discussion is so vital to engineering pedagogy in itself.

The sheer amount of writing required by the HSA courses at HMC posed a challenge to Mr. H2, for whom writing does not come easily. However, he agreed that writing will be an indispensable part of his career.

> Mr. H2: I'm going to need it (writing) no matter what I end up doing. If I end up engineering, I'm gonna be writing specs docs and papers and stuff like that. If I ended up doing science, I was going to end up writing research papers. And I've read enough bad research papers and specs documents that it's like "I am not gonna do that." So with every humanities course I'm taking the goal is, maybe not like learn to write an essay about philosophy or whatever, something like that, but more of learn to write well in general so that I can write technically.

Mr. H4 witnessed the significance of communicating with people from different backgrounds in his on-campus research activities.

> Mr. H4: we also had the cross-departmental work with the physics department—and I really realized that whatever I do if it's engineering or robotics more specifically, I'm gonna have to communicate with people. And most likely those aren't going to be people doing the same thing I'm doing, so I need to be able to communicate with physicists that are working in the other end of it.

When Ms. P4 chose the engineering major, she thought it was purely math and logic. This view was changed as she took more engineering courses, and especially after she completed the a senior engineering design course.

> Ms. P4: But then I realized that engineering is more than just math and logic. It teaches you how to deal with people, how to be efficient. So at the end of day, I'm really grateful that I made this change to be an engineering major, because it's like you actually interact with people so many times and you learn about managing projects.

A number of my interviewees also commented upon the importance of effective collaboration and teamwork for completing engineering projects at work and in college.

Mr. H2 had struggled with teamwork, which is extensively required in HMC's engineering curriculum. Despite the struggles, Mr. H2 appreciated the requirement, believing it properly prepares the students for professional engineering.

> Mr. H2: So it's not easy for engineers to do team stuff, and I'm kind of glad it is forced on us early and often while we are here because if we didn't do team-based engineering, then instead of learning how to do it here we will learn how to do it at job and it would be worse. We will learn how to do it and be poor at it when we start.

Ms. D7 recalled her most impressive design project in PDI: a video game for elementary school students that teaches them fraction. Ms. D7 was the team leader for that project. Besides other things, she especially cherished the lessons she learned about leading a team: "*I also learned the way to motivate people to do a good job is to make sure that they are really engaged and excited about the outcome of the project*."

Similarly, Ms. H1 also considered teamwork one of the major lessons she learned out of the Engineering Clinic.

> Ms. H1: I guess teamwork is definitely one of them. I can tell you that I was not a team player when I was in high school. Because when I was in high school I knew I was smart, or at least I thought I was smart, and I could do all the group projects by myself and just like give people the part they would have to present. Basically in high school group work was me doing it and other people listening to me. But that is not the case here. Here it's so hard that you actually need your teammates to work with you to be able to do anything right.

Besides the social skills required in the completion of engineering and/or design tasks, some interviewees also valued the ability to define engineering/design problems.

> Ms. D4: (In Studio Two) we did a hypodermic needle to prevent cross contamination in developing countries, because they reuse needles a lot there. It was something in the field that none of us really knew about. None of us were biomedical engineers; none of us had any experience with that stuff—(to begin with) we did a lot of research. The biggest thing to learn with any project is what the problem actually is and focus directly on that problem and don't get distracted by other problems—keep focus and learn exactly who it's affecting, why it's affecting them, how it's affecting them, and all the repercussions of it, and once you have that focus and you fully could understand the problem then you can really solve it.

> Ms. D5: I would say that PDI is problem seeking. Because a lot of times we will start a project by—in Studio Two our assignment was called "mission impossible," and it was to solve a world problem, but the product that we design had to be in the size of a bread box—That was a very general assignment, and so the way that we approached it was "OK, what problem do we want to address?"

It is worth noting that most of these "micorocontextual" understandings of engineering refer either to actual experiences with the engineering professions or imagined projections about professional situations. Overall, most of my interviewees seemed to rely on the engineering professions as the primary context to make sense of engineering learning.

A number of my interviewees reported that they believe conventional engineering students or engineers often lack the knowledge and skills related to the microcontext of engineering; e.g., they cannot communicate effectively, or they are not good team players. Some interviewees noticed such "conventionalists" in their peers. Ms. D7 recalled the "straight engineering" interns she had worked with, who had difficulty presenting.

> Ms. D7: So I'm interning with XXX (the name of the company) and they wanted us to do presentations a lot. My manager was not worried about me doing presentations at all—other people were coached and stuff prior to presenting—I'm comfortable talking to other people, and you know how to be professional and engaging but still be able to communicate what you are talking about to people who may not have an engineering background. I was not worried about trying to edit yourself so that people will understand, which I think a lot of interns, the straight engineering interns struggled with.

Ms. D5 noticed a difference between her classmates in PDI and those who majored only in mechanical engineering: many of the latter had little experience working in teams.

> Ms. D5: The interesting thing about IED (Introduction to Engineering Design) is that for a lot of other students who aren't in the Design, Innovation and Society, that's kind of their first teamwork situation other than professor encouraging them to work together on homework or a lab—I think that students who don't have some of the background with a lot of teamwork situations had trouble approaching IED because they are overwhelmed by all these aspects of a project we are given and didn't

> really realize that you could specialize in something and will have a better project overall.

Ms. P6 considered herself a confident writer and a powerful counterexample to the prejudice that engineers can't write. However, as a dual major in engineering and a policy related discipline, she was not sure to what extent her communication skills can be attributed to engineering learning alone.

> Ms. P6: I think the expectation that being an engineering major means that you aren't able to communicate is something that definitely needs to be worked on. What I don't know is if I weren't a double major and if I weren't taking a lot of classes outside my majors, whether or not I'd be getting the same communication skills. Because I do take a lot courses that require that, like I've taken a lot in government and policy. So I'm not sure.

For a few of my interviewees, engineering meant not only numbers and machinery but also a social world that consists of people and interpersonal relations. For example, Mr. D1 discovered his project in Introduction to Engineering Design was shaped not only by technical principles but also by the expectations of different team members. Completing the project turned out a social process with negotiations and compromises.

> Mr. D1: In IED I ran into some issues with what people are interested in—It was I really wanted to focus on the wind turbine and what's the most efficient wind turbine for our application that looks the best—but my group members were like "I'll just do this easiest to make vertical (?) wind turbine because it's easy to make." They are interested into being easy to make and they wanted to focus on other things. They weren't interested in the efficiency of that wind turbine. So I didn't have the ability or the time or the authority to step up and say "no we are using this wind turbine." It was a democratic process; everybody said "this is good let's move on," and if I didn't move on I was just hindering the group.

Mr. H2 also witnessed the impacts of social activities—such as team meeting—on the outcomes of engineering work.

> Mr. H2: (the team courses) just take so much time and so much effort because working with people is hard—because an individual project, you do when you want, and you do to the level you think you need to do to learn the material. But with the team courses, you are kind of all in it together, and you spend a whole bunch of time doing meetings. You have to figure out how to do meetings correctly. You've seen our Clinic meetings, there are times we are getting things done; there are times we are all just sitting around like "what we do next?"

The macrocontext of engineering

Some interviewees' understandings of engineering went beyond the technical mechanisms and the immediate actors and skills involved in engineering teams or organizations; they positioned engineering in broad political, economic, cultural, and environmental contexts, sometimes at a global scale. However, there are significant differences among the interviewees in how they conceived the relationship between engineering and the macrocontexts. Some of them recognized that the macrocontexts are essential for appropriate engineering practice, yet a substantial proportion of these students thought such broad considerations incompatible with and separated from engineering. Others considered the macrocontexts not only necessary but also integral components of engineering.

The segregated views existed more often among PDI students. When Ms. D2 first came to RPI, she chose mechanical engineering and PDI with the hope that the combination would allow her to improve the world by making useful and creative products. A few months later, having learned some of the (negative) social impacts of technoscience (mainly from the course Science, Technology, and Society), Ms. D2 became more skeptical about her previous choice; she found that engineers' traditional focus on making new products conflicts with careful examination of the products' social consequences.

> Ms. D2: I think that in order to make things you kind of have to let go at some point of thinking about consequences and just make it—I personally don't think I could do that myself, because I'll feel bad.
>
> Author: You mean ideally people ought to be more thoughtful when they make things?
>
> Ms. D2: yeah. I think so.
>
> Author: You don't think you are capable of doing both thoughtful decisions and making at the same time?
>
> Ms. D2: Yeah. I don't know if I can do that. It's really I think it must be a really smart kind of person to do both of them.
>
> Author: So if this is an either/or choice, you would give up the making things part and focus on the thinking part?

Ms. D2: I guess so.

Contrary to Ms. D2, Mr. D1 considered design (of new products) a wonderful means to improve the world not only technically but also socially and aesthetically. Yet Mr. D1 drew a line between the comprehensive design and engineering; for him the latter is only concerned about the (technical) functions.

> Mr. D1: there are other designers at this school and definitely all over the world that are way more invested in the artistic side—whereas me, I come from an engineering perspective, and I want to engineer things. I want to design how things work, but with that personal relation and with that "well great, I'm glad that this beam can support it, and if there's any way I can tailor this beam for the user [...] even though I got it to work, can I make it more sustainable, can I make it look better," even though those aren't engineering concerns.

In the previous section, I reported that some students stressed the "system" (see page 193), by which they meant primarily the functional system of the production line, indicating that they considered the system to be internal to engineering. Mr. D1 also emphasized the "system." In his definition, however, engineering occupies but a corner in the system, which is separated from the non-technical components.

> Mr. D1: In order for me to think about things properly for me to change things—you have to understand the entire system. A big part of that system is the artistic approach, is the feel, the personal—it's something, something that is not a technical factor that determines the design choice, it's a social factor—design allowed me to go that much deeper into project, it's not just like "well you figure out all the engineering aspects, you are done, move on to the next thing." Well you have the engineering aspects, you also have the artistic and social, and then on top of that the sustainability and world economy. I want to be able to latch up the entire project on my own. [...] The feel I get when I'm just doing the straight analytical work, the straight engineering, I feel I'm missing something.

The boundary between engineering and the broad contexts might be attributed in part to the contrast between students' experiences with the PDI program and their learning in the regular engineering departments. As I point out in Chapter 5, many PDI students perceive little alignment between the design program and their regular engineering courses, and they understand PDI and their engineering majors as two types of education pursuing different objectives. For example, Ms. D5 described the different focuses of design and engineering education: "*Problem seeking for design and problem* *solving (for ME), and I think more problem seeking needs to go this way, or at least come from the mechanical or from the engineering field*."

For some of my interviewees, the separation between engineering and the broad contextual matters mirrors a discrepancy between the ideal college learning (the unity of different fields of study) and the reality (the compartmentation of knowledge). For example, Mr. D6 believed ideally all knowledge should be connected, and he pursued that connection by himself.

> Mr. D6: There isn't knowledge within this area or not within this area. I think knowledge are always related to each other, and that's why I took two majors and a minor. I try to look all sides to define knowledge, to see the relationship.

In the meantime, Mr. D6 was also aware that knowledge is divided in the real world for practical reasons.

> Mr. D6: Why mechanical engineers don't do industrial design? Why they don't design the appearance of the product? Because that's what people do in the job market. We have industrial designers, we have engineers, that's how people collaborate. That's why we have to distinguish those majors in school. That's why we have a B.S. degree in mechanical engineering and a B.F.A. in industrial design. Because that's what we have in the job market, that's how the school prepares us for the job market.

Integrated views about engineering and the macrocontexts were expressed most frequently by Picker students. Some Picker students explicitly stressed the non-technical dimensions of engineering. For example, speaking of her [engineering class] team, Ms. P7 pointed out one thing she and her teammates had in common, "*we are all interested in the non-technical, I mean all engineers should be, but us in particular are really interested in the non-technical components of engineering.*" Ms. P7's team collaborated with a local public sector to improve municipal infrastructure. Ms. P7 enjoyed the interdisciplinary nature of the work.

> Ms. P7: This one was really in line with my interests. And our liaison also, he is not an engineer, he is like the interdisciplinary person. Our project is, even though it's definitely very civil, but it's also very all over the place.

Some interviewees saw a synergy between engineering learning and studies in non-engineering disciplines. For example, Ms. P6 was working on a dual major in engineering and a policy related discipline; she was interested in the policy aspects of environmental engineering and appreciated the reciprocal relation of the curricula in both majors.

> Ms. P6: I don't necessarily have to distinguish this is what I'm learning in engineering (and) this is what I'm learning in other courses. Because things that I get better at in other courses help me do better in engineering and vice versa.

Besides the mutual enrichment of engineering and other non-technical disciplines, some interviewees conceived both engineering and social/environmental issues in very broad terms so that they intersect with each other.

> Ms. P5: My opinion of sustainability can be incorporated into every branch of engineering. We actually had this discussion at one of our […] meetings. Like material science does do sustainability. We were trying to think about people who can make solar panel flexible, or who come up with new material that are more sustainable or just—I mean Boeing, we did a talk, Boeing came here. You don't think of airplane as sustainable or has to do with liberal arts, but it does. Like airplane carry people. I mean, thinking about human factor, of course it's getting into sustainability. I feel like even though we are not—doing a garden or doing a solar panel, you still have to think about sustainability, because it is going to impact your project.

I suspect the higher ratio of Picker students who hold comprehensive and integrated views of engineering is pertinent to the liberal arts environment at Smith and Picker's holistic approach of engineering education. I discuss this correlation in the following section.

6.2.2.2 Formulating and transformative experiences

Chapter 4 explains how Ms. P3's earlier technocentric understanding of engineering was changed by her academic and residential experiences at Smith. In particular, Ms. P3 named two courses, which significantly changed her perspectives, as she learned in these courses how global political and economic dynamics shape the outcomes of engineering.

Likewise, a few other interviewees recalled specific courses in which either the contents or the styles of instruction played a part in shaping or changing their epistemological understandings.

> Ms. P6: I think there's so much interdisciplinary work. I don't know, I guess, I'm sure you get it from other engineering programs also, but—
>
> Author: You mean interdisciplinary by—there are different types of interdisciplinarity: one is within engineering like civil with electrical—
>
> Ms. P6: And I'm thinking also completely outside of engineering. And I just find that really, really important.
>
> Author: You find Smith offers a lot of that option or is it more because you have dual major?
>
> Ms. P6: Again I guess I don't know. I'm trying to think if I were just an engineering major if I'd still have the interdisciplinary focus. I think it's kind of built-in already. I mean Prof. PB's (identity concealed) course is a prime example. Because it was thermo and actually it's interesting a lot of students have been frustrated by how much ethics she incorporated. I really liked it, but she does take a lot of things typically considered outside of engineering and put it into engineering courses.

At the very beginning, Mr. D1 approached the design studios with a function-oriented mentality, which had been reinforced by two years of study in mechanical engineering. Yet it was not long before he had a mindshift.

> Mr. D1: My first project, I worked with XX (name of a student)—we were redesigning a hummingbird feeder. And I was all about drawing the CAD up I was all about, well if we had a hummingbird feeder with wheat grass at the top, and the idea is that water will run and get filtered by the wheatgrass, go through a sugar pad and refill the hummingbird feeder. [...] And I really was like where is the shell, how does the sugar pad get changed, what happens when it get clogged. [...] I was thinking all these engineering questions. And then we made this poster, she made the poster. We went up and we were presenting, and XX (name of the professor) was our professor. And you know I was expecting to get all these "did you do the calculation for how fast the water will fall through the filter? Did you think how quickly it will get clogged?" all these things. And what he asked about was like is this square going to be an attractive thing for your user. It was just like, none of the engineering questions. That's kind of the click, I realized "oh it doesn't have to work. It's just a concept, this is an idea." This a completely different approach.

While courses might encourage a more comprehensive and contextualized understanding of engineering, they might also do the opposite.

> Mr. D6: For engineering classes, if it's science based, like—there is defined right and wrong. I never had any experience a professor made any mistake.

In this case Mr. D6 expressed an understanding of engineering as black-and-while problem solving. This understanding came not from abstract reasoning, but from actual experiences with engineering courses.

Extracurricular activities in some cases also influence students' epistemology. As Chapter 4 shows, Ms. P3 attributed her shift to a more "*social science approach of engineering*" not only to influential courses but also to the experience of being a residential assistant (see page 106). Similarly, Ms. P5 discovered the diverse implications of engineering through her involvement with student clubs.

> Ms. P5: Because I think Smith has a very diverse student population. And our […] meeting talked about keystone pipeline. The conversation evolved into sort of the politics of environmental action. I had a physics major talking about fusion. And XX (name of a student) came from an island in the Caribbean, so she was talking about, you know, a non-U.S. perspective on this issue and from the global development issue when it comes to support different types of energy. So everyone brings their own background, and because they are looking at it with a different lens, the conversation, the discussion can become so much more than what I had envisioned it to become.

6.2.3 The world beyond college: Professional imagination and preparation

6.2.3.1 Imagining future careers

Among the ten interviewees who shared their plans for short- and long-term future, nine preferred not to work as a traditional corporate-employed engineer, while the other one was still undecided. Just as they explicitly distinguished themselves from the stereotypical engineering students (see Page 196-197), they also sought for alternative careers that would distinguish themselves from an "*engineer engineer*," who is "*locked in a lab being like a nerdy person.*"

> Ms. P5: I don't see myself becoming an engineer engineer. I don't see myself going ending a white shirt and tie behind a desk and do calculation. I'm very talkative, I like people, I like running teams. I like leadership. I want to do something along those lines.

> Ms. D7: I knew from day one at school that I'm gonna be the person who is the liaison between the engineer and the designer. That's where I want to be. A position where I am in the loop with the details of the project but communicating the big picture objectives to different stakeholders. I want to be able to understand what everyone is doing, but I don't need to be writing code, I don't need to be like fixing something. I'll just need the overall understanding. Studying engineering taught me these concepts and how to communicate them effectively.

Among the nine students who described their ideal careers, two PDI students wanted to own their own design companies; two Picker students wanted to do policy related engineering design (in disaster relief and water management, respectively); one Picker and one HMC student wanted to practice engineering in non-capitalist ways; one PDI student wanted to get her engineering credential and to work as an educator to remind engineers of the social implications; one PDI student wanted to work as a coordinator for production and eventually the vice president in manufacturing companies; one Picker student decided to leave engineering and work in urban planning, community housing, or union organization.

Although nearly none of my interviewees preferred the trajectory of a traditional corporate-employed engineer, their quests for alternative careers seem to suffer from a lack of visible exemplars. When I asked them to envision how they might get to their ideals, all the respondents (four in total) resorted to the common engineer-manager career ladder. Ms. H3 planned to work in electrical engineering for a while and then get an MBA and switch to management.

> Ms. D7: My course of action for the next five years will definitely be where I'm now, go through XXX's (the name of the company) management development program, you do rotations through different positions and you end up as a manager in three or five years. Hopefully do a rotation in logistics during that time to understand that part of it, maybe working on short-term planning on the production floor, to see that part of it. Then maybe end up in a manger role on the floor (physical line) to get more experience dealing with people. I could see becoming a

> plant manager down the line but after that who knows, that's a long time from now.
>
> Mr. D1: The more I do it the more I participate in PDI, the more I want to be a designer. I want to be sitting there with my Macbook and come up with the latest and greatest product in terms of, from both sides, engineering and aesthetic. I would work for a company as a designer but in the end I really want to be on my own. Even as a mechanical engineer, thirty years down the road, I would love to have a company.
>
> Ms. P5: It may end up that I do become, you know, I do go work for an engineering company, but I think I'll do that and try to get to the point of a leadership position, running a company being a project manager, something along that.

Besides painting images of their careers, a number of interviewees also attentively gauged what their future employers and co-workers might expect from them. Interactions with the professional world, such as experiences of internship and campus research, provided the barometer for them to measure professional requirements and to evaluate how well their colleges prepare them for what many referred to as the "real world."

6.2.3.2 Assessing professional requirements

In 6.2.2.1, I observe the engineering profession in most cases served as the primary "microcontext" for students' understandings of engineering learning. For example, students' emphasis on the non-technical dimensions of engineering, e.g., communication and teamwork, is often reinforced by their actual experiences with the profession. Both Ms. D7 and Ms. D8 admitted their communication skills—presenting, talking to people of different backgrounds, etc.—helped their success at internship. Ms. H3 also witnessed the importance of communication at a job interview: when she handed out a research report to the employers, instead of looking into the research, they checked her grammar and style of writing. In addition, Ms. D7 found the teamwork experiences she accumulated at PDI helped her quickly adapt to the organizational culture in the company.

> Ms. D7: PDI students have a leg up because the biggest part of PDI is the community of it. You are with a small group of people and you get very

> close to them. I think that's how you really work in an office, where everyone is working on different stuff, and so and so may have the skills that I need and just because she is not on my project I'm still gonna go to her and ask her for help, which is how you work in an office. So I think coming from that kind of community and being pushed to an office community was amazing. You also enter the work force with a strong sense of team spirit and willingness to help when you can. It's super easy transition.

Mr. D6 interned for one semester at a toy company. There he found the principles about teamwork he had learned in PDI studios were very rigorously followed by his co-workers. For example, because the engineers and managers in the company are all involved in multiple and sophisticated projects, following the team schedule becomes crucial for timely delivery of new products.

Besides communication and teamwork, some interviewees also felt that taking initiatives is a sign of maturity at work; e.g., taking responsibility, seeking information by oneself, or independently building prototypes. When Ms. D4 interned at a toy company, she discovered her abilities to use tools and build prototypes—things she had learned in PDI—gave her great advantages to other interns who didn't have much experiences with tools.

> Ms. D4: I was more familiar and more comfortable in the environment again, the machine shop environment or just like around tools in general. And that helped me get the job done quicker than everyone who is intimidated or confused about what tools to use for what.

6.2.3.3 Professional preparation in colleges

Contact with the profession and estimations of professional requirements provide the basis for students to examine how well their college education prepares them for the professional world.

<u>Strengths</u>

In all three programs—HMC, Picker, and PDI—my interviewees spoke highly of the intensive training in communication and teamwork, which worked to their advantages in adapting to the professional settings.

The engineering programs at HMC and Smith both offer degrees in general engineering, which focus on a broad knowledge basis that covers several fundamental engineering disciplines. The breadth of learning in engineering is supplemented with an extensive curriculum in the liberal arts. In general, interviewees from both HMC and Picker applauded the broad education for their professional development. They found the breadth of learning especially beneficial in the long run and for managerial positions.

> Ms. P2: I think it (the general engineering science degree) will be really valuable for my future, because they help us develop skills that are important for a person who holds a manager position.

When asked how the education at HMC would assist his career goals, Mr. H4 emphasized the breadth of learning in both engineering and in the liberal arts.

> Mr. H4: Just the broad base of knowledge that I'm getting both from the engineering program alone but then the humanities, of which I'm taking a huge concentration on economics. I'm concentrating on as a Robert Day Scholar, which means basically I'm taking master's level classes at CMC—I feel like those are going to be important for any decisions that I make in future if I'm in any position of management. And it will be important to know or be aware of the impacts of my decisions on the community and the world as a whole.

<u>Weaknesses</u>

In terms of professional preparation, the main shortages of the three integrated programs, according to my interviewees, are also closely related to their "hybrid" nature. One key recognition is that as the ideal of integrating engineering and the liberal arts is not yet well known among professional engineers, employers sometimes had difficulty understanding such educational initiatives and doubted the quality of their graduates. Also, as my interviewees pointed out, the breadth of education is in many cases achieved at the expense of deep and specific disciplinary knowledge.

The interviewees from Picker and PDI more often encountered employers' suspicion on the credibility and value of their degrees. When I interviewed Ms. P3, she had had several job interviews but not an offer. She recalled having to sell to employers the notion and merits of a degree in general engineering, a problem she thought a more discipline-based engineering major would not face. Although a firm believer in the value of a general engineering science degree, Ms. P2 also had to admit *"[i]t gave me a lot of trouble when I try to find jobs. Because companies don't really recognize this degree."*

The engineering and design dual majors in PDI encountered similar suspicions.

> Ms. D7: It makes them (employers) a little bit worried. Because they don't realize that each major is fully there. They think when they hear mechanical engineering with something else, they think it's a watered down version of an engineering degree with this other kind of like non-sense that they don't understand.

It is likely that employers' doubts also had to do with the relatively short history of Picker and PDI. Though HMC also offers a general engineering degree, its over half a century record of successful graduates has gained the program a reputation for producing high quality engineers. Therefore, most Mudders are confident that their degree is highly regarded among employers.[98]

With the same length of study in college (mostly four years), students in the integrative programs often face trade-offs between the breadth and depth of learning, and the structures of these programs usually favor the former (unless students go out of their ways to pack extra "tech courses" into their schedules). While recognizing the benefits of this choice for their long-term career development, a number of my interviewees witnessed the price of the trade-off when they looked for entry level jobs: employers sometimes preferred graduates with immediately applicable technical knowledge to those with a more comprehensive education.

> Ms. P2: for entry level jobs, it's (the general engineering science degree) not that applicable, because of the breadth of learning. Because if they ask you some questions and then you have never learned that, you don't

[98] See Page 79 about the legend of employability.

> know how to answer that, they will probably assume that you are not capable of doing this job, which is not true.
>
> Mr. H5: Harvey Mudd's engineering program is very well rounded. If you want to be working at a very specific mechanical engineering firm, you are gonna want to go to grad school, probably.

Some interviewees also wished they had been taught more specific skills called for by the profession, so that their transition to the profession could be smoother.

> Ms. D7: In terms of things they should teach us? They should teach us how to use Excel. A hundred percent. It's ridiculous how much the real world is run by Excel. People in the real world are shocked that students are coming in (not knowing it). Because we say like "oh I know how to use Excel", but you don't even understand what Excel is capable of.

6.3 Significance and conclusions

While many of my interviewees consciously sought liberal arts colleges or interdisciplinary programs which would provide different learning experiences from more traditional engineering programs (like those in large, public universities), their preconceptions and expectations about engineering did not seem radically different from those who study engineering at more conventional locations.[99] This provides an interesting "baseline" for comparing students' epistemological stances in traditional and alternative engineering programs and for identifying the correlation between epistemological differences and different models of education.[100]

Overall, my interview data shows that a high proportion of students in the three case study programs recognize the (non-technical) contexts of engineering, although to a limited degree on the whole. A small proportion of students understood engineering as a purely decontextualized mathematical and scientific endeavor. Some of these students considered the liberal arts courses "easy" because, in my judgment, they had not fully

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[99] For a survey on students' reasons for majoring in engineering at Cal Poly San Luis Obispo, see Lehr, Finger, and Kwang (2012).
[100] Future studies of my own or interested colleagues could examine students' epistemological stances in more traditional engineering programs.

grasped and did not appreciate the underlying questions, methods, and logic of inquiry in the non-technical disciplines. Yet even in such cases students more often than not recognized the relevance of the liberal arts to engineering practice, e.g., some of them valued the communication and teamwork training in the liberal arts courses. The majority of my interviewees (at least thirteen out of twenty) showed awareness of the "microcontext" of engineering. Among these students, the majority (at least ten) seemed to identify the engineering profession as the primary context to make sense of engineering learning. It might be fruitful to compare this result with students' understanding of contextual matters in traditional engineering programs. Although I have not yet conducted extensive and systematic studies along these lines, preliminary results from a pilot study, in which I interviewed five regular engineering students at RPI and six engineering and PDI dual majors, suggest students in the latter group show more comprehensive understandings of engineering, especially pertaining to its non-technical dimensions.[101] Also, as Sections 6.2.2.1.2 and 6.2.3.3 indicate, most of my interviewees held a very positive attitude toward the non-technical professional skills, especially communication and teamwork. This contrasts with the findings of a prior study, which reports engineering students in general "perceived math and science skills as more important than professional and interpersonal skills" (Sheppard et al. 2010).

Fewer of my interviewees expressed clear understandings of the macrocontext of engineering, i.e., the broad political, economic, cultural, and environmental issues that help shape the objectives, methodologies, and the limitations of professional and academic engineering. Perhaps even more noteworthy is the fracture displayed by students who did perceive the big picture: among the eight or so students who expressed awareness of the macrocontext, only two declared with strong confidence that the broad concerns (e.g., sustainability, policy, etc.) belong to engineering. This suggests an "anomaly" to the findings in the contemporary literature on technical/social dualism, for

[101] In the pilot study most regular engineering students broke down "knowledge" by the subject of courses they had taken, whereas most PDI students interpreted "knowledge" as a set of diverse capabilities (Tang 2013).

the literature often documents "imbalanced" dualists, who prioritize the "technical" and downplay or ignore the "social" (Faulkner 2000, Nieusma and Tang 2012).

Furthermore, almost none of the interviewees foresaw a clear career trajectory that would allow them to practice engineering while serving broad social purposes. It is true that engineering has not been known for preparing young people for a broad variety of careers other than the engineering-managerial pathway, yet it is worth questioning how much the integration of engineering and the liberal arts has succeeded if students from such initiatives are not capable of imagining and attempting to pursue alternative engineering careers.[102]

Despite a strong sense of "owning" their education, my interviewees exhibited very little reflection upon their "engineering selves." In other words, these young members (in the making) of the professional engineering club, displayed little critical examination of the assumptions, commitments, and ambitions commonly upheld by the profession. It is harder to identify precisely the causes for the lack of critical reflection by interviewing the students. Instead, I would call my readers' attention to the structure of education in these programs. For example, the liberal education at HMC and Picker is primarily met through courses in traditional liberal arts disciplines (where little attention has been paid to engineering). In comparison, STS components are more extensively included in the PDI curriculum, yet the objects of STS analysis are often the design process and products, not the content of students' engineering majors.[103] In Chapter 5 I report many PDI students maintained a conceptual division between their design learning and their engineering learning; it is therefore likely that few of these students apply the STS theories and methods to examine their engineering learning.

The absence of students' critical reflection on engineering might in part explain their reluctance to recognize the "macrocontextual" matters as a legitimate part of

[102] At Picker, graduates who had gone on alternative career paths were invited as exemplars to share their experiences.
[103] This coincides with a general scarcity of engineering studies scholarship in STS.

engineering, for their conceptions of engineering have not been sufficiently unpacked, scrutinized, and extended through a social analytical perspective in their education as a whole. In other words, contrary to the wish of many educational reformers, engineering in these programs is not studied "as a liberal art" as much as a field of knowledge and practice that can be supplemented with the liberal arts but not strongly integrated within them (Bucciarelli 2011).

7. Conclusion

Through studying the visions, strategies, and effects of educational reforms that attempt to integrate engineering and liberal education, this thesis seeks to enrich our understanding of how knowledge affects learners' self-reflection and the significances of *the concept of technology* in social problem solving. Chapters 2 to 5 explain how some educators have attempted to translate non-traditional visions of engineering knowledge into intuitional, curricular, and pedagogical strategies to teach well-rounded and socially responsible engineers. Chapter 6 documents students' reflection on the holistic educational experiences and their conceptions of engineering knowledge. This chapter assesses the impacts of a more holistic engineering education on students' epistemology and reflective learning. Following that, it examines deeper ideological factors that help maintain dominant thinking patterns in engineering and prevent a more effective integration of engineering and liberal education.

7.1 Toward a liberal education for engineers

7.1.1 A critique of visions

Few leaders in professional and academic engineering today would deny the value of "the liberal arts" or "a liberal education" for the cultivation of young engineers, yet this welcoming attitude might overshadow the fact that "a liberal education for engineers" is often not clearly defined by those who invoke its virtues. While I agree it is also of strategic importance to keep the definition and practice of "a liberal education for engineers" flexible,[104] it is also crucial for educators who are committed to integrating engineering and liberal education to offer a clear, well-articulated vision for any attempt to achieve such integration. They might start this endeavor by asking: "How do we define a liberal education for engineers? What should an education of this kind strive to accomplish? What are some appropriate criteria for evaluating the strengths and weaknesses of educational initiatives that seek to achieve this goal?"

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[104] See Akera (2014a).

During my fieldwork, I have noticed two problems that hinder the genuine integration of engineering and the liberal arts. These resulted from the lack of a thoughtful, well-articulated and shared vision for the integration in educational institutes. First, many students in the three case studies are not able to grasp the idea of a liberal education that encompasses their whole college experiences, thus they understand the liberal education as only relevant to the electives in humanities, social sciences, and arts. For example, when I asked students to comment on their program's mission to provide a liberal education, HMC and Picker students' replies often focus on the HSA and Latin Honors requirements.

Second, for many students and some faculty in the case studies, the goal for integrating the liberal arts has too often emphasized the refinement of students' professional skills—communication, teamwork, information literacy, project management, etc.—at the expense of more extensive intellectual goals. While a liberal arts education can be helpful in improving engineering students' professional competence, a number of liberal educators over the decades have sought to broaden engineering education to move beyond programs of "EMBA"—the combination of "Engineering" and "MBA" education—that is, beyond educational formats that seek to serve industry by training students who know both engineering and business (Sjursen 2006; Bucciarelli 2011). The teaching of engineering as a liberal art, I would argue, should not be considered fulfilled by simply changing the definition of the liberal arts to include engineering as it is. Simply teaching what is wanted by those who write the paychecks might be more appropriately called preparation for a trade than a genuine education that "liberates" the young engineers. For those who recognize its merit, engineering does have the potential of becoming a truly liberal art, a discipline that combines critical analysis with the skills of a broadly based literacy. [105]

Admittedly, a new educational initiative is more likely to succeed when its vision is well attuned to the mission of its home institution. Thus, educators who aspire to a fruitful integration of engineering and the liberal arts would do well to specify their own,

[105] See page 222 for what I mean by "critical" analysis.

“local” vision for the integration they seek. As a step in this direction, I discuss two objectives—epistemological pluralism and reflective engineers—which are deemed worthy by some educators in engineering and the liberal arts (Perry 1970; Belenky et al. 1986; Baxter Magolda 1992; King and Kitchener 1994; Colby et al. 2011; Claris and Riley 2012). For each objective, I first explain its meaning and importance for an engineer’s liberal education. Next I offer some overall observation about how well students in the three case study programs—HMC, Picker, and PDI—meet the objective. After that, I highlight some specific factors—e.g., the administrative structure, educational philosophy, and institutional culture, etc.—in each program that facilitate or impede the accomplishment of the goal.

7.1.1.1 Objective one: Epistemological pluralism

Perry (1970) considers the fostering of epistemological pluralism the key of liberal education in the 20th century: a pluralist epistemology is linked with acceptance of pluralist values in societal and political affairs. He argues that by facilitating students’ epistemological development, a liberal education prepares students for a pluralistic and democratic society (Perry 1970). Students learn to appreciate how crucial questions and issues can be seen from a variety of points of view. The relevance of Perry’s teaching is echoed in a recent study of reforms to integrate liberal learning and business education (Colby et al. 2011). Authors of this study introduce a conception of liberal education that encompasses three modes of thought: “Analytical Thinking, Multiple Framing, and the Reflective Exploration of Meaning” (Colby et al. 2011, 59). In particular, the authors’ definition of “multiple framing” illustrates epistemological pluralism:

> Multiple Framing is the ability to work intellectually with fundamentally different, sometimes mutually incompatible, analytical perspectives. It involves conscious awareness that any particular scheme of Analytical Thinking or intellectual discipline frames experience in particular ways (Colby et al. 2011, 60).

Extensive learning in the liberal arts has the potential of facilitating a pluralist epistemology by introducing students to a variety of disciplines, each of which might be based upon different epistemological frameworks and that have distinct methods of inquiry. It would be a blessing to engineering students if studies in the liberal arts help them appreciate, or even better apply, multiple epistemological rules or frameworks in non-engineering disciplines. Besides improving their intellectual versatility, epistemological pluralism might teach engineers to respect and understand different approaches to engineering endeavors, which often involves respect for groups of people that are not professional engineers. This might in turn contribute to more collaborative problem formulation and solution, for "[r]espect and understanding are preconditions for mutual trust and equal conversation" (Tang 2014).

Many of the students I observed and/or interviewed in the three programs do not appear to demonstrate epistemological pluralism at a high level. In just a few of them I discerned an understanding that an academic topic (especially an "engineering topic") might be approached differently from an engineering point of view as compared to a viewpoint in the humanities, social sciences, and arts. In Chapter 6 I report some HMC students considered the humanities courses "easy" because of the absence of "difficult questions" engineering students are familiar with: complex math problems. Similarly, some PDI students found the design studio courses easy, as they perceived no solid ground on which the quality of design can be evaluated other than the amount of work one puts into a project. Such views indicate that students have little or no grasp of the distinct epistemological frameworks accepted in the humanities disciplines or even in various fields of design, modes of knowledge and practice which entail different criteria for evaluation than those widely used in the engineering sciences. At Smith, I met a relatively higher number of engineering students who exhibit pluralist epistemology (especially in ESW@Smith), yet I saw little evidence that the pluralist epistemology significantly affects their approaches to engineering work. For example, while most students in the engineering classes I observed demonstrated impressive skills of presenting and substantially incorporated the social contexts in the framing of their projects, their core methods for solving the problems and evaluating the outcomes almost always centered on numerical analysis alone.

This observation is by no means the last word, however. The actual degree to which students master the epistemological frameworks in non-engineering disciplines, and the terms in which they engage these frameworks in their approaches to engineering, are more complex and diverse. In previous chapters I reported my observations of Mudders who work hard on the HSA courses, PDI students who strive to synthesize the functional, social, and aesthetic aspects of design, and Picker students who take a "social science approach" to engineering. In particular, the administrators and faculty in these programs play important roles in the education of epistemological pluralists.

Although HMC is widely known as a liberal arts college for science, engineering, and mathematics, its HSA faculty has always had a strong voice in shaping the academic and administrative landscape of the college. The seven founding faculty hired in the summer of 1957 included two physicists, two chemists, one mathematician, and two English professors: William H. Davenport and George C. Wickes (Platt 1994). In contrast, by the time HMC had its first curriculum study in 1958, no engineering faculty had been hired. When I visited HMC in the fall of 2013, HSA faculty took important administrative roles in the college: the Dean of the Faculty is a professor of literature, and the Chair of the Faculty is a professor of economic history.

Unlike the situation at Smith, where faculty in the liberal arts departments and in the engineering program own their respective curricula, at HMC the curricula—both the common core and the majors—are planned by a college-wide joint committee, with representation from the HSA department. To make sure that new faculty fit well with the college's mission of providing a liberal education, every candidate for faculty positions in the science, engineering, and math departments is also interviewed by the chair of the HSA department. These institutional arrangements help maintain a shared vision of liberal education across the college. In addition such measures help prevent the marginalization of the non-technical disciplines, a situation that arises in many technical colleges.

One of the main barriers toward epistemological pluralism—or a hybrid epistemology—at HMC stems from a mentality to protect the "purity," of both the HSA disciplines and the Mudd community as a whole. As I reported in Chapter 3, from the very beginning of the college the HSA faculty at Mudd made a conscious choice to teach "authentic" liberal arts instead of courses tailored for scientists and engineers. In theory, this choice seems congruent with fostering epistemological pluralism through systematically communicating to students the essential values and methods of each HSA discipline. In practice, such ideal is overshadowed by at least two factors. First, although Mudders take at least one quarter of their courses in HSA, the sampling of different HSA disciplines does not convey a clear and coherent epistemological framework as coherent as the one offered by the engineering curriculum. Second, the separation of the HSA content from the content of engineering courses at the best reminds students that there are multiple epistemological frameworks, while contributing little to their possible integration. Furthermore, the broader cultural valuing of one (the technical) over the other (HSA) contributes to a sense of the liberal arts as rounding as opposed to providing robust epistemologies in their own right.

Furthermore, if Perry were right, a pluralist epistemology should be correlated to student acceptance of plural values, backgrounds, etc. While the Mudd community encourages intellectual diversity (in terms of exploring broad fields of study), culturally it tends to assimilate its members within a fairly homogeneous set of beliefs and values instead of welcoming values radically different from its own. The recent resistance against college expansion attested to Mudders' unease about opening up their small and close community. The lack of diversity in ethnicity and family income, etc. might limit students' exposures to different values, motivations, and different approaches to epistemological questions.

A member of a consortium of five liberal arts colleges and two graduate institutions, HMC shares diverse intellectual resources with its neighbor colleges, each of which excels in some different disciplines. The five undergraduate liberal arts colleges also have their own distinct campus cultures. Therefore, although Mudders routinely take courses together with students from Pomona, Pitzer, CMC, and Scripps, politically and culturally Mudders are to a large extent walled within their own community.[106] At Smith, there is less of such a wall between the engineers and the liberal arts majors on campus. During my roaming on Smith campus, I frequently ran into Picker students at events like Liquid Futures (a panel on water, sustainability, and design), business plan competition, etc. A variety of topics also find their way to engineering classrooms. In one of the engineering courses I observed, students made announcements of various kinds: climate change and social justice meeting, performance to raise fund for charity, panel on violence against women and political change in South Asia, Smith senior dance show, "Women's voice" monologue, and other events across a broad cultural spectrum.

Close contact and collaboration with students from other majors at Smith help the fusion of different epistemological perspectives. For example, during the ESW Think Tank meeting (see page 100-104) students who had majors/minors in education or environmental science and policy brought their perspectives to engineering projects. Ms. P3 worked on architectural projects with students from landscape studies. Ms. P4 told me she received significant help on presenting from her roommate, a theatre major.

In contrast to Picker students' exposure to multiple epistemological frameworks, the majority of the Picker faculty are trained in traditional engineering disciplines. As I indicated in Section 4.3.5.1, some faculty in the Picker program expressed displeasure with Prof. PB's engineering courses, for they challenged the traditional engineering epistemology. The conflicts within the engineering faculty heightened in recent years and Prof. PB, arguably the most interdisciplinary-oriented engineering faculty, recently left Smith for another teaching position in higher education.

Compared with the parallel model of engineering and liberal arts education at HMC and Picker, the design studios in PDI provide direct "melting pots" for students to

[106] The five colleges represent respectively different political cultures. Pomona, Pitzer, and Scripps are traditionally liberal, and CMC is significantly influenced by the neoliberal ethos. HMC is perhaps the least politically active among the five colleges. For example, at the first "5 Colleges Fossil Fuel Divest" team meeting, about fifty students showed up from the five colleges; only two of them came from HMC.

combine the analytical methods from a variety of fields: engineering analysis, social history analysis, life-cycle analysis, etc. Many PDI students recognize design represents a distinct body of expertise from engineering, and the former is more comprehensive.

Given this recognition, it is somewhat surprising that relatively few PDI students apply the comprehensive design approach to engineering learning. Instead, a lot of them accept that engineering is a reductive, "plug and chug" activity. The experiences of comprehensive learning in PDI even at times reinforce students' conceptual separation between design and engineering. Based on the limited clues I gathered from interviews, this conceptual separation partly results from the little resonance of the design pedagogy in the engineering departments where most PDI students are pursuing a dual degree. Many a PDI student reports that even the design-based courses in engineering—e.g., Introduction to Engineering Design and Engineering Senior Project—feel very different from the PDI studios: the instructors often place more emphasis upon technical feasibility and most non-PDI engineering students approach the design projects in ways similar to normal engineering homework.

7.1.1.2 Objective two: Reflective engineers

Epistemological pluralism is related to, and partly achieved through, students' reflections on their learning, especially their scrutiny of the assumptions often quietly passed down from teachers. The activity of reflection has garnered a lot of attention from engineering educators in recent years. An illustration of such enthusiasm is the recent founding of a Consortium to Promote Reflection in Engineering Education (CPREE). The CPREE website states:

> Reflecting, or exploring the meaning of experiences and the consequences of the meanings for future action, has always been essential in the development of expertise. Reflection and the promotion of reflective techniques are becoming more important in engineering education because of the expanding need for diverse, adaptive, broad-

> thinking, and nimble engineering experts who can respond to the ever-increasing challenges that society faces.[107]

Since this consortium started fairly recently, it is yet unclear how its partner institutions interpret “reflection in engineering education” and what strategies they choose to promote the corresponding causes. Here I lay out my vision of “reflective engineers,” one that encompasses three key aspects.

Self-knowledge. Besides transferring knowledge and skills via textbooks and classes, college is also an essential environment for the development of students’ intellectual and personal maturity (Heath 1968). Such maturity comes more from a student’s systematic and iterative review of her college experiences, using them as “raw materials” to formulate and renew her self-understanding. Self-reflection of this kind leads to ownership of one’s education. Without advancing one’s self-understanding, we can hardly call an education “liberal” in the sense of contributing towards one’s “liberation.” Knowing oneself provides the basis for a student to choose what to prioritize in college, what type of person she wants to become, what she plans to do after college, etc.; these decisions are important regardless of major.

Intellectual reflection. Reflecting on one’s own epistemological standpoint is considered an important indicator of epistemological development by the psychology literature; such intellectual reflection is also recommended as a fundamental objective for college education (Perry 1970; Belenky et al. 1986; Baxter Magolda 1992; King and Kitchener 1994). In particular, King and Kitchener (1992) propose a model for reflective judgment, which summarizes students’ views of knowledge and justifications of beliefs in three categories: pre-reflective thinking, quasi-reflective thinking, and reflective thinking. From pre-reflective to reflective thinking, according to King and Kitchener, students move away from an unexamined belief in a singular model of problem-solving and come to locate problems in particular contexts and to evaluate the strengths and weaknesses of different solutions by the available evidences. For engineering students, intellectual reflection has the potential of destabilizing the kind of epistemological

[107] Consortium to Promote Reflection in Engineering Education.

authority exclusively and unconditionally granted to a mathematics-based analytical framework (in many cases nicknamed the "black box" method). For example, an intellectually reflective engineer would engage a problem in public health by reviewing and comparing diverse approaches rather than presuming a big-data driven solution is the best. The epistemological pluralism resulted from intellectual reflection is essential for engineers who live in an increasingly complex world and often work in situations with cognitive uncertainties (NAE 2004).

Liberal arts education provides powerful means to expose students to multiple beliefs, narratives, rationales, etc. It also focuses on helping students formulate their own viewpoints when confronted with the world's complexities and contradictions, enabling and encouraging them to review carefully the evidence provided by various sides in a controversy, assessing the respective strengths and weakness of every argument. Traditional pedagogies in the liberal arts also allow students to examine their own views through discussing and arguing with their peers (Kezar, Hartley, and Maxey 2012). As a result, liberal arts education not only provides students with the gift of comprehensive perspectives but also help them "unpack" or deconstruct assumptions and beliefs often taken for granted and shielded from scrutiny. Similar efforts can be made to examine and question the limits of the "black box" method prevalent in engineering problem solving.

Critical reflection. What I mean by "critical" is derived from Habermas's (1971) concept of "a critical social science" in *Knowledge and Human Interests*. The activity of criticism in this context has a revealing function, which "reconstructs what has been suppressed" (Habermas 1971, 315). Such critical reflection constitutes a first step toward liberation by exposing "ideologically frozen relations of dependence that can in principle be transformed" (Habermas 1971, 310).[108] In other words, by reflecting on (making visible) the dominant power structure that conditions our thinking and actions, we might emancipate ourselves from unconsciously depending on the dominant sources of power in society and explore alternative ways of organizing thoughts and actions.

[108] A similar idea is also contained in the concept of "praxis" in critical pedagogy e.g., see Freire (2000).

It is not too unearthly to speak of transforming the power structure by engineers. For one thing, engineers routinely take part in shaping the dominant power structure in society (Winner 1986; Bijker, Hughes, and Pinch 1987). Yet such deeds are very often masked by legends about "neutrality" circulated in the profession or by promises of serving public welfare encoded in the professional canons. To make this unsaid business audible, a number of critical questions can be asked: What is engineering for (Downey 2009; Lucena 2010)? Who is it that engineers serve primarily? What forces give shape to engineers' self-understanding and collective imagination? Questions of this kind call for, as well as generate rich opportunities for, inquiries that bring together engineering and a variety of liberal arts disciplines.

Consider a familiar example of cost-benefit analysis, which is routinely taught in engineering programs in the format of calculating monetary values. The teaching of bookkeeping is often deemed good practice of "comprehensive" education, which implants in engineers' minds the "societal" (i.e., economic) concerns. However, without carefully examining the definitions of "cost" and "benefit" and questioning the logic and limits of such "analysis," the simplistic computation is in the best case trivial and in the worst case (e.g., as in the Pinto gasoline tank scandal) perverse. Critical reflection upon the purposes and methods of engineering requires not the banning of cost-benefit analysis. A different approach to it might open doors to a number of broad and profound questions. For example, comprehensive definitions of cost and benefit require knowledge not only in economics but also in history, cultural anthropology, environmental science, etc. Designing effective mechanism to distribute cost and benefits entails knowledge of political science and policy studies. Assessing the fairness of various distribution mechanisms involves a keen awareness of political and moral philosophy. This is but one example of how an ability to reflect critically upon engineering work through the liberal arts perspectives can be greatly beneficial.

What I mean by "intellectual reflection" overlaps with my discussion of epistemological pluralism above. In that light, the following evaluation of the three programs focuses on students' development of self-knowledge and critical reflection on the engineering profession.

In general, students in all three case study programs exhibit a high level of self-understanding and ownership of their education.[109] The majority of students I interviewed were able to draw the connection between the specific courses they were taking or knowledge and skills they were learning as well as a holistic picture of their college education. Most of them planned their future careers based on assessments of their own strengths and weaknesses and set priorities according to their intellectual and personal interests.[110]

Although students in all three programs (especially in Picker and PDI) learn to comprehensively analyze the outcomes of engineering/design projects, critical reflections on the fundamental assumptions undergirding engineering or the ambitions, interests, and limitations of the engineering profession are rare. Most students at HMC and PDI respectively receive "leadership" or "innovation" as the guiding philosophies with little questioning. Professional values and norms are readily accepted in all three programs. At Picker and HMC, I heard very little criticism of engineering or the engineering community inside and outside classes. Among PDI students, such criticism sometimes emerges in class discussions, but it often turns most of the audience defensive.

HMC's commitment to a liberal education is realized through multiple administrative and pedagogical arrangements. Besides faculty's concerted efforts to plan and implement the curricula, the college also makes efforts to engage the students to collectively explore the meaning of (a liberal) college education. One of the engagements happens in the opening sessions of HSA10, where every student is invited

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[109] In a previous pilot study of six PDI students and five engineering-only or engineering and science majors at RPI, the former tend to understand their college learning more comprehensively and demonstrate more confidence of managing their education than the latter, see Tang (2013).
[110] This observation might reflect some biases of my sampling, especially at HMC, where the engineering students I interviewed were all juniors and seniors.

to argue whether HMC provides a liberal arts education. In the following semesters faculty also evoke this question in HSA as well as in the majors as a reminder for students to continuously grapple with the meaning of their college education.

Critical examination of the profession one is preparing to enter is hard, as it involves risk of alienating oneself in the professional community. This might be true for any program of professional education. Although HMC identifies itself as a liberal arts college, it maintains close ties to the professional world. Among the seven departments on Mudd campus, engineering is known to be the most vocation-oriented. In Chapter 3 I draw out the various avenues through which the values and norms embraced by the engineering profession trickle into the hearts of young engineers at Mudd: classes, seminars, awards, Clinic projects, corporate info sessions, etc. The consistent and positive (if not heroic) presentation of the engineering profession in the program leaves little space for critical questioning.

Smith's college culture, especially its embracement of diversity and justice, encourages reflections on matters of power, dominance, exploitation, etc. Yet such reflections are seldom directed toward engineering. The skills of the college's liberal arts faculty seldom include an ability to unpack the engineering "black box," while for most engineering faculty, this kind of non-technical assessment seems beyond their disciplinary boundary. The work of crossing these boundaries did occasionally appear within the Picker program. Prof. PB actively pursued liberative pedagogies and taught a number of engineering courses to facilitate students' critical reflection on the problematic roles science, technology, and engineering play in inequality, environmental deterioration, global energy crisis, etc. But her departure from Smith makes the prospect of such critical education in the program more uncertain.

According to the classes I observed, the dominant attitude toward the engineering profession in Picker seemed to be appreciative. Besides the usual factors (professional network, industry-university partnership, etc.) which gravitate the mindset of some of its faculty toward the profession, Picker's unique identity as a women's engineering program also intensifies a thirst for recognition, and what recognition would be more powerful than the wide employment of its graduates? Hence some Picker educators eagerly gauge the currently prominent professional expectations and prepare their students accordingly. For example, as Chapter 4 shows, the teaching of ethics and networking adheres to widely accepted codes in the profession.

At PDI, students' self-understanding is assisted by the student community itself as well as by the design pedagogy. As I report in Chapter 5, the studio sequence and PDI students' strong sense of belonging to the program help create a bounded community. PDI students of different cohorts frequently mix together in classes, project teams, social events, etc. Hence younger students usually learn from senior ones about a clear trajectory within the program. Meanwhile, several PDI instructors consistently emphasize students' reflective learning. For example, Prof. DA regularly includes a reflective session at the end of each studio course he teaches, asking students to assess how the studio help them develop their designer identities.

Critical reflection is a major theme of many STS courses included in the PDI curriculum. As I describe in Chapter 5, the STS instructors in the design studios also make various efforts to help students evaluate the assumptions, processes, and implications of design from social, political, and cultural perspectives. Yet such efforts face challenges that stem from an imbalanced power dynamics, which might be called the Freire dilemma. I have discussed this dilemma at the end of Chapter 5.

In the following section I discuss some pedagogical issues about blending engineering and the liberal arts. I start the discussion by revisiting the Freire dilemma.

7.1.2 A critique of pedagogies

7.1.2.1 The Freire dilemma

In engineering programs that seek to integrate the liberal arts, students often experience imbalanced exposure to a technoscience-focused approach to engineering and a more comprehensive approach that substantially incorporates insights from non-technical disciplines. However, in many cases the technoscience-focused approach plays a dominant role in the curriculum, the institutional culture, or the peer influence.[111] This imbalance of influence creates a conundrum Freire, for all his insight, did not fully appreciate. In *Pedagogy of the Oppressed*, Freire (2000) describes an educational setting inside the oppressive power structure, but this education represents the antithesis of the "banking concept of education" that is common in an oppressive regime: the Freirean educators are committed to establishing non-oppressive power dynamics in classrooms. The liberative educators are experts in helping students critically examine the oppression and injustice imposed by the dominant power structure.

I agree the spirit of critical pedagogy, if not the very measures suggested by Freire, is essential for the education of critically reflective engineers. In other words, a liberal education for engineers should focus on cultivating students' active and reflective agency, instead of stuffing their minds with the facts and viewpoints printed in history or philosophy books. However, as I point out in the case of PDI, when the Freirean educators are teaching together with more traditional-minded educators, and when traditional values, such as a technocentric understanding of engineering, dominate the institutional environment (like what PDI students experience in their engineering departments), the Freirean approach with its more open, questioning modes of inquiry, might give way to the more assertive educators who reinforce the traditional values and approaches by assuming authority in the classroom. I do not have a satisfactory solution to this conundrum. Perhaps a "protected environment" is needed at the beginning of practicing a more equal power relation between the educators and the students. Yet I am not certain that protection of that sort would avoid reproducing the "technical/social dualism" I have described.[112]

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[111] For accreditation reasons, an engineering degree often requires more course credits than most liberal arts degrees.

[112] To elaborate this point, "protected environment" means an educational setting only accessible to the "liberative educators." In this setting students can study engineering from a more reflective standpoint, and they can be given greater authority to question or disagree with their instructors. My worry is that students might grow too comfortable with the "liberal arts perspective" in an insulated learning environment that

7.1.2.2 Student-centered learning and scaffolding

Another school of educational thought, one that also seeks to empower the students, has had an increasing impact on engineering education. For lack of a more precise term, I call it student-centered learning, but I realize the way I interpret this educational philosophy might well intersect problem/project-based learning, experiential learning, open-ended (design) learning, and some other theories and concepts in engineering education research (Felder et al. 2000; Prince and Felder 2006). What these educational ideas have in common is the recommendation that students ought to have great latitude in formulating problems, acquiring relevant knowledge and information, creating/designing solutions, and reflecting on/evaluating the learning process.

In a number of respects, open-ended pedagogy of this kind improves students' understanding of complex problems and their contexts, encourages independent thinking and decision-making, and provides students' with a strong sense of owning their education (Savery 2006). However, I have observed not a few educators who misunderstand student-centered learning as a "hands off" sign on their part. In some cases, the instructors simply tell the students to go ahead and perform a task by themselves without proper "scaffolding"—to provide the basic framework of analysis or to point them to relevant resources (Hsi and Agogino 1995). For example, the Engineering Clinic at HMC requires students to analyze the social implications of their clinic projects without sufficient structured instructions about how to do such analysis. In Chapter 3 I argue this open-ended assignment fails to help many students think deeply on the social dimensions of engineering.

I find three additional considerations relevant to the "hands-off" style of student-centered learning. First, the appropriate degree to which learning should be left to the students is contingent upon how much space students have for "trial and error." For example, most PDI students have seven semesters to experience the "messy" and iterative design process. Therefore, in spite of the initial confusion, frustration, and

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they fail to accept the traditionally trained engineers as their colleagues and thus entrap themselves into a "social/technical dualism."

resistance some students felt in early studios, most of them grow increasingly comfortable with and competent at the design process as they proceed through the design studio sequence. The same strategy might be less suitable at Picker, where students only have one design course during the first year and one during the senior year. Second, because successful students-centered learning actually depends on instructors' massive work behind the scenes, the depth of students' learning therefore corresponds in part to the instructors' expertise in the domain where learning is supposed to happen. For example, if the instructors of the Engineering Clinic are not experts in analyzing the social implications of design, students will encounter more difficulty trying to "figure them out." In contrast, the "learn by oneself" approach gains greater success in E80, partly thanks to the instructors' rich expertise in experimental engineering (it happens that instructors are often willing to leave questions they are not best at to the discretion of students). Third, students' chance of success in learning by themselves is affected by the environment they are more frequently exposed to. In other words, when students are left on their own, they are more likely to learn things that are similar to what is available from other courses or from classmates, etc. For example, if PDI students are left alone to develop their own design approaches, they might draw heavily from their engineering learning, which takes the majority of their course time, and develop a more "engineering" than "social science" approach to design. Thus, it may be that there remains a "hidden curriculum" even within the best meaning programs that seek to reform and broaden the education of technical professionals (Synder 1970).

7.2 Technocracy, regime of truth, and the ideology of the engineering profession

Close observation in three educational initiatives that strive to bridge engineering and the liberal arts offer an opportunity to revisit the question of technocracy. One might assume such hybrid programs are less "technocratic" than the conventional engineering programs. This might be true if by "technocratic" one means overwhelming attention to the technical principles and relative disregard to the non-technical factors. Yet technocracy would be less salient among instructors and students preoccupied with equations, mechanical drawings, and circuits if by that word one refers to a philosophy about the proper relation between technology and society, e.g., as Alder suggests, "a monolithic entity whereby politics is reduced to administration, and the social life is subordinated to the demands of the machine" (Alder 1997, 317). In contrast, the three educational initiatives examined in this dissertation all take pain to make engineering learning socially relevant; they also create numerous opportunities for engineering students to confront social problems. Through observing engineering students' attempts to solve social problems I perceive a kind of technocratic thinking that has not been elaborated in philosophy and sociology of technology. In the following paragraphs I try to characterize technocratic thinking of this sort and to explore the structural forces that empower this thinking pattern.

7.2.1 Technocracy as a habitual way of thinking

In the course of conducting this research project, I was intrigued by the engineering students who are not content with "crunching numbers" and who aspire to apply engineering to social changes according to their own visions. Indeed, the trust in the primacy of numbers, the worship of efficiency, and the suspicion on non-technical and non-expert perspectives are still strongly present in the thinking of these students, in spite of their relatively holistic education. Nevertheless, in their daily learning experiences, on many a mundane occasion when they are asked to put on the hat of "engineer the problem solver," rarely do they make decisions based on a systematic philosophy that evaluates the pros and cons of technical or alternative rationales. Instead, they tend to approach the problems somewhat instinctively.[113] It is in their instinctive approaches to social problems I have come to notice technocracy of a particular sort.

What I refer to as technocracy here is a habitual way of thinking. Chapter 5 documents a few manifestations of this "technocratic way of thinking." This mode of understanding includes several key features. First, before identifying particular

[113] If one traces these instincts carefully, one might discover their link to the discourses students live in; e.g., the youth culture, the media, teachers, family, etc.

techniques, artifacts, or other technological solutions which might help address the problems in front, the technocratic students often invoke *the concept of technology* itself. That is, they tend to assume the core of the solution has to be technology of some sort, while the specifications of, or even the existence of, such technology is yet undetermined. With this resolution, further analysis of the problems is replaced by counting (or expanding) the inventory of technology. For example, in PDI Studio One, students discussed the difficulty of not knowing enough details to choose the technology that will perform the intended function, and they were told (and agreed) not to worry about it because sooner or later a new technology will come along to fill that "black box."

Second, drawing upon the technocratic way of thinking, students automatically enroll the concept of technology in social problem solving, as if there is no need to justify the preference for technical solutions over alternative, non-technical ones. There is no evidence that such a preference is based on rational calculations of maximum efficiency or optimal outcomes. The enrollment of the concept of technology appears more like a habitual move built into the minds of these students, perhaps a deep cultural presence generated by earlier experience in their lives. As Chapter 5 shows, a number of students in PDI Studio One turned to smartphone apps as an omnipotent solution to problems of education and healthcare. Why a smartphone app could deepen one's learning or how surveillance of physical data would improve healthcare seemed no problem to them. This choice seem for them a normal, sensible response to whatever problem was posed for consideration.

Third, the habitual resort to technical solutions is based more on ideological than methodological concerns. Ideally, if technology provides the appropriate tools and methods for problem solving, choices about when to incorporate technology, which technology to include, and how to deploy it should be made according to inquiries into the particular problems. However, the technocratic students presume the omnipotence of the technical tools and often neglect the substances of the particular field where the problems arise. They frame problems not according to the "thick" contexts of the problems but through the lens of the particular technical tools within today's technological milieu. For example, educational problems within the mode of "big data" are not defined by the rules of teaching and learning but by what "data" should be collected, if the students presume "big data" as the final answer.

This logic reflects what Winner calls "*reverse adaptation*—the adjustment of human ends to match the character of the available means" (Winner 1977, 229). Winner also reveals the ideological nature of the reverse adaptation:

> But even more significant is the state of affairs in which people come to accept the norms and standards of technical processes as central to their lives as a whole. A subtle but comprehensive alteration takes place in the form and substance of their thinking and motivation (Ibid).

Indeed, this "technocratic way of thinking" is not confined to the realm of engineering. Examples in other fields abound. One could easily discern it in the obsession with standard tests in K-12 education, the reliance on computational models in finance, the medicalization of problems about emotions, sex, appetites, weight, etc.

7.2.2 A dominant "regime of truth"

Section 7.2.1 describes technocracy as a habitual way of thinking, which is automatically prioritized by many engineering students with little practical ground. This may lead one to assume that technology really acquires some autonomy not in the material world but in the realm of thinking. In my view this assumption is not true. For the technocrats, the concept of technology may appear like a sovereign in the kingdom of thinking, but the dominance of habitual ways of thinking is not confined to technocracy alone. In the recent four decades, the concept of "free enterprise" has acquired no less prominence in politics, economy, and other realms of social problem solving than that of technology (Harvey 2005). Diane Ravitch (2011) provides an insider's account of how the "free enterprise" ethos colonized American educational thinking since the 1980s. With little empirical justification, the "entrepreneurial reformers" launched waves of initiatives to reconstruct public education; these reconstructions centered on "accountability" and "test," concepts directly copied or derived from market economy and corporate management: private run schools were encouraged; resources were reallocated to incentivize competition; the autonomy of professional educators was attacked. The moves toward bold reconstruction of long-standing institutions reflects an assumption similar to what is withheld by the technocrats: the field of education can be successfully reconstructed with an omnipotent tool—in this case the rules for organizing corporations—and there is no need to seriously engage the substance (knowledge) of education or the expertise of professional educators. Another example of habitual way of thinking can be found under the flag "innovation." As is true of common beliefs about "technology" and "free enterprise," the widespread fascination with "innovation" today enjoys significant ideological and linguistic power and shapes the "mega-narrative" of our time (Winner 2009).

Philosophers of technology have reminded us of the connection between technology and the dominant power structure in society. Winner (1977) suggests the foundation of power shifts from political support to knowledge possession with the ascendency of technocracy. In a similar vein, Feenberg (1999) argues the technological order acquires social hegemony when it is increasingly accepted as "natural" and shielded from critical examination. If technology alone does not determine the prevalence of technocratic thinking, I wonder whether there is an assemblage of more profound structural forces that "enthrones" technology as the sovereignty to govern the realm of thinking, and whether the same forces might also systematically empower other particular thinking patterns (e.g., free enterprise, innovation, etc.).

This hypothesis finds some support in Foucault's concept of a regime of truth. In *Power/Knowledge*, Foucault (1980) dispels the illusion of truth that exists free of/outside power dynamics. Instead, Foucault argues:

> Truth is a thing of this world: it is produced only by virtue of multiple forms of constraint. And it induces regular effects of power. Each society has its régime of truth, its 'general politics' of truth: that is, the types of discourse which it accepts and makes function as true; the mechanisms and instances which enable one to distinguish true and false statements, the means by which each is sanctioned; the techniques and procedures

> accorded value in the acquisition of truth; the status of those who are charged with saying what counts as true" (Foucault 1980, 131).

Foucault goes on to characterize five important traits of the regime of truth which is operating in contemporary Western societies: it centers on a "scientific discourse" and the institutions that produce this discourse; it is subject to "economic production" and "political power;" it provides the object of "immense diffusion and consumption;" it is dominated by a few "great political and economic apparatuses" (including university); and finally, it undergoes "ideological struggles" (Foucault 1980, 131-132). Foucault adds that such a regime of truth is "a condition of the formation and development of capitalism" (Foucault 1980, 132).

Technocracy, as I observed from the case study programs illustrates the functioning of a regime of truth, consistently designates a particular way of thinking as "truer" or more appropriate in social problem solving. In addition, technocracy embodies what Foucault takes to be the governing regime of truth in contemporary Western societies—what I call the dominant regime of truth—in at least three ways. First, the privilege enjoyed by the concept of technology resonates with the centrality of a scientific discourse. Second, the prominence of technocracy among engineering students is reinforced through a great, highly regarded institution in society—the university.

7.2.3 Predictable rewards and punishments

Foucault's thesis of a regime of truth is laid out in a reply to an interview question about the changing role of intellectuals in the second half of the twentieth century. In the brief response Foucault does not explain how the regime of truth operates in intellectuals' daily cognitive practices. However, a clue for this question is offered in *Discipline and Punish* (Foucault 1995). In the section entitled "Normalizing judgment," Foucault depicts a penal mechanism, which plays at the heart of all disciplinary systems (Foucault 1995, 177-184). In particular, Foucault notes the dual-function of the gratification-punishment, i.e., the employment of rewards and penalties, works to reinforce behaviors that are deemed "normal" by the disciplinary system and correct those labeled “abnormal.” From my fieldwork I observed a similar mechanism at work in engineering education, where predictions about rewards and punishments provide the primary means to actualize the dominant regime of truth. To be sure, engineering students’ ways of thinking are affected by multiple incentives and constraints. In the meantime, a great many students’ intellectual lives seem oriented by the prospect of rewards and punishments embodied by jobs, instructors, and the boundary work of what is (or is not) engineering.

In all three case studies, the concept of “job” serves as a crucial indicator of an economy of symbolic rewards and punishments. Imaginations about employers’ preferences and the terror of unemployment—the yin and yang of a reward/punish agent—are woven into the texture of students’ college experiences. In previous chapters I note several cases in which appeal to employers’ interests is incorporated as a cognitive subject into engineering teaching and learning; e.g., the staff of HMC Career Services solicited employers to the job fair during the orientation of the Engineering Clinic; the engineering class I observed at Smith invited a PR specialist to lecture on network skills, etc. The symbolic weight of one’s conceivable future job—often in a business firm—is also institutionalized in the career offices that exist in all three colleges—HMC, Smith, and RPI—and obviously many other institutions of higher education.

By the term “symbolic weight” I do not deny the existence of rewards and punishments associated with a job. After all, the benefits of a good career and the financial burden inflicted by unemployment are real. However, the realities of being hired or unemployed need not always happen, for expectations and predictions about what makes one “employable” often suffice to guide students’ thinking and actions. For example, in Chapter 3 I report a student at the info session of PA Consulting Group, who felt anxious when his prediction of the need for technical capabilities was not mentioned by the human resource staff from the company. The terror of not having a job at the age of twenty-two becomes more intensified as students are faced with rising cost of college education and an uncertain economy. It often appears to many students their college education has been a complete failure if they are not hired immediately after graduation.

Yet strong emphasis upon unemployment seems exaggerated. I interviewed two HMC and five Picker senior engineering students, and none of them had been hired at the time of the interview. They also told me many of their peers were prepared to keep looking for jobs after graduation.

As I saw in the three programs, many engineering instructors are willing to demonstrate their professional credentials to students, and the latter look to their instructors as direct role models. Hence instructors' comments and advice, both positive and negative, constitute a powerful mechanism through which students are, in effect, rewarded and punished. For example, Chapter 3 documents the instructors in E4 who accentuated the constraints and the relevant actors at the professional setting (e.g., the production line, the supply chain, etc.). Such emphasis drew students' attention to the "microcontext" of engineering, to the immediate people and materials that take part in the functioning of an engineering system. Chapter 4 records students' deliberation on an ethical dispute reached a "closure" after they read an authoritative answer from the National Society of Professional Engineers. The instructor's action implied ethical dilemmas should be resolved according to the "cannons" of professional societies rather than through on-going inquiries. Chapter 5 notes the instructor of PDI Studio One cordially praised students whose design ideas express bold visions or strong faith in the progressive values of technological innovation, whereas students who attempted to question the feasibility or appropriateness of such audacious design were asked to drop their critical attitudes. The instructors' responses communicated a clear message to the students about which particular ways of thinking are encouraged or discouraged.

Students' individual reports also reveal the impacts of instructors' acknowledgement or its absence. For example, Ms. P5 pointed out the instructors' approval (e.g., the awarding of a scholarship) encouraged her to thrive as a leader in connecting engineering to relevant social purposes. In a different case, Ms. P7's attempt to bring her personal (racial) identity to engineering was frustrated by the aloofness of some engineering faculty about such matters.

Chapter 6 shows students often have their own distinct definitions of engineering. Yet in light of Foucault's arguments on similar matters, the boundary work of what is or is not engineering is not free from the operation of power. When a student's definition of engineering conforms to the vision widely shared among the instructors and in the profession, she can readily predict a favorable reception. In contrast, those who are determined to pursue alternative definitions of engineering are also preparing for possible skepticism and rejection. For example, from a professional point of view, cost is accepted as a legitimate part of engineering. Thus in the Engineering Clinic at HMC, a team that proposed to order a 3D-printed model heat exchanger without sufficient analysis of the economic cost (risk) was serious questioned by the instructors. Ms. D2, who received the distinct impression from her teachers that engineers tend to be hostile to sociological critique, decided not to pursue an engineering career but one that works both inside and outside engineering (as an educator of engineers about the social contexts). When students present themselves on the job market, they are measured by what employers take to be proper the engineering capabilities. Chapter 6 reports a number of broadly learned students who are "punished" by the employers' boundary work—their visions of more disciplinary-based engineering. In these cases, the rewards and punishments associated with the definition of engineering overlap with those related to prospects for finding a job.

To sum up, the main springs that link together the machines of rewarding and punishing in engineering education—job, instructors, and the boundary work of what is engineering—embody the ideology of the engineering profession: a job represents the permission of entrance to professional engineering; the instructors—experienced members of the engineering community—personify the norms and values of the profession; the boundary work charts the epistemological terrain of engineering.

7.2.4 The prospect of reconstructing engineering as a liberal art

Besides affecting methodological choices, technocracy also quietly continues a political tradition pioneered by ambitious engineers during the Technocracy Movement, or even earlier, during the Enlightenment. This tradition paints a "neutral" picture of technology and conceals the political nature of engineering epistemology. The myths of "neutral" technology and "apolitical" engineering epistemology have been thoroughly explored and criticized within the literature of Science and Technology Studies. (Layton 1986; Winner 1986; Bijker, Hughes, and Pinch 1987; Smith and Marx 1994; Alder 1997). I merely want to add that the assemblage of the privileged ways of thinking, e.g., the coupling of technocracy and a mega-narrative of innovation, contributes to the functioning of today's political-economic machinery of capitalism. On the production side, this assemblage induces workers (e.g., engineers) who are creative of sorts and think "out of the box" so far as to bring about new products and ideas that stimulate the curiosity of consumers who spend more for wants than needs. But creativity of this kind does not extend to the work of examining and, perhaps, challenging the ideological foundations of the profession and the existing political-economic order. On the consumption side, the complex of privileged ways of thinking tout the model life of a professional with expected income, material comfort, etc. The appreciative attitude toward technical innovation also prepares the professionals for their own timely consumption of new gadgets, new experiences, etc.

Hence it is understandable that the prevailing system of rewards and punishments in engineering education is configured in ways that encourage cheers for familiar technocratic instincts and frown upon any need for critical reflection, since the latter threatens to reveal and challenge the dominant power structure in the engineering profession and in society as a whole. The kinds of critical reflection characteristic of a genuinely liberal education might lead to doubts about the authority of technical professionals and recommendations of more democratic and inclusive decision making in engineering practice. It might even suggest that young engineers do not have to follow the old codes of behavior and pay tribute to established members in the profession. It might encourage engineers to design in ways that envision less rather than more material consumption in an emerging social future.

Political leaders in the U.S. continue to call for more and better educated graduates, including scientists and engineers. However, what they have in mind are often the engineering and science students educated in China, South Korea and India, who spend millions of minutes soaking up repetitive and reductive methods of problem solving (Compton 2007; Koo 2014). It is therefore uncertain how much today's leaders in efforts to reform the education of technical professionals can reasonably expect to achieve. For in fact, a genuine liberal education comes not only from schools but also—more importantly—from culture at large. It is hard to imagine children raised in a culture of careful reading, deeply engaged discussion, and free inquiry to feel at ease if they are taught decontextualized and technocratic problem solving in engineering schools. On the contrary, it might be difficult to teach a holistic, interdisciplinary, and reflective approach of engineering for students who have grown up in a culture that encourages obedience, greed, and excessive consumption. Perhaps the final test for the integration of engineering and liberal education is to determine the extent to which we are committed to a genuinely meaningful education for young people within the boundaries of our society, economy, and culture as a whole.

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