ENGINEERING

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An Invitation

This thought paper is an invitation to the university community to reflect on the role of engineering at Santa Clara University. That we are at a Catholic, Jesuit university, located specifically in Silicon Valley, is only part of the story. The rest is the particular nature of Santa Clara University, including our history, our mission, and our values. How engineering helps the University become recognized as one of the top five Catholic universities in the country is another part of the story. The rest is helping the University achieve its self-defined goals, which all of these thought papers address. My thoughts and those of the reflectors in this paper represent only an initial response to my invitation. I hope that many more people will contribute theirs.

The Discipline of Engineering

When Santa Clara's school of engineering opened its doors in 1912, an engineering education prepared students primarily for the development of civic infrastructure and secondarily for development of technologies derived from the industrial revolution (mechanics and electricity). In the 92 years hence, engineering has expanded considerably to become the most prominent form of applied science, but its purpose remains to provide the most evident advances in societies and civilizations: sanitation, housing, transportation, communication, production of goods, and tangible vehicles of commerce and economic development.

The engineering design process I view as a triad: We start with a foundation of mathematics and the physical sciences (representing laws of nature we cannot change), seek solutions to human needs and desires, and bound our choices by economic reality. Imperfect, constrained problem solving constitutes the basis of engineering, and the mental discipline to incorporate basic knowledge, design creativity, and the judgment to weigh suboptimal solutions serves an engineer well both within the sphere of professional activity and in other aspects of life. In his thought paper1 on ethics and justice, Paul Fitzgerald advocates exposing students to "truly ambiguous and vexingly difficult situations" and while he refers to ethical ones these are the very conditions engineers encounter regularly in their work. In a similar vein, two engineering professors, Richard Felder and Rebecca Brent, have recently outlined the necessary progression of students from absolutists who believe in the perfect wisdom of others, to contextual knowers who respond to the complexities of the world by taking responsibility for their own learning.2

Because we need to experiment with and develop real systems, we face the "vexingly difficult" task of actually getting things to work. Often the most vexing part is having to sacrifice the ideal aesthetic in the design (and aesthetics play an important role in every type of engineering design, including software and electronics – indeed it is in design aesthetics that engineers often express Godliness) for the mundane constraints of practicality and cost. Add to that the human difficulties of communicating and understanding design specifications and the daunting challenges of bringing

[1] Paul Fitzgerald, "Ethics and Justice as integrating factors in a Santa Clara education," December 14, 2004
[2] R. Felder and R. Brent, "The Intellectual Development of Science and Engineering Students: Part 1: Models and Challenges," Journal of Engineering Education, October 2004

to a successful conclusion projects that are larger (often many times larger) than what one person can tackle, and you have a multi-dimensional profession of which technology is only a small part. For a solution must recognize the social, moral, and sentimental lines drawn by users. This is also an iterative process, and one often marked by conflict, as users are not monolithic and often want different things. There is also an element of teaching and translating, as many users do not know what is realistic or possible. To be an engineer is to listen to all these voices simultaneously. (The unintended prize? – a unique perspective on bureaucracy, in all its terrible and interlocking modalities.)

For this reason, an engineering education prepares students for many careers (and is especially well suited as preparation for medicine and law). Consider also the many career transitions an engineering graduate can expect throughout the duration of a career, not only within engineering but beyond. Fewer than 50% of engineering graduates will practice engineering to the end of their careers. The others will move, temporarily or permanently, into roles of sales, product marketing, customer support, management, or other functions in companies that also do engineering, not to mention those that move into entirely different careers. But the thought process and mental discipline, especially calling for creativity, problem solving, communication, and judgment, remain valuable over a lifetime.

Formation of Engineering Students

Students typically enter engineering school knowing little or nothing of the profession. They usually like doing things they associate with engineering, such as building things or playing with computers. I doubt that many have considered the contributions engineers make to society, though the evidence surrounds us constantly. Many students, like the public at large, equate engineering with technology. Identical they are not.

Our job, as engineering educators, is to aid their formation as leaders contributing to the creation of a humane and just world, with engineering skills and judgment dominating their toolbox. We move their thinking from tasks to outcomes; we broaden their perspective to include the real world that (oft-quoted) Father General Peter-Hans Kolvenbach refers to3 when he calls us to "educate the whole person of solidarity for the real world." We place engineering in a context that includes the other disciplines of the university, but we don't do this well enough. One of the reasons I joined Santa Clara was the inclusion of ethics, religion, and liberal arts for engineers (if only all engineering schools did this) but there are two problems. One is that most of our students do not have time to take enough of these courses. They do enjoy the community experiences we offer them both locally and internationally, but their basic requirements are heavy. To maintain our accreditation we have to cover a lot of ground in engineering and most students cannot afford to take five years for a B.S degree (though the national average for engineering is 4.8 years). The other is that our students seem to mentally separate engineering and the university core. Thus we have to do a better job in our engineering courses demonstrating the relevance of the Santa Clara core to our students ourselves.

The Jesuit values get introduced overtly in the human needs side of the triad that defines the engineering discipline and in the judgment required to find a solution under the constraints of the

[3]Peter-Hans Kolvenbach "The Service of Faith and the Promotion of Justice in American Jesuit Higher Education," October 6, 2000

three sides. We encourage students to understand "the conflict between the urge to do the right thing and an understanding of the complexities of what the right thing is."4 We want students to consider needs more than desires, to pursue both "the good of each and the good of all"5 to the extent they can. Both engineering and ethics share the objective of utility (social, economic, technological), and from a theological viewpoint both are rooted in the tension between what is and what ought to be. The objective nature of engineering provides little or no room for self-deception, and sustained exposure to an unyielding reality can lead to a kind of self-discipline that is conducive to a discerning faith. Thus engineering can reinforce concepts taught in the university core.

Note that many engineers cannot know or predict how their inventions and designs will be put to use. How would the person designing error-correcting codes for loss-prone transmission media know that they would one day enable farmers in remote villages in India to share a cellular phone to ascertain crop prices? or a drug dealer in Medellin to arrange invisibly a shipment of cocaine from Cartagena to (ironically) Corpus Christi? Through our senior design projects and faculty research we make every effort to confront students with opportunities to advance social justice through engineering, and we already have a reputation for community-based learning. We know "it is not sufficient to give students direct experiences that make them want to work for justice"6 and "all too often, students are rushed into the field to make justice happen, without sufficiently rigorous intellectual inquiry into what justice means and how its conditions ought to be fulfilled, "7 but it is unacceptable for us to deny them these experiences. They must, however, be accompanied by the "whole person" education we claim to offer.

The Blessing and Curse of Silicon Valley

Every engineering school in the country except probably Stanford and San Jose State envies Santa Clara for our location in Silicon Valley. We are embedded in the midst of opportunity, innovation (in technology, business formation, employee practices, funding, core competencies), and – the Valley's most distinctive feature – acceptance of risk and failure. We are surrounded by success, but also by excess. No place is closer to a meritocracy (evidenced by cultural diversity), but a pure one still eludes us; it works pretty well for ambitious men and Asians, less so for women, Hispanics, African-Americans, and devoted parents. Engineering students benefit by learning from those who have succeeded, and failed, sometimes in spectacular fashion. They taste the chance to contribute to innovations that the whole world knows about, and they are afflicted (positively) by the zeal for entrepreneurism, which many view as achieving the highest level of Maslow's hierarchy.

Despite its fame and benefits, the Valley presents the school with challenges. The needs of employers change rapidly, and sometimes irrationally, and the time-constant of change is shorter than the time students go through college. So the job market they find when they graduate could be quite different from the one that existed when they enrolled. The fortunes of companies rise and fall overnight, and employees move often between companies, making it difficult for the school to maintain long-term relationships with industrial partners. Topics that need to be learned by undergraduates as well as working professionals change a lot faster than the lifetimes of tenured

[4] Alan Wolfe, "The Intellectual Advantages of a Roman Catholic Education," Chronicle of Higher Education, May 31, 2002
[5] Paul Fitzgerald, ibid.
[6] Mark Ravizza, overarching thought paper on "The Mission of Santa Clara as a Catholic, Jesuit University in a Globalizing World," December 14, 2004
[7] Alan Wolfe, ibid.

faculty. And the needs of graduate students in general are pointedly career-focused, if not purely job-focused, and they are not seeking formation.

Indeed, one of our most difficult challenges is understanding how to respond to the needs of the working professional, in his or her thirties or forties, often of foreign birth, for graduate education. It would be hard to articulate what makes their graduate education distinctly Santa Claran. And it is tempting to dismiss their need as being alien to Santa Clara's mission of basic education and character formation for resident undergraduate students, but we are not a university located in rural Nebraska. This is our community, and we cannot turn our back on it. How in good conscience can we exhort our undergraduate students to engage in lifelong learning and inculcate in them a desire to do so, and then when our graduate students are doing just this, simply say NIMBY? Moreover, this community needs us for our values and as a refuge from the stress and excess the Valley dynamics engender.

We cannot settle for anything less than an engineering program worthy of our location; such is a condition of our becoming one of the top five Catholic universities in the country. To draw the talented professionals and families in Silicon Valley (and students who aspire to be so) to the school we have to offer them a high-caliber engineering education in appropriate traditional and emerging fields. To challenge them to become leaders of competence, conscience, and compassion in the process, we align our curriculum to better reflect our values, we invoke community-based learning and other tools that foster growth of character in learning, we reflect our values in our own actions daily, and we hire faculty and staff with all this in mind. Thus we infuse the Jesuit values into the broader community, one that typically does not receive such influence.

The Opportunity

The opportunity before us is to leverage the engineering school's commitment to advance the mission of Santa Clara with concrete means that will benefit undergraduate and graduate students, the school, and the university. Having a great, Jesuit-values-infused engineering program that is well-integrated into the university will benefit all parties involved; it brings the values to a previously underserved community and brings their engagement and resources to the university. I'd like to suggest a few possibilities for us to consider; I invite your ideas as well.

Define a broad, common engineering core that is not discipline-specific and that concentrates on the fundamentals of the profession. This could eliminate inefficiencies across the departments and allow us time to relate engineering to the intellectual challenges of ambiguity, complexity, and justice that are common across the university. The core could also include community-based learning for all students in engineering at all levels.

Emphasize (and support with resources) interdisciplinary programs within engineering and between engineering and other schools at SCU. Indeed, we should seek a variety of means of integrating engineering students and faculty with their counterparts across the university. This will keep the school at the forefront and distinctive academically, it will strengthen other parts of the university, it will apply engineering to many problems whose solution advances the university mission, and it will project the university into the community. We have started to do this with the Center for Nanostructures and are investigating how to incorporate bioengineering into our program; though we have not completed the bioengineering study it is clear to me that we have to do something -- one suggestion is an interdisciplinary major that is a hybrid between engineering and biology -- and it will take an investment of time, energy, and money. Other interdisciplinary themes emerging

from the faculty are environmental sustainability, mechatronics and robotics, information assurance and security, and social science studies of technology. To make them, or others, strong programs, we will need administrative resources to run them.

Introduce system design projects in every year of engineering school, and include business topics as part of the system. The role of engineers in Silicon Valley will increasingly require greater understanding of business questions and customer needs, as routine engineering moves offshore. For a start, every senior design project should entail consultation with business students and a component of the presentation that addresses the business case for the project. Stronger ties with Leavey should pervade our undergraduate and graduate programs, as should ties with local industries and the entrepreneurial community. Doing all this with an eye toward solutions applicable to the economies of the developing world would contribute to the university's goal of healing economic disparities.

Increase diversity in our engineering student body not simply through focused recruiting but through a recasting of the profession in terms of achievable impact rather than isolated activity, and through outreach activities where appropriate. Our experience, and that of others, has been that minorities and women are more attracted to engineering if they see what it can do for their communities. Santa Clara engineering is blessed with the highest percentage of female faculty of any accredited engineering school in the country,8 at nearly three times the national average, and we need to provide these faculty with support to enable them to serve as ambassadors for the profession and leading advocates for the recasting. We are barely above the national average in percentage of African-American and Hispanic faculty (at 5% each); we should double that. We are ranked 35 out of 350 engineering schools in the country in our percentage of undergraduate women, but with the drop in enrollment, especially in the class of 2007, the absolute numbers are just too small, and the percentages are still in the range of only 20%; why not 50%? Fortunately, we have received a $100,000 NSF grant to begin a formal study of some of these possibilities.

Completely re-examine the graduate program to optimize for quality, distinctiveness, and service to our constituents, not simply for revenue, while continuing to raise the profile of the program by advancing the research program of the school and encouraging more M.S. students to work on interdisciplinary theses. The result should also integrate grad students with the SCU culture, and involving them with undergrads could bring enormous benefits to both groups. (In anticipation of the university program review of our graduate programs in 2006-7 we have recently initiated such a study.)

To achieve our goals and still enable our students to graduate in four years will not be easy. However, if we concentrate on arming them with the fundamentals that will last them a lifetime, and leave more of the deeper, discipline-specific studies for graduate school, we will have succeeded. Too much of what engineers are taught at the traditional engineering schools, whose emphasis is narrowly focused on technology, becomes obsolete within ten years of graduation. A Santa Clara engineering education should yield graduates who can make informed choices about what to learn throughout their careers. They should be well-rounded professionals, aware of the impact their work and careers have on the world. They should have the career agility the profession demands, especially in Silicon Valley. And their conduct, at work, with their families, and in their communities, should mark them as products of Santa Clara engineering for the admiration of all.

[8] Accreditation Board for Engineering and Technology, 2004

Reflectors

Mark Aschheim, Ruth Davis, George Fegan, Silvia Figueira, Tim Healy, Brian McNelis, Leigh Star, David Tauck, Alex Zecevic