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The Missing Link in Engineering Education: The Arts and Humanities

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Abstract: We suggest that engineering education would benefit from a closer integration with the arts and humanities: to improve the design process, to attract a more diverse student body, and to sensitize students to the social impact of technology. Conversely, in today's high-tech environment, the liberal arts would be strengthened by introducing students to engineering concepts. We propose a program, Liberal Studies in Engineering, and outline its key components. Creating this interdisciplinary program in higher education requires confronting and transcending academic silos.

Keywords: Reforming engineering education, interdisciplinary majors and concentrations, technology and society

1. Introduction

For centuries, universities have been organized on a discipline by discipline basis. Often, those with advanced degrees in one discipline have seen no need to communicate with those outside their field. However, increasingly in the 21st Century, creative research is interdisciplinary. This kind of innovative scholarship requires both new cognitive skills and organizational flexibility in confronting academic silos. These challenges can be seen most directly in the field of engineering.

In past reports calling for the renovation of engineering education we find some claiming that the traditional engineering curriculum is too narrowly defined and inadequate to serve as preparation for professional practice. James Duderstadt, former chair of the National Science Board has said,

> "In view of...changes occurring in engineering practice and research, it is easy to understand why some raise concerns that we are attempting to educate 21st-century engineers with a 20th-century curriculum taught in 19th-century institutions." (Duderstadt, 2009, p. 4)

All other professions require completion of an undergraduate degree - some form of major in the liberal arts - before seeking professional training and certification. Engineering differs in that the first professional degree is the Bachelor of Science degree. (This means that students must decide to major in engineering before they graduate from high school.) Because of this, the undergraduate program is filled with science/engineering core requirements and restricted electives thought necessary to prepare students for practice. This severely constrains educational innovation. Furthermore, a curriculum so focused on solving well posed problems via instrumental means detracts from student understanding of the social, economic, and environmental constraints and impacts of engineering innovation - factors increasingly important in today's world of rapid technological change. This is one reason for looking to the other end of campus to establish a smoother, broader pathway into engineering.

Another reason springs from the data that shows that enrollments in engineering are declining. There is a need to broaden participation in the discipline. The American population has been changing dramatically, but the demographic profile of engineers has not - women, students of color, and students from poverty are under-represented.

We believe that one curricular innovation could address each and all of the issues: **a tighter integration of engineering education with the liberal arts.** We propose a new kind of degree program - a *Bachelor of Arts in Liberal Studies in Engineering (LSE)* - to both better prepare students for engineering practice and to increase participation in the discipline.

We acknowledge that curriculum design is a zero-sum game, and we allow for flexibility in planning an LSE program. Some institutions may find room for the liberal arts courses by replacing engineering electives. Others may introduce a master's degree in engineering as the program that provides a professional credential.

2. Women and Students of Color

National concern repeatedly has been expressed about achievement gaps in science and engineering - especially between male and female students and between White students and students of color. These gaps not only raise issues about equity in our educational systems, but also raise alarm about the future competitiveness of the United States in a high-tech information economy. These gaps are as striking in the field of engineering as they are in other fields.

Wang, Eccles, and Kenny (2013) studied a large sample of young people twice: as 18 year olds and 15 years later. They compared the SAT scores of these youths with their occupational choices at 33. They were particularly interested in those who chose a STEM career. Forty nine percent of those with high math scores and moderate verbal scores chose a STEM career. However, only 34% of those with high math scores and *high* verbal scores chose a STEM career. The majority of the missing 15% were women.

Some have suggested that fewer women choose STEM careers because women lack an aptitude for math, science, and technology. Maybe it really is the opposite: some women don't find science and engineering subjects, as currently presented, to be interesting and challenging enough. In the words of Jud King, "*That's not an achievement gap; it's an interest gap*." (personal communication)

Computer science programs have been particularly resistant to broadening the demographic. The AAUW, in a report on women in STEM, recommended a fix: (Jane Margolis and Alan Fisher, quoted in Hill, et al, 2010, p. 63): "Broaden the scope of early course work."

The challenge facing women in technical careers was articulated well by Jean Bartik, the first programmer of the historic ENIAC computer, who said that women in computing should "look like a girl, act like a lady, think like a man, and work like a dog." (Beach, 2013, p. 173)

Other observers of this phenomenon claim that "A critical part of attracting more girls and women in computer science is providing multiple ways to 'be in' computer science" noting (Hill, et al, 2010, p. 60)

> Computer science programs often focus on technical aspects of programming early in the curriculum and leave the broader applications for later. This can be a deterrent to students, both female and male, who may be interested in broader, multidisciplinary applications, and especially to women, who are more likely to report interest in these broader applications.

This finding parallels the conclusion of a classic study by Helen Astin about the research experiences of frequently-cited authors:

> "women appear to be more interested in how their work can be useful to others….They see their research as integrating knowledge and providing direction for further work." (Astin p. 68)

Based on this principle, that women seek programs that help humanity, the New Jersey Institute of Technology has offered programs to attract women to engineering for more than 30 years. (Koppel et al, 2002).

Lina Nilsson, who holds a Ph.D. in biomedical engineering, reports,

> "An experience here at the University of California, Berkeley, where I teach, suggests that if the content of the work itself is made more societally meaningful, women will enroll in droves. That applies not only to computer engineering, but also to traditional, equally male-dominated fields like mechanical and chemical engineering." (Nilsson, 2015, p. A19)

She reports similar findings from other universities. For example, 74% of the 230 MIT students enrolled in the interdisciplinary D-lab at MIT, which focuses on developing "technologies that improve the lives of people living in poverty", were women.

Research cited in an international conference, Gender and Interdisciplinary Education for Engineers, 2011, concluded:

> "that 34.6% of the male and 37.9% of the female engineering students want more interdisciplinarity (like subjects from the humanities) in their engineering degree courses and second that 26.9% of the non-engineering students say that they would have changed their minds about studying engineering if there had been more subjects from the humanities and social sciences included (Thaler, 2011)"

A study of physics departments that revealed that historically Black colleges and universities have had unique success in attracting students of color and women to physics majors by offering alternative paths to the major (Hill, et al, 2010, p. 64).

Jeffrey Froyd, in a White Paper on Promising Practices in Undergraduate Education, observes that (Froyd, 2008)

> While many national reports have repeatedly called for a set of attributes for STEM graduates that these reports state are required by recent global, societal, and economic conditions, these reports have not taken steps to clarify these attributes in terms of learning outcomes. Frequently mentioned desirable attributes include *critical thinking, lifelong learning, representation competence, interdisciplinary thinking, entrepreneurship, and systems thinking.* [our emphasis]

These are some of the attributes contributed by study of the liberal arts; verbal skills in particular are necessary for successful interdisciplinary work. Each year, the Keck Science Department at the Claremont Colleges offers a unique double course for freshmen which combines physics, chemistry, and biology. Students consistently reflect about how significant this course was in their development, "AISS encouraged me to ask deep, meaningful scientific questions in a way other science courses did not. I loved the interdisciplinary approach." Evaluators each year employ a variety of independent variables, e.g., high school grades, SAT scores, self-concepts and expectations about college, to predict the final AISS course grade (Drew and Dor, 2013). Virtually every year, the top predictor, surprisingly, has been the student's verbal SAT score.

We expect that interdisciplinary courses, including those that combine the humanities and technical subjects - the kind we see as constituting the core of a Bachelor of Arts in Liberal Studies in Engineering - will attract students who possess both quantitative and verbal skills.

3. Empathy & Engineering

In a thoughtful examination of liberal education, Michael Roth notes that "Critical thinking is sterile without the capacity for empathy and comprehension that stretches the self…..Creating a culture that values the desire to learn from unexpected and uncomfortable sources as much as it values the critical faculties would be an important contribution to our academic and civic life." (Roth, 2014, p. 184).

And a recent article about the Stanford School of Design (Miller, 2015) discussed

> "…the core of what is significant about the D School's work for the rest of academe and for the humanities in particular: Human-centered design re-describes the classical aim of education as the care and teaching of the soul; its focus on empathy follows directly from Rousseau's stress on compassion as a social virtue."

The explicit linking of empathy and technology is evident in the engineering of products and systems for the media e.g., music, games, film. Corporations in this line of business seek creative technical workers who have both skill sets. If we in higher education do not educate and train such workers, industry may develop new in-house educational programs. Cal Poly's David Gillette (personal communication) notes,

> "We had just come from the meeting with NBC Universal and were talking with them a great deal about the LAES program and they were quite impressed and receptive--especially where it concerned their internship program. They can get media-studies type students by the bucket at NBC and so they aren't that interested in seeing more media-trained students. They have a hard time getting hard-core engineers interested in them as a technology company. But the LAES students seemed to offer to them the benefits of both: engineering-trained/interested students, along with media-trained/interested with a specific hybrid crossover between the skills that their best people at NBC all had as well. The top people in TV production are all cross-trained, hybrid-trained people with crosses between technology competency and artistic training/appreciation."

Cal Poly's Michael Huang (personal communication) adds,

> I met with hiring representatives from Rosetta (http://www.rosetta.com), Disney, and Dreamworks. Rosetta stated they were looking to hire what they call "Creative Engineers". Disney, of course, has their Imagineers. And, at CalPoly, we created a new interdisciplinary minor that combines Art and Computer Science to address the needs of companies like Dreamworks and Pixar.

And in a commencement address at Stanford, Steven Jobs famously reflected about how his study of calligraphy after dropping out of college contributed to his later technological innovations.

> "Reed College at that time offered perhaps the best calligraphy instruction in the country. Throughout the campus every poster, every label on every drawer, was beautifully hand calligraphed. Because I had dropped out and didn't have to take the normal classes, I decided to take a calligraphy class to learn how to do this. I learned about serif and sans serif typefaces, about varying the amount of space between different letter combinations, about what makes great typography great. It was beautiful, historical, artistically subtle in a way that science can't capture, and I found it fascinating. ….None of this had even a hope of any practical application in my life. But 10 years later, when we were designing the first Macintosh computer, it all came back to me. And we designed it all into the Mac. It was the first computer with beautiful typography. If I had never dropped in on that single course in college, the Mac would have never had multiple typefaces or proportionally spaced fonts. And since Windows just copied the Mac, it's likely that no personal computer would have them. "(Jobs, 2005)

4. Integrating the Liberal Arts and Engineering Education - A Way Forward.

How to do this?

We believe it is time to make the humanities, arts and social sciences more of a core ingredient of an engineering major. This seems to be the sort of innovation encouraged by the engineering deans who signed a letter to President Obama in support of the National Academy of Engineering's Grand Challenges Initiative, an effort focused on “ambitious but achievable goals that harness science, technology and innovation to solve important national or global problems”:

> “We further note that achieving these Grand Challenges requires technology and engineering, but that none can be solved by engineering alone. Hence, there is a crucial need for a new educational model that builds upon essential engineering fundamentals to develop students’ broader understanding of behavior, policy, entrepreneurship, and global perspective; one that kindles the passion necessary to take on challenges at humanity’s grandest scale.”

We take this a step further: any new educational model meant to develop students’ broader understanding of the vagaries of stakeholders' behavior and interests, of the rough and tumble of policy decision making, of the risk-laden history of the business of entrepreneurship, and of the challenges of dealing with a foreign culture that lives, survives, maybe thrives according to different values and norms than us in the US, is going to have to build upon more than “essential engineering fundamentals”. Instrumental rationality falls short, will not suffice, when these Grand Challenges are fixed as much by social, political and cultural forces and currents as by engineering constraints and opportunities.

Our proposed program would give the liberal arts as prominent a place in the education of the engineer as the engineering sciences, laboratory exercises, and design studios and to do so in a way which explores the tensions which may emerge between the two cultures when brought into close contact. The aim is to provide a firm basis for the students' understanding of the cultural contexts of production and widespread use of technology, improve the creativity of engineers in the design and making of products and systems, and prepare them for a life of change and learning. (Studies show that twenty years after college, 40% of engineers are not doing engineering.) Pulling this off will not be easy – for either faculty or students. It raises the bar, rather than lowering it.

We envision three different venues for Liberal Studies in Engineering programs - the university, the liberal arts college, the community college - with different forms adapted to the different needs and opportunities of each. At the university, the program might find a home in either a liberal arts college or a school or college of engineering. The four year college seeking to revitalize its so-called, “3-2” pre-engineering program presents a second opportunity. The community college with an established record of successful student transfer into an accredited engineering program after a two year Associate in Science degree is a third possible site.

The program would be grounded in the liberal arts, to achieve the goals of broadening engineering education, encouraging critical thinking and preparing students for leadership. This best comes from the liberal arts - even if the program is housed in a school of engineering. (Note that *Liberal Studies in Engineering* also provides a growth opportunity for the liberal arts, where enrollments have been dropping.)

Given this wide variety of possible venues, we dare not venture to prescribe a curriculum, a set of requirements (nor to say anything about ABET accreditation). We do lay down two functional design requirements.

- The core of the program would consist of courses in the liberal arts infused with exemplary, substantive engineering content and taught from the perspectives of the humanities and the social sciences.
- The core sequence should be of such intensity, robustness to ensure a sense of community among students (and faculty).

While we avoid listing specific courses, we aim to flesh out possible course content by recruiting interested parties to develop “module”, learning units that meet the first of these requirements. *Science and the Courts* is an example. (Bucciarelli, 2015)

The big challenge is moving faculty from engineering to collaborate with faculty of the humanities and social sciences in the development and teaching of core courses. It may be that it is too much to ask that the two cultures, like oil and water, be mixed. But we believe otherwise: It's time for engineering education to open up to the ways of engineering in the world and for the liberal arts to acknowledge and embrace engineering as a subject worthy of study as part of its canon.

Collaboration is a critical 21st Century skill. Universities have tended to be organizations that resist change. It has been suggested that if the Edsel Division of Ford had been a university department, it would still be in existence. However, there is ample evidence that faculty from different departments and disciplines can work together to effect change. Consider the EPSCoR program of NSF, a Federal funding program to increase the competitiveness of scientific research at universities in states that traditionally had received little research support from the government. Successful state programs developed strong *collaboration* within and among universities and between academia, the business world, and state government (Drew, 1985). Or consider the LSAMP program of NSF, through which, for example, a consortium of colleges and universities in Houston doubled the number of minority students receiving bachelor's degrees in STEM in only five years. *Collaboration* between institutions--for example, careful articulation between community colleges and four year universities—was essential, as was *collaboration* among professors from different departments within each institution (Drew, 2011).

Two years ago, we co-chaired a workshop of educators - faculty from the liberal arts as well as engineering - at the National Academy of Engineering in Washington, DC to discuss the possibilities for establishing an undergraduate, pre-professional *Bachelor of Arts in Liberal Studies in Engineering* (Bucciarelli, Drew, and Tobias, 2015).Argument ranged over the challenge of promoting and sustaining collaboration to the need to provide a convincing argument to students that an engineering program rooted in the liberal arts made sense.

Subsequently, a special double issue of the journal, Engineering Studies, was devoted to presentation of our proposal (Bucciarelli and Drew, 2015) followed by the responses and reactions of thirty scholars who attended the NAE conference. Currently we are conducting a national feasibility study of this programmatic concept under funding from the National Science Foundation.

To conclude, we return to Steve Jobs. In 2010, when he was struggling with serious illness, he became reflective and philosophical during a product presentation of the iPAD. He said, "It's in Apple's DNA that technology alone is not enough. It's technology married with liberal arts, married with the humanities, that yields the results that make our hearts sing."

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References

Astin, H. (1991). Citation Classics: Women's and Men's Perceptions of Their Contributions to Science, in The Outer Circle: Women in the Scientific Community, ed. H. Zuckerman, J.R. Cole, and J.T. Bruer (New York: Norton)

Beach, G. (2013). The U.S. Technology Skills Gap, Hoboken, New Jersey: Wiley.

Bucciarelli, L. (2015). Science and the Courts, Available: https://edge.edx.org/courses/MIT/0.123x/Sandbox/courseware

Bucciarelli, L. and Drew, D. (2015). Liberal Studies in Engineering: A Design Plan. *Engineering Studies, 7*(2-3).

Bucciarelli, L., Drew, D., and Tobias, S. (2015). *Liberal Studies in Engineering*: Workshop Report, March, 12, 2015. Available: https://dspace.mit.edu/handle/1721.1/96672

Drew, D. (1985). *Strengthening Academic Science*. New York: Praeger/Greenwood.

Drew, D. (2011). *STEM the Tide: Reforming Science, Technology, Engineering, and Math Education in America*. Baltimore, MD: The Johns Hopkins University Press.

Drew, D. and Dor, A. (2013). *Evaluation of the Advanced Accelerated Interdisciplinary Science (AISS) Course*, Technical Report, Claremont, CA.

Duderstadt, J. (2009). Engineering for a Changing World: A Roadmap to the Future of Engineering Practice, Research, and Education in *Holistic Engineering Education: Beyond Technology*, ed Grasso, D. and Burkins, M. New York: Springer.
Froyd, J. (2008). White Paper on Promising Practices in Undergraduate STEM Education. Texas A&M University, commissioned paper for NAS Board on Science Education STEM Education Workshop, June 30, 2008.
Hill, C., Corbett, C. and St. Rose, A (2010). Why So Few? *Women in Science, Technology, Engineering, and Mathematics, AAUW*.
Jobs, S. (2005). Stanford Commencement Address, June 12, 2005.
Johnson, S. (2011). Marrying Tech and Art. *The Wall Street Journal*, August 27, 2011.
Koppel, N., Cano, R., and Hyman, S. (2002). An Attractive Engineering Option for Girls. Conference Proceedings, *Frontiers in Education*.
Miller, P. (2015). Is Design Thinking the New Liberal Arts? *The Chronicle of Higher Education*, March 26, 2105.
Nilsson, L. (2015). *How to Attract Female Engineers*. New York Times, April 27, 2015.
Roth, M. (2013). Beyond the University: *Why Liberal Education Matters*, New Haven: Yale University Press.
Thaler, A. (2011). Interdisciplinarities--Students' Perceptions of Interdisciplinary Engineering Education in Europe. *Gender and Interdisciplinary Education for Engineers (GIEE) Conference*, Paris, 209-221.
U.S. Engineering Schools Deans. (2015). *Educating Engineers to Meet the Grand Challenges*, March, 2015.
Wang, M.T., Eccles, J.S., & Kenny, S. (2013). Not Lack of Ability but More Choice: Individual and Gender: Differences in Choice of Careers in Science, Technology, Engineering, and Mathematics. *Psychological Science*, *24*(5), 770-775.