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When Engineering Meets Self and Society: Students Reflect on the Integration of Engineering and Liberal Education

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Introduction

A growing number of educational institutions and educators have taken up the mission of providing young engineers with a liberal education. Lessons learned through integrating engineering with teaching and learning in the liberal arts are routinely shared at the Division of Liberal Education/Engineering & Society in American Society for Engineering Education and other platforms, such as Union College's annual symposium on engineering and liberal education.[1] Publications on the integration of engineering and liberal education focus primarily on the perspectives of faculty and administrators; few have investigated students' experiences of learning engineering in a liberal education environment. Except for the occasional headline success stories about alumni who graduated from programs that blend professional training with broad studies in the liberal arts, we seldom hear students evaluate such integration-oriented programs in their own terms: What do they expect from a more holistic model of engineering education? In what ways do they find a more comprehensive learning experience empowering or constraining? What do they appreciate the most about their programs? What changes do they wish to see? This paper looks into the "user experience" of educational initiatives that seek to bring together engineering and liberal learning.

The analysis presented here draws partly upon my dissertation research, a cross-institutional investigation of integrating engineering and liberal education. The dissertation research seeks to understand the forces that motivate educators to blend engineering learning with liberal studies, the institutional and pedagogical strategies used in different integrative programs, and the impacts of liberal learning on students' understandings of engineering and its social context. In this paper, I focus on a subset of the research questions posed for the dissertation:

- What motivates students to study engineering in a liberal education environment?
- In what ways does the experience of "a liberal education for engineers" assist students' personal growth and career development?
- To what extent does students' understanding of engineering take into account the social dimensions?

Methods

My dissertation research includes in-depth case studies of three programs that seek to educate engineers as liberal learners: the engineering program at Harvey Mudd College ("HMC" hereafter), a liberal arts college for engineers, scientists, and mathematicians; the Picker Engineering Program ("Picker" hereafter) at Smith College, the only ABET accredited engineering program in a women's liberal arts college; and the program of Design, Innovation, and Society ("DIS" hereafter) at Rensselaer Polytechnic Institute, a program that blends engineering, arts, and critical social studies in design learning.

Data for the dissertation research project was collected using three qualitative research methods: archival research, interviews, and participant observation. Documents containing information about the history, institutional arrangements, and educational policy of each program were acquired from online publications and archives. A total number of 39 semi-structured interviews were conducted with faculty, administrators, and students from the three programs. I spent about 220 hours as a participant observer in classes, research activities, and campus events; I wrote extensive field notes about the teaching styles, group dynamic, and student reactions in every program. Fieldwork at HMC was conducted from September to October 2013, at Picker from January to May 2013, and at DIS from August to December 2012.

What I report hereafter is primarily based on interviews with 13 students from the three programs (five from HMC, four from Picker, and four from DIS). An IRB approval was acquired from Rensselaer Polytechnic Institute prior to the interviews. The interview protocol resulted from a pilot study on engineering students' epistemological development that I conducted in 2012.[2] A sample interview protocol is presented in Table 1. Students volunteered to participate in the interviews, which lasted from half an hour to one and a half hours (most interviews lasted about an hour). With the consent of my informants, interviews were digitally recorded and transcribed. Coding of interview transcriptions started with a set of mid-range schemes derived from the research questions presented at the end of the "Introduction" section.[3] Transcription excerpts were first grouped into six categories: "choice of major," "choice of college," "evaluation of college experience," "career plan," "imagination of the profession," and "notion of engineering learning." Within each category, inductive coding was conducted to discover recurring themes from student reflections.[4] Where appropriate, field notes from participant observation were used to supplement students' narratives (e.g., sometimes students in the interviews referred to their projects, the content of which was documented in my field notes). Data from archival research was used to compose a brief introduction of the historical and contemporary background of the three programs and their respective pedagogical approaches in the following section.

The Case Studies

The three programs I chose for case studies all share a common objective: to educate engineers as liberal learners. In the course of unifying engineering and the liberal arts, however, each program follows a unique trajectory and takes distinct pedagogical approaches.

In 1957, Harvey Mudd College welcomed its first class in Claremont, California. Several founders of the college had worked in military-related projects during the Second World War, when they witnessed the power of modern technoscience and the shadow of its destructive potential.[5] Inspired by a nationwide postwar discussion of reforming engineering education, founders of HMC envisioned a new pattern for educating technoscientific experts, who would become leaders in utilizing science and technology to serve social good.[6] Educators at HMC strived toward this vision in the following half a century. As of 2013, HMC has some 780 students studying six majors: engineering, math, physics, chemistry, biology, and computer science. The college is a member institution of the Claremont Colleges, a consortium of liberal arts colleges. According to the latest *U.S. News & World Report* "National Liberal Arts College Rankings," HMC is ranked the 16th best liberal arts college in the U.S.[7] It is also ranked the 2nd best undergraduate engineering program among U.S. schools "whose highest engineering degree offered is a bachelor's or master's."[8]

HMC students enjoy rich resources for liberal arts education, both on campus and from the other member institutions of the Claremont Colleges. Though surrounded by some of the most renowned liberal arts colleges in the country, HMC keeps a significant faculty in humanities, social sciences, and arts (HSA). The HSA faculty plays an indispensable role in maintaining HMC's commitment to liberal education. All HMC students take a Common Core curriculum during their first three semesters. This experience provides all students--regardless of their majors--with a common language and a broad knowledge basis. The Common Core includes courses in every major as well as in academic writing, and a critical inquiry class taught by the HSA faculty. The critical inquiry class has multiple sessions taught by different instructors. Each session focuses on a topic that is related to the instructor's specialty, yet all the sessions have a common component: for the first few weeks, students and instructors engage in a discussion of the meaning of liberal arts education and its implications for HMC. In addition to completing the Common Core, every student at HMC is required to take at least ten courses in HSA, with at least four courses in an area of concentration. The engineering curriculum at HMC consists of three stems: design, engineering sciences, and system. The design stem includes three courses: Introduction to Engineering Design (E4), Experimental Engineering (E80), and the Engineering Clinic, where students work on a real world problem proposed by an industrial sponsor.

About four decades after the founding of HMC, educators at Smith College--a women's liberal arts college in Northampton, Massachusetts--thought engineering a logical extension to the liberal arts curriculum and to Smith's history of providing women with opportunities in advanced education.[9] Smith College founded the Picker Engineering Program in part to combat the underrepresentation of women in engineering. The college also came to appreciate the essential role of responsible engineering practice in bringing about social justice and sustainability, goals to which Smith has committed itself. Over the past decade or so, Picker has graduated 278 women.[10] The program offers two degrees: an ABET accredited B.S. degree in Engineering Science and a B.A. degree in Engineering Arts; the latter is a liberal arts degree for the study of engineering.

At Smith, an engineering student has to either fulfill the Latin Honor--by taking 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--or to complete a minor in an area outside engineering and natural science. Engineering education at Picker is oriented to applications, especially those related to sustainability and community service. Most courses at Picker encourage students to use engineering knowledge to analyze and solve problems in the real world. In the introductory course Engineering for Everyone (EGR100), students work on projects like community farming and disaster relief. The Design Clinic, a year-long capstone design experience required for every B.S. engineering student, often collaborates with public sectors or NGOs on projects like wetland restoration, water purification in developing countries, and so forth. The college's mission of promoting women in fields of leadership is also echoed in the engineering program. For example, the Design Clinic dedicates a number of class sessions to discussing women engineers' career paths, work-life balance issues, and negotiation skills at workplace.

Around the same time that Picker was founded, educators at Rensselaer Polytechnic Institute, one of the earliest engineering schools in the U.S., were also attempting to renew its educational paradigm. Inspired by the studio-learning method widely used in architecture education, founders of the program in Design, Innovation, and Society created a sequence of design studio courses that blended engineering, arts, and critical social analysis. To make sure students become socially sensitive and responsible designers, the new interdisciplinary design program was hosted in the Department of Science and Technology Studies, a critical social studies department. At present, DIS recruits some 30 students every year, the majority of whom pursue a dual degree: a B.S. degree in mechanical engineering and a social sciences degree in design. Besides mechanical engineering, students also come from a variety of disciplines: electrical engineering, computer science, management, graphic design, cognitive science, etc. Students routinely work with teammates from different departments.

Students in DIS take seven design studio courses. Each studio emphasizes a particular theme: Interdisciplinary Design, Product Development, Industrial Design, Introduction to Engineering Design, User-centered Design, Design Entrepreneurship, and Capstone Design. Instructors come from a variety of disciplines: engineering, social sciences, management, and the arts. Several studios are co-taught by faculty from different departments. In every studio, students complete one or several individual or team-based design projects. An iterative design process characterizes many a project, which starts with user need analysis and problem identification, and, in many cases, ends with prototypes and presentations to instructors, classmates, and guests from the public.

Due to the distinct histories, demographics, and pedagogies that characterize the three programs, students in each program are affected by different visions of engineering learning; they also experience modes of liberal education that differ from one another. Considering the scope of this paper, I focus upon some of the common themes expressed by students across the institutions. Occasionally I point out features that are most relevant to a particular program.

To protect the identities of my informants, their names are replaced with codes. The five interviewees from HMC are referred to hereafter as H1, H2, H3, H4, and H5, the four interviewees from Picker P1 to P4, and those from DIS D1 to D4.

Table 1. Sample Interview Protocol for Students.

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?

Findings

Choosing Engineering in a Liberal Education Environment

For all my informants, the choice of engineering was made after weighing a number of factors.

Some of their motivations were similar to those that drive students to traditional engineering programs: family influence, love of math and science, and career prospects. At least five informants have one or more family members who are engineers; some of them believe they were "raised to be" engineers. Almost every informant enjoyed and excelled in math and science during high school. Some informants' rationale for studying engineering matches the common image of engineers as "pragmatists": they value the career flexibility provided by engineering training. For example, H2 thought an engineering degree would open doors to a variety of careers: an M.B.A., law school, graduate school in science or technology disciplines, and so forth. Four other informants also see a natural pathway from engineers to managerial positions later in their careers.

The career flexibility afforded by engineering is further increased as educators in the three integrative programs take a holistic approach and focus their teaching on the fundamental skills required for engineering practice. In both HMC and Picker, the primary engineering degree is a B.S. degree in general engineering, a deliberate choice by the educators to minimize the boundaries separating different engineering fields and to equip students with the basic knowledge in a number of engineering disciplines: electrical, mechanical, chemical, etc. Once a broad knowledge basis is established, students are free to choose a field of concentration, or to continuously branch out their learning. H4 concentrated in mechanical engineering during his junior year; later he discovered his real passion in communication and easily switched his concentration to electrical engineering. H5 spent her first two years at HMC shopping courses in engineering and computer science. She eventually majored in engineering because of her love for the hands-on work, but her expertise in computer programming made her a favorite in the Engineering Clinic team. In Picker, the option of a B.A. degree gives students even greater latitude. P4 finished her first three years as a B.S. student, and then she discovered she was more enthusiastic about social sciences than engineering. Switching to a B.A. degree in engineering arts allowed her to build on all the engineering knowledge she had learned while giving her the freedom to explore subjects like women studies and arts. D4 wanted to study industrial design but was not sure about going to art school; she was therefore delighted to find the combination of engineering and design at DIS.

Some of my informants' choices of programs reflected their preferences for alternative modes of engineering training. Five informants looked for engineering programs with substantial hands-on experiences; another four students expressed an explicit need to study technical knowledge that serves clear human purposes. I do not deny that students in traditional engineering programs might have similar preferences. Nevertheless, the three programs I chose to study all emphasize open-ended problem identification and solution, the ability to work with tools and to make products, and consideration of the people affected by engineering; these priorities arguably give students more opportunities to do engineering with their hands and hearts. When H4 visited HMC as a high school student, he stayed with an HMC student, who was taking a tool class. Late that night, the student brought H4 to a workshop where a group of students worked together to build a hammer. There H4 discovered the kind of college life he had looked for: friendship, relaxing group dynamics, and the hands-on work. H5 lingered between engineering and computer science for quite a while; she eventually chose engineering because in computer science there are not a lot of objects "you can touch and make sure it works." Among all the six majors at HMC, engineering is widely regarded to have the heaviest workload, and sometimes H5 would question her choice when she was overwhelmed by homework and projects. However, whenever she managed to make a product work, she felt "satisfaction, relief, and just plain happiness." At DIS, students are introduced to prototyping techniques within the first two months of college, whereas most of their peers in engineering don't start their first design project until the fourth semester. Design learning is also built into the first engineering class at Smith--EGR100. Every week, the class meets twice in a studio and once in a lab. In the lab sessions, students learn to use a variety of tools. Every student team is also required to build a prototype for their final course project.

Serving people's needs was also regarded as a top priority for engineering learning across the three programs I studied, a crucial factor for some of my informants' choice of engineering. P2 had worked as a graphic designer for a company before she went to Smith College. Although she enjoyed the artistic and creative aspects of graphic design, she found her work experience unfulfilling. In contrast, engineering gave her a sense that it mattered. For her Design Clinic project, P2 and her teammates made a medical device to reduce hair loss for cancer patients during chemotherapy, a project that actually helps people in need, whereas "making business cards" didn't make her feel that she was "contributing to the greater good." At HMC, the Introduction to Engineering Design course (E4) often culminates in a project for which students collaborate with a non-profit organization. In this class, H3 worked with Aid Africa to develop an efficient stove for people in Uganda. In the second studio course of DIS, the final assignment asks students to define one of the major world problems and to design a device to help tackle it.

Expanded Horizon and Well-rounded Professionals

Students' evaluation of their educational experiences partly reflects the extent to which they are committed to the idea of liberal education. In other words, as I was told by more than one informant, "you get out as much as you put in" a liberal education. Most students I spoke to sincerely appreciated the opportunity to study extensively in the liberal arts, which reminded them of the big picture and helped meet their diverse intellectual interests. At the same time, a few of my informants take a more instrumental approach to liberal education.

P2 had always been told she should go to a liberal arts college: "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." As an engineering major at Smith, "it's been obvious we're members of the world, not members of the engineering world." P2 lived an active college life as a member of the world. In college she designed advertisements for a local art school, edited a magazine to present scientific research to public audience in more interactive styles, and co-founded the aeronautics club at Smith. Some of her classmates chose to expand their horizon by travelling to different parts of the world. P1 spent a semester in an exchange program studying architecture in Denmark; she also made a field trip to Nepal with her teammates, gathering information for their Design Clinic project. P4 pursued a minor in Portuguese. While she was studying in an exchange program in Brazil, an independent study course attracted her to social sciences, after which she made her mind to switch to engineering arts.

When H4 first came to HMC, he didn't have a good understanding of what a liberal arts college meant, other than taking a bunch of humanities courses. He changed his view over the following years, when the liberal education "has often manifested itself in that we are not OK just passing classes." Students at HMC want more than a passing grade; they are eager to learn something from every field by putting in honest work. As a senior, H4 thought liberal education is less about taking classes in humanities or any particular subjects: "The love of learning mentality is important to liberal arts than whether a class is humanities or tech. We kind of learn to love learning by taking some humanities classes that aren't so easy for us and figuring out this is how I want to approach things I don't necessarily love." A similar passion for learning is also embodied by students in DIS. D3 noticed a difference between her peers in mechanical engineering and her classmates in DIS. When D3 took Introduction to Engineering Design with other mechanical engineering students, one of her teammates rejected a task involving electronics because "I'm not an electrical engineer." D3 recalled students in DIS were not used to saying "Oh I can't do that." On the contrary, they believed in "fail earlier in order to succeed sooner." In the design studios, students often intentionally switch their roles so that people can work on something they are not so good at.

More than half of my informants appreciated the liberal arts requirements in their programs, which created opportunities for them to pursue their interests in numerous fields of study. H4 told me one of the coolest courses he had taken at HMC was a course in Victorian literature. In class they read a number of Dickens and Hardy's works. During the winter break following the course, two professors took the class on a trip to England, where they visited the places written about in the books they had read. After switching to an engineering arts degree, P4 had more freedom to take courses she enjoyed: dance, swim, etc. D2 came from an engineering family. Though she always felt she was raised to be an engineer, she wanted a twist, a "more creative approach to engineering." DIS, which teaches not the right or wrong answers but creative problem solution, met her expectation perfectly. H3 chose HMC partly because he wanted the space to explore his interests in politics and third world development, together with engineering. At HMC, his interests were met not only by the HSA department but also by the other institutions of the Claremont Colleges.

HMC and Picker require students to take a higher proportion of non-technical courses than most traditional engineering programs. Overall my informants found the "humanities courses" a nice break from more demanding technical courses. Electives in the humanities are often considered "easier," "less stressful," and they do not have homework due every week. As a result, some students take advantage of the liberal arts requirement and choose courses strategically to balance their heavy workload generated by technical courses. H4 chose economics as his concentration in HSA. He admitted that economics classes usually involve less reading and writing than other humanities courses; whenever he had a semester full of difficult technical courses, he took an economics course that did not stretch him too much. Although he enjoyed being stretched whenever he could, the engineering curriculum at HMC did not usually allow him to do so.

Like students in other small liberal arts colleges, many of my informants benefitted from a close relationship with professors who were dedicated teachers and tutors. Students from both HMC and Picker highlighted the valuable experience of doing research with professors early in the program. Before she came to Smith, P2 was offered a scholarship from another well-known college, which would allow her to work with a researcher during her sophomore year. Access to faculty and research, something the other college was selling as a privilege, was "automatically" provided at Smith, where she was doing research with professors her first summer.

Most of my informants believed the liberal education they received will help them build a more successful career, especially in the long run. At least eight of them had internship experiences, either as researchers on campus or as corporate employees. Working on real jobs revealed to them that the professional (engineering) world requires much more than math and science. Some of the more important skills they witnessed at work included communicating with people from different backgrounds, time management, acquiring information by oneself, and reaching out for help. In retrospect, they appreciated the written and oral communication training they received from HSA courses, the teamwork experience from group-based projects, and the learning skills they developed from solving open-ended design challenges. Some informants considered their liberal education invaluable for assuming managerial positions. H1 planned to take master level economics courses at a neighboring college, as he thought knowledge of economics will be important when he makes decisions as a manager in the future. He also valued learning in subjects like history, which would increase his awareness of how his decisions impact the community and the world as a whole. D1 wanted to own his own design company, for which he pursued a minor in marketing in addition to his dual major in mechanical engineering and design.

The broad scope of liberal studies also inspired students who were not interested in the typical "engineer-manager" path to pursue alternative careers. Among the three programs, Picker stands out in preparing students for more diverse careers. The Design Clinic had a session to talk about career prospects, during which three Picker alumni were invited to join the discussion via video chat. Each of them had pursued a different career after getting an engineering degree, working as a teacher, a lawyer, and an owner of fashion business. Looking at the post-college life, P4 planned to get more experiences in urban planning, affordable housing, or labor organization, areas of her interests; she also applied to Teach For America. P3 came from Nepal. She wanted to help developing countries with her expertise and looked for jobs related to water management.

While a liberal education was widely considered beneficial for my informants' long-term professional development, their broad learning was often acquired at the expense of more specialized knowledge and skills. Dilemmas of this kind sometimes embarrassed my informants at job interviews. P1 recalled questions she had been asked at interviews, some of which were related to specific engineering disciplines, to which she didn't always have the answers because she had not taken the particular courses. Sometimes students from Picker and DIS also suffered from lack of recognition for their programs. DIS students often met employers who were confused about the social science degree in design and questioned its credibility. HMC is in a better position, for its engineering program has won significant reputation over the past fifty plus years. However, HMC students acknowledged they were not immediate fit for niche positions in traditional engineering disciplines, for which they would need graduate training.

The Social World of Engineering and Engineering as a Social World

Instead of seeing engineering as a liberal art, my informants tended to identify liberal education with their humanities courses, teamwork experiences, and communication training. In general, liberal education was regarded as a helpful but separate appendix to their engineering learning. Students in the interviews often equated engineering to the "tech courses." However, despite a rather explicit distinction between the "social" and the "technical," all my informants realized engineering does not exist independent of the social context. Furthermore, some informants had come to recognize the social interactions inside engineering practice and learning, although in most cases they were not able to articulate the social dimensions of engineering using the language of social sciences.

Awareness of social impacts is the primary goal for ethical education of engineers at HMC. According to the mission statement of HMC, the 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."[11] This mission statement suggests the dominant framework for teaching the relation between engineering and society at HMC. In the Engineering Clinic, every team was required to present the social implications of its project in a design review. Economy seemed to be the most popular field where students looked for social impacts. Among the design reviews I observed, most teams named increased efficiency and reduced cost as the major social impacts of their projects. H1 thought awareness the key for learning in HSA as well: "we are not studying to learn the facts; we are studying to be aware." Several DIS studio courses required students to analyze impacts of their design beyond economy: life-cycle analysis, environmental impact, power relation between designers and users, etc. Student were also taught to identify the “winners and losers” in sociotechnical innovations.

Design learning is another important venue to teach students about various stakeholders, as design projects often require students to think beyond the product and to pay attention to the people: users, suppliers, manufacturers, regulators, and so forth. P1’s Design Clinic team worked on improving a ceramic water filter for households in Nepal. P1 and her teammates travelled to Nepal, talked to engineers, NGO workers, potters, and went into local residents’ families to see how the existing water filters were used. “Users” is one of the key concepts emphasized in the first DIS studio course. In order to design an environmentally friendly replacement for plastic bags, students went out to interview customers in grocery stores about their shopping habits. For another project aiming at improving education, students imagined themselves as “users” of higher education; they also interviewed their friends and classmates to identify problems with the educational system. Campus research also provides opportunities for students to contact different stakeholders. H1 “worked with real world constraints” when he did research in a robotics lab, where he learned to care about project objectives and timeline and to communicate with people coming from different backgrounds (e.g., they collaborated with people from the Physics Department).

On rare occasions, I was surprised by my informants’ profound understanding of engineering through the lens of broad political, economic, and cultural contexts. P3 used to worry that the engineering education at Smith was too “friendly” and not technically challenging. She eventually changed her view as she came to realize engineering meant more than solving difficult technical problems. She took an engineering and global development course, which dealt not with math or technical questions but the intricate social aspects of engineering in the developing world. One of the case studies in the class looked at water projects in Libya, which somewhat succeeded technically, but caused constant suffering for the poor people. Intending to work in water management, P3 was significantly affected by that finding. She started to “take more of a social science approach to engineering.” When she studied in an exchange program in Israel, P3 took an engineering course on water system. Besides studying the technical problems, she also became aware that the ownership of water is a source of political conflicts between Israel and other Arab countries. She discovered which people have access to water is more crucial than the technical design of water projects.

Besides recognizing society, economy, politics, etc., which compose the macro-context of engineering, the majority of my informants also experienced the micro-context of engineering via interacting with, being a member of, or otherwise living in the social world inside engineering practice and learning. Students who had worked as interns often found their professional experiences enlightening. Reflecting on what they learned from work, they often highlighted not particular knowledge but observations like how work was arranged and coordinated between different sectors, how professionals collaborated with each other and sorted out their own positions in the corporate ecology, and so forth. During her internship, D4 redesigned a human computer interface for the engineers in her company, for which she talked to numerous engineers and manufacturing workers. D4 found that her experiences working in interdisciplinary design teams since freshmen year prepared her for communicating with different sectors at work. During one of her internship interviews, H2 handed out a research report. Instead of focusing on the research, the interviewer checked the grammar and style of writing. H2's experience reaffirmed the importance of communication in the professional world, a skill also consistently emphasized in the engineering program at HMC.

More than half of my informants frequently referred to the engineering profession as the most relevant social context of engineering learning. D1 attributed the division of different engineering departments in college to the professional world: "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." Students' tendency to identify the profession as the primary context of engineering was partly affected by the philosophy of teaching and the institutional design in their programs. In a mechanical drawing class I observed at HMC, the instructors repetitively called students' attention to the audience of their drawings: machinists, inspectors, and people who were not visible in the classroom but would be working side by side with engineers in the factories. At the program level, both HMC and Picker created structured space to bridge learning in classrooms with the professional world. Senior design projects in HMC's Engineering Clinic and Picker's Design Clinic are both supervised by industrial liaisons. In the Engineering Clinic, regular contact with industrial liaisons is formalized in a series of requirements, which are meant to prepare for students' transition to professionals. Each design team ought to have a one-hour teleconference with their liaisons every week. A team also pays at least two visits to the sponsoring company, where students learn about professional work and present their project to a professional audience. Through interacting with liaisons and visiting companies, students adopt the language, dressing code, and norms of behavior in the professional world. They also learn from liaisons a body of tacit knowledge that is not conveyed in their engineering textbooks, such as assessing team capacity, setting goals, and negotiating timelines.[12]

Knowledge about the "social world" inside the engineering profession was accompanied by students' incremental realization of the social dimensions in engineering schools. H5 had not been a team player in high school; after she came to HMC, she found the assignments so difficult that she actually needed her teammates in order to complete them. For students like H5, learning how to work in teams is one of the biggest challenges in college: very often it is nearly impossible to find a meeting time that fits everyone's distinct and busy schedule, not to mention accommodating the different learning styles. H4 recalled the many times when he and his teammates just sat together, not knowing how to proceed with their project. Despite such painstaking moments, H4 felt lucky that they had intensive teamwork experiences in college, for if they had not learned the hard lessons in college, they would have to learn them at work, paying the price of poor performance. While students I met during my fieldwork by and large accepted the non-technical work--scheduling, planning, writing documents, etc.--as a necessary part of their projects, more often they saw them not as a part of, but hurdles to, engineering. At several Engineering Clinic team meetings, I heard the team leader apologizing to her teammates for keeping them doing non-technical work: writing the problem statement, making team charter, and so on.

Like other realms of social endeavor, engineering is a world of people with relationships. This lesson became especially clear for Picker students, who often confront the gender dynamics in the engineering world. Three out of the four informants from Picker expressed concerns about the underrepresentation of females in the engineering profession and engineering schools. Two of them chose to study engineering in a women's college because they foresaw the pressure of being the gender minority in a co-educational school. More importantly, Smith's overt acknowledgement of sexism and its resolution to empower women greatly boost students' confidence. P2 visited different engineering schools when she was applying to colleges. Sometimes she met people who questioned her capability of studying engineering because she was a woman. It occurred to her "people say that racism isn't a thing, classism isn't a thing, and sexism isn't a thing, but they are all real...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."

Conclusion

Overall, students' reflections evince the merits of integrating engineering and liberal education. In particular, a well-rounded education refines students' communicative and professional skills, enhances their ability to identify problems, and broadens their knowledge bases. To begin with, my informants not only received intensive training in writing, presenting, and teamwork but also developed an (correct) attitude towards the communicative and interpersonal skills, viewing them as essential for being competent engineers. Previous studies reported engineering students in general "perceived math and science skills as more important than professional and interpersonal skills."[13] Although the results of my study were qualitative and limited to a small sample, the fact that most students actively highlighted communication and teamwork as one of the defining features of their education indicates a stronger appreciation of these skills than average engineering students.

It has also been suggested that project-based learning has the potential of moving engineering education beyond "problem-solving" toward the more comprehensive paradigm of "problem definition and solution."[14] The three programs I studied all provide rich opportunities for students to work on open-ended design projects, through which students learn to identify problems out of complex, quasi-real world conditions.

Besides assisting engineering students' professional development, extensive learning in humanities, social sciences, and arts also open their eyes to different aspects of engineering and the world beyond engineering. In addition to teaching specific knowledge and skills, a liberal education kindles students' passion for learning and encourages them to learn by themselves, thus preparing them to be "lifelong learners."

The effects of a liberal education on students' understanding of the context of engineering are mixed. Most of my informants were aware of the social impacts of engineering; quite a few of them also recognized the roles played by different stakeholders in engineering projects. However, in most cases their notion of the "context of engineering" was limited to the engineering profession, whereas broad political, social, and cultural contexts were ignored. Society often entered these students' imagination as a passive recipient of the engineering work; hence instead of assessing social needs or examining the social causes for the problems engineers attempt to solve, my informants were used to analyzing social impacts after the engineering work had been done. Few of them realized engineering itself is a social enterprise. The mentality of a "social/technical dualism," which was reported in studies of engineering culture, was also reflected in the way many of my informants viewed the "social work" embedded in engineering learning: although they accepted the indispensable nature of communication and teamwork in the success of engineering projects, they were often confused or frustrated when they were "held back" by scheduling or negotiation and didn't jump into the technical work right away.[15]

The "social/technical dualism" was also embodied by my informants who drew a boundary between their engineering learning and liberal education, attributing the latter to humanities courses. Meanwhile, they often failed to recognize disciplines in the humanities (and HSA in general) have their own, distinct epistemological standpoints. Assessing HSA disciplines against the epistemological rules in engineering, they often concluded that learning in HSA was only about "awareness" and communication skills, because there was no right or wrong answer in these disciplines. Such misunderstandings implied students' confusions about the goals and approaches of liberal education. Many of them considered their college education a parallel of engineering and the liberal arts, rather than an integration of the two.

Based on the aforementioned findings, I suggest liberal educators for engineers, including faculty in both engineering and HSA, more explicitly articulate the goals of integrating engineering and liberal education. Particular educational objectives and strategies shall be developed locally, taking into account the missions of different institutions. To start this conversation, I suggest a few generic goals: epistemological pluralism, reflection, and contextual learning.

The term epistemological pluralism is borrowed from William Perry.[16] For engineering students, it means learning about and trying to apply the methods of inquiry and the criteria for validating knowledge claims that are often used in non-engineering fields. Appreciating the value of different epistemological frameworks will help engineers respect and understand other "members of the world." Respect and understanding are preconditions for mutual trust and equal conversation.

I agree with H1 that "we are not studying to learn the facts." Liberal education is about unpacking and re-examining taken-for-granted assumptions. Stories and ideas taught in the liberal arts are but tools to assist our reflection. The engineering profession is empowered as well as constrained by a number of firmly held assumptions.[17] Liberal education should strive to help students re-imagine engineers' roles in society by reflecting on the most powerful and constraining assumptions.

Knowledge is meaningful only within particular contexts. This lesson applies to not only engineering but also history, literature, music, and any other field of study. Understanding the contextual nature of knowledge will help students assess engineering knowledge more comprehensively and practice engineering in ways more sensitive to local and global contexts.

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