Breaking Boundaries with Liberal Studies in Engineering

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Introduction

In January of 2015, a diverse group of teachers of history, literature, philosophy anthropology, economics and other domains in the humanities, arts, and social sciences came together with teachers of engineering at a workshop in Washington D.C to explore possibilities for establishing an innovative undergraduate degree program - a *Bachelor of Arts in Liberal Studies in Engineering.*

The program would infuse exemplary and substantive engineering content throughout a sequence of core courses rooted in the liberal arts. It aims to provide a smoother pathway into engineering, to better prepare engineering students for the "grand" challenges they might face in an uncertain future, and to provide liberal arts graduates with basic knowledge of engineering and technology.

The National Science Foundation provided support for our workshop[1] and, subsequently, we have received an NSF grant to explore the feasibility of establishing a program of this nature at a variety of colleges and universities. As part of this effort over the past two years we have developed, and posted online, four modules which illustrate the integration of engineering content into courses in the liberal arts.

Engineering practice changed, engineering education challenged.

Our motivation is rooted in the observation that the world of engineering practice has changed over the past few decades prompted, in large part, by an epidemic of innovation in information processing and computer technologies. The world of engineering education has experienced a corresponding disruption with challenges to traditional ways of preparing students for practice as evidenced by...

- a dramatic increase in the fraction of students choosing to major in Computer Science[2]
- at the same time, an increase in number of students seeking to study across traditional disciplines, e.g., biology and engineering, management and engineering.
- a broader definition of the design process that includes attention to the social context of design and often includes the arts
- emergence of an ideology that stresses entrepreneurial prowess as a legitimate objective of undergraduate engineering education

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1. Bucciarelli L., Drew D., Tobia S., *Liberal Studies in Engineering - Workshop Report*; Support was provided by the NAE, the Teagle Foundation, by the Dean of Humanities, Arts, and Social Sciences at MIT and by the Dean of the School of Education at Claremont Graduate University.
2. Computing Research Association (2017): *Generation CS: Computer Science Undergraduate Enrollments Surge Since 2006*. http://cra.org/data/Generation-CS/

- increased student interest and participation in co-curricular activities, e.g., inter-collegiate competitive design and build projects[3]; service learning; foreign study.
- faculty (and ABET) statements of the need to prepare students for work that requires sensitivity to the social/political context, negotiation with “stakeholders” who have different and often conflicting interests in, and awareness of, how culture can inform the design of products and systems[4].
- faculty recognition of the impossibility of preparing graduates for all that they might be called upon to do in the future; emphasis on teaching students how to learn – life-long learning[5].
- attempts to open up engineering education to a more diverse population, e.g., women and under-represented minorities[6].
- an associated heightening of interest in, and legitimizing of research on, how to teach and reflection on what is it that is essential for engineering students to learn.[7]

These are symptoms of how the engineering education as a system - students, faculty, administration - is disturbed by, and attempting to accommodate, dramatic changes in engineering practice. They are a disjointed lot, seemingly unrelated and hard to attribute to any single cause, though in the future an historian might look back and construct a coherent story. (It’s not enough to gloss the whole as a consequence of the “computer revolution”. More needs to be said about the interests and practices of students and professionals.)

At a more fundamental level, significant, fully thought out, successful accommodation to the changes we see today in engineering practice is severely hampered by three entrenched, no-need-to-speak-of, beliefs:

- preparation for the engineering profession requires but four years of undergraduate study; students commit prior to enrolling at university.
- an essential component of that preparation must include success in a series of pre-requisite courses in mathematics and science whose content has not changed for half a century although “delivery” methods have changed.
- the core requirements of a major must consist of courses, including engineering design, that are rooted in an ideology that sees the world of engineering practice as problems to be solved by the classical instrumental theories and methods taught in the engineering sciences. All else is of minor importance.;

3. Schuster, P., & Davol, A., & Mello, J. (2006, June), *Student Competitions The Benefits And Challenges* Paper presented at 2006 Annual Conference & Exposition, Chicago, Illinois. https://peer.asee.org/1055

4. ABET: *Criteria for Accrediting Engineering Programs, 2016 – 2017* http://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2016-2017/

5. Dutta, D., Patil, L., Porter, J.B. Jr., *Sustaining American Competitiveness in the 21st Century; Lifelong Learning Imperative in Engineering,* NAE, Univ. Illinois. https://www.nap.edu/read/13503/chapter/1

6. Malcom-Pique, L.E., Malcom, S.M., *Engineering Diversity: Fixing the Educational System to Promote Equity,* NAE: The Bridge, vol. 43, 1, 15 March, 2013. https://www.nae.edu/19582/Bridge/69735/69743.aspx

7. *Engineering Education Departments and Programs (Graduate*), http://engineeringeducationlist.pbworks.com/w/page/27610307/Engineering Education Departments and Programs (Graduate)

If faculty hold to these tenets, then the current undergraduate engineering major, so full of requirements, presents few opportunities for change that would better prepare students for contemporary engineering practice - an openness to different perspectives; sensitivity to cultural values; ability to work with others, negotiate; reflect on one's work; communicate clearly, listen attentively; eager to learn; open to moving on.[8]

The prevailing ideology that stresses instrumental thinking infects student attitudes as well. Most all, save those who choose to double major or actively engage a minor in the liberal arts, follow along and see their humanities requirement as "soft", something to get through with as little distraction from the really important courses of their major.[9]

Yet there are promising signs that change is possible: At a surprising number of institutions there have been attempts to break the mold of the past (that is, lecture/recitation, students work as individuals in competition with their peers; canonical presentation of engineering sciences; single answer problems; cook-book laboratories; technology focused design classes). Think of project based learning; design experiences that stress user interface; portfolios for assessing a student's progress; increased concern for teamwork and communication; and the, not unrelated, push to increase the diversity of students of engineering. And it's not that there is lack of recognition by funding agencies, by philanthropies, as well as by NSF, of the need for change. But, in general, it remains very difficult to convince one's faculty peers of the worth of educational innovation, especially of the sort we advocate here and, as a result, to make and sustain such a change.

Two Design Challenges

We propose the establishing of a new kind of undergraduate experience that would integrate engineering studies in with courses in the humanities, arts, and social sciences. Immediately, two challenges arise:

Rigid Structures: James Duderstadt has said that we are trying "to educated 21st Century engineers with a 20th Century curriculum in 19th Century institutions."[10] As professors with decades of university experience and as observers of academia, especially the professorate, we recognize that universities are very s-l-o-w to change. Furthermore, innovations in higher education often are rejected as perceived threats to quality. We have realized that in proposing a closer integration of engineering education with the arts and humanities, including collaboration in teaching of faculty from both domains, we are trying to introduce some fluidity into a rigid structure, going against the grain. So while we have proposed a *Bachelor of Arts degree in Liberal Studies in Engineering*, we recognize that institutional change may need to occur; this would best be done in small steps. Moreover, we have underscored consistently that we are raising the bar for engineers, not creating "engineering lite".

8. National Academy of Engineering. 2004. *The Engineer of 2020: Visions of Engineering in the New Century.* Washington, DC: The National Academies Press. doi: 10.17226/10999. pp 40-41.

9. Shivani Prasad, *STEM Study Suggests UCSB Humanities are "Soft and Useless"*, https://theblacksheeponline.com/uc-santa-barbara/ucsb-study-suggests-humanities-are-soft-and-useless

10. Duderstadt, J., "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, 2009)

A Narrow Demographic: To this day, most engineering students are white males. But most university programs, have become more diverse demographically, along a number of dimensions, especially gender and ethnicity. A series of studies and task force reports[11] has suggested that the most effective way to diversify engineering enrollments is to broaden the coursework, address the social/political contexts of engineering practice, and explicate the implications of technology for society, especially in the early years of undergraduate study.

Some have suggested that the under-representation of women in engineering, especially in computer science, is because they find the work too challenging. We offer a contrary interpretation: perhaps they don't find the content interesting and relevant enough. Consider a study by Wang et al[12], who studied eighteen year old college students and then revisited the same students when they were 33. In one analysis, they compared the SAT scores of the students with whether or not they had chosen a STEM career 15 years later. Forty nine percent of those with high quant scores and modest verbal scores were working in STEM. But only 34% of those with high quant scores and high verbal scores were working in STEM. Most of the missing 15% were women.

Two Design Requirements

Our advancing the idea of a new kind of undergraduate degree and calling it a *Bachelor of Arts in Liberal Studies in Engineering* is, in the main, a strawman, a sociotechnical imaginary[13], meant to move faculty of engineering and of the liberal arts to think seriously about the possibility that preparation for work as an engineer, for the vocation, requires now a firm basis in the liberal arts and that all graduates should be sensitive to and prepared to reflect upon, not just "impacts", but the complex social/political contexts of engineering practice at all levels - within the firm, the community, nation, the world.

The core idea goes as follows:[14]

> . . . take exemplary, substantive content of the 'traditional' undergraduate engineering program– the engineering sciences, the laboratory tests, the design projects – and subject this to study from the perspectives of the humanities, arts, and social sciences as well as engineering. The method is to build on the content and form of instruction in today's engineering program but dramatically transform both content

11. See, for example: Froyd, J., "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, "Why So Few? Women in Science, Technology, Engineering, and Mathematics", AAUW, 2010;

Thaler, A. "Interdisciplinarities--Students' Perceptions of Interdisciplinary Engineering Education in Europe", Gender and Interdisciplinary Education for Engineers (GIEE) Conference, Paris, 2011, pp. 209-221.

12. 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.

13. Sheila Jasanoff & Sang-Hyun Kim (2015): *Dreamscapes of Modernity. Sociotechical Imaginaries and the Fabrication of Power*, Univ. of Chicago Press

14. Louis L. Bucciarelli & David E. Drew (2015) *Liberal studies in engineering – a design plan,* Engineering Studies, 7:2-3, 103-122, DOI: 10.1080/19378629.2015.1077253

> and form to achieve the goals of a liberal arts program – 'critical thinking' is the key phrase in this regard – while attending to the fundamentals of the traditional engineering course of study. To do this, 'fundamentals' must necessarily be redefined.

We also put forward, as a second "design requirement", that

> ...the program's structure, course requirements, and conduct should engender a sense of community among students and among faculty. Students should see the program as their intellectual home.

The aim is to encourage students to identify as a group, a community, and see themselves as standing apart from their peers who have chosen to major in traditional fields. Those seeking this new form of undergraduate education will be strengthened in their resolve and professional identity formation by participation in a cohort experience. Supplemental instruction programs built around cooperative study groups have dramatically increased success rates in undergraduate STEM fields, in institutions as diverse as Harvard, Cal Poly Pomona, and Texas Southern University[15].

Rooted in the liberal arts

> Ruefully—and with some embarrassment at my younger self's condescending attitude toward the humanities—I now wish that I had strived for a proper liberal arts education. That I'd learned how to think critically about the world we live in and how to engage with it. That I'd absorbed lessons about how to identify and interrogate privilege, power structures, structural inequality, and injustice. That I'd had opportunities to debate my peers and develop informed opinions on philosophy and morality. And even more than all of that, I wish I'd even realized that these were worthwhile thoughts to fill my mind with—that all of my engineering work would be contextualized by such subjects.[16].

We see a program in *Bachelor of Arts in Liberal Studies in Engineering* as an antidote, a way to engage students in engineering, even entrepreneurship, while rooting learning in specially designed courses in the Humanities, Arts and Social Sciences that stress reflective thought and practice, show the importance of cultural values, listening, reading, and open discussion with peers. Think of the program, not as "engineering lite" but as "liberal arts enriched". Think of the program as pre-professional.

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15. See, for example, Bonsangue, M. and Drew, D. "Increasing Minority Students' Success in Calculus", *New Directions for Teaching and Learning,* 1995, (61) pp. 23-33

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

Light, R. *The Harvard Assessment Seminars: Explorations with Students and Faculty about Teaching, Learning, and Life,* Cambridge: Harvard University Graduate School of Education, 1992.

Triesman, P.U., *A Study of the Mathematics Performance of Black Students at the University of California, Berkeley,* Ph.D. dissertation, University of California—Berkeley, 1985.

16. The title of the piece by Tracy Chou, from which the quote was taken, is instructive: *Leading Silicon Valley Engineer Explains Why Every Tech Worker Needs a Humanities Education* https://qz.com/1016900/tracy-chou-leading-silicon-valley-engineer-explains-why-every-tech-worker-needs-a-humanities-education/

The challenge is: How to integrate “exemplary engineering content” in with the teaching/learning of literature, philosophy, history, anthropology, sociology, government, economics...in a way that contributes to enriching the host course and engenders an understanding and critique of the engineering in context? Perhaps the best way to illustrate a way forward is to show how three colleges have met the challenge.

At Wellesley College, Amy Bazaert, an instructor responsible for the college’s engineering course offerings, and Catia Confortini, Associate Professor of Peace and Justice Studies, collaboratively teach *Intersections of Technology, Social Justice, and Conflict.* The course is jointly listed - ENGR 305/PEAC 305. For students in the Peace and Justice Interdepartmental Major within the School of Liberal Arts, the course is a required, “capstone” course. For these 8 (of 14) students, the assigned engineering exercises set the experience apart from their other P&J requirements. The engineering students see it as different from what they are accustomed to doing in Amy’s other courses; Catia’s assignments press students to think hard about the context of technology.

Three technologies (socio-technical systems) were studied: human-powered water pumps, drones, and cook stoves. The *Liberal Studies in Engineering* online module, *Techno-Anthro Two Pumps* served as a resource for the water pump segment. Student exercises were evenly split; half were defined by Professor Confortini and asked students to write a paragraph (75-100 words) posing a question prompted by the readings. Half were assigned by Professor Bazaert. These “Tech assignments” were in the form of engineering analysis of the technology, consisting of background reading, mathematical estimation exercises grounded in the fundamental equations of the associated technology, exploration of the design requirements and processes associated with the technology.

Another example: At Purdue Polytechnic, Todd Kelley, Professor of Design Thinking at Polytechnic collaborates with Sherylyn Briller, Professor of Anthropology in the College of Liberal Arts, in teaching a design and project based course *TECH 22000, Designing Technology for People*. Although the course is housed in Polytechnic, of the 45 students enrolled in the course, roughly half of the students are majors in anthropology, the other half, majors in engineering technology. Both Professors Briller and Kelley are active, teaching, in every meeting of the course. The course is structured around a major group project whose purpose is to use ethnographic methods to explore user experiences and develop a new design solution.[17]

At Smith College, one of the few liberal arts colleges offering an accredited engineering undergraduate major, Professors Susannah Howe, director of the Engineering Design Clinic, Suzanne Gottschang, Anthropology, and Domminique Thiebaut, Computer Science, collaborate in “coaching” a team of students in an engineering capstone design course. The course brought students majoring in Anthropology together with students of engineering. The small team was charged with designing a digital version of a screening questionnaire for pediatric toxic stress. In this, they worked closely with the Baystate High Street Health Center. For the students majoring in Anthropology, there exist few opportunities at the undergraduate level to work on a project in the “real world”.

These examples illustrate what we see as essential features of a Liberal Studies in Engineering teaching/learning experience.

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17. S. Briller, T. Kelley, E. Wirtz, *Designing for Prople*, Anthropology News, 2017; http://www.academia.edu/28605431/Designing_for_People

- The mixing of engineering in with the liberal arts requires the collaboration of faculty from both domains - in planning as well as in teaching. “Turn teaching” will not suffice. That is primary.
- Students too are mixed.[18] Some are intent on studying engineering, others are majors in the liberal arts.
- All three courses are specifically required to complete a major - at least for some of the students. They are not simply elective.
- All three examples engage students actively: At Wellesley, classroom discussion is the norm, discussion prompted by questions students themselves pose (and write out before class). At Purdue Polytechnic and at Smith College, students do projects, in teams.

It is notable that, in all three examples, the liberal arts faculty was a Professor of Anthropology. One can see how Anthropology is a good fit with engineering design, with its concern for the vagaries of human use or misuse of a product or system.

Four modules illustrate “infusion”

The *Techno-Anthro Two Pumps,* used as a resource at Wellesley College, engages faculty from the liberal arts (Anthropology) and engineering (Fluid Mechanics) in the analysis of the fate of two, human-powered pumps, in sub-saharan Africa. The reader should not get the idea that Anthropology is the only liberal arts field that can be integrated with engineering in the classroom.The module is but one of four posted online.[19]

Another, *Science and the Courts*, builds upon a recent decision of the US Supreme Court in which a citizen of the State of New Mexico was arrested and charged with driving while intoxicated (DWI) on the basis of evidence obtained from the analysis, via gas chromatography, of a blood sample. The individual, a Mr. Bullcoming, petitioned the Supreme Court claiming that the way the evidence was presented in a New Mexico court violated the confrontation clause of the 6th amendment of the Constitution. The US Supreme Court agreed.

The objective of the module is to move students to reflect on the source of authority in science, the integrity of data obtained via sophisticated instruments, and the qualifications of the individual running the machinery; in addition they would be asked to consider what is required in making the results of laboratory tests understood and useful in contexts other than that of the laboratory itself - in this case the context of the courts.

Along with study of briefs submitted to the court, the decision itself, and the 6th Amendment of the US Constitution, *Science and the Courts* would have students doing an experiment using Thin Layer Chromatography (TLC), a cruder method than gas chromatography, but one that, working on the same fundamental principal, provides a way to identify compounds and determine their purity.

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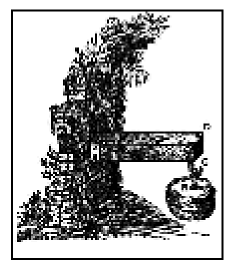
18. In a full Liberal Studies program, we see classes of students with different interests; some may go on to pursue an engineering degree, others may follow different paths. Bucciarelli, Drew, *Liberal Studies in Engineering - a Design Plan*, Engineering Studies, op cit.

19. For access to the modules, “register” at https://edge.edx.org/courses/MIT/0.123x/Sandbox/about

Doing the lab exercise, students should gain a sense of how things can go wrong; how doing a laboratory procedure requires fine tuning ingredients to obtain “good data” - all this should be journaled in a lab notebook. Students will learn that to do an experiment, one must know a good bit about the outcome before one starts. The question of “bias” due to an experimentalist’s foresight can be introduced at this point. A more general question regarding human error - as contrasted with other sources of error - might also be put on the table.

Contrasting the machinery required to do Thin Layer Chromatography with that deployed in Gas Chromatography can lead to a discussion of how the experimentalist’s (and theorist’s) knowledge and know-how is captured and resides in the machine itself. Where, then, lies the authority in science (and engineering)? Is it in the “wonderful machine” itself - so a “surrogate’s” presentation of the evidence in court is allowed? Or does the authority rely upon the standing of the scientist(s) whose theoretical and craft work framed and inspired the design and production of the machine? What about the lab technician, the licensed operator of the instrument? What does he or she contribute to this picture? What if the actual person, technician, who ran the test is required, as the US Supreme Court ruled, to present the evidence in court? What must he or she “know” about the workings of the machinery if we are to accept the data as evidence? One author of this piece is licensed to drive an automobile; but would not claim that he could explain the cause of every knock, whine, stall or reverberation whenever such might occur. The other drove a large truck (about the size of a semi) while a graduate student, but, if engine trouble developed, he was instructed to step aside, as that “was a different union”.

A third module *Galileo and the Resistance of Beams* is meant for use in a course in the History of Science and/or in an engineering course in Statics and Strength of Materials. Students read the original source (in translation) of Galileo’s analysis of conditions for fracture of a cantilever beam subject to a large weight at its free end.



Galileo’s model and fundamental result, are wrong (according to today’s treatment) but his scaling laws were, are, correct. Students are asked to consider how an engineering theory can be both wrong and right.

An excerpt from a letter of Descartes, what we would call a book review of Galileo’s *Dialogue concerning Two New Sciences*, prompts reflection on the differences in thought and practice of scientists and engineers today. To relieve students’ anxiety, the module explains how today’s engineers analyze a cantilever beam. Students, in an engineering problem set, are asked to compare Galileo’s result with the result found in today’s textbook.

The fourth module, *Engineering Narrative, Gender, and a Computer Science Exercise,* is meant for use in a course in Gender and Science and/or a course in Computer Science. The module's objective is to lead students to reflect on engineering instruction, how it both constrains and enables, limiting one's thinking about the real world context of an assigned exercise (if there pretends to be one) while providing the student with knowledge of the powerful instrumental ideas and methods used in engineering problem solving. In particular, our interest is in studying the way exercises are stated and addressed in engineering course-work. Part of this is what the engineering student is schooled not to see, to ignore, for this is an indication of values as much as any explicit statement of what is good, what is right, what is just.

To give the reader a sense of the power of the instrumental ideas and methods that take priority in engineering education, we solve a computer science exercise that might be assigned in an introductory CS course. That same exercise provides material and focus for the study of values implicit in engineering narrative.

For most all of the exercises a student encounters in an engineering science course their narrative is carefully constructed to lead the student on without revealing too much about how to solve the problem. Most are sparsely written, providing only that information essential to framing a solution. Including excessive information that may lead the student astray is considered bad form. But infrequently, one encounters an exercise whose narrative is more interesting in its own right. The Computer Science exercise we treat is of this nature.

Whatever the form of a narrative clothing the instrumental ingredients of a problem, the student's job is to see through the problem's presentation and draw out the mathematical structure that will enable a solution. This underlying structure is fixed relative to the freedom authors have in constructing a narrative. The end of a chapter in an engineering textbook will include a good number of problems, each a different story, but the logic that applies for doing the exercise is one and the same if one digs deep enough. The power of, the scope of applicability of the engineering sciences is displayed in this way.

Narrative, when prevailing unquestioned and apparently needing no articulation (everyone is in on it), can blind ourselves to the possibility that things can be different, that different stories are possible, that presumptions can be called into question There is a now famous little story about fish that makes the point:[20]

> There are these two young fish swimming along, and they happen to meet an older fish swimming the other way, who nods at them and says, `Morning, boys, how's the water?' And the two young fish swim on for a bit, and then eventually one of them looks over at the other and goes, `What the hell is water?'

This module is intended to move students to move their thinking off its `default setting'; to become sensitive to the water they swim in - without drowning. Creativity requires this kind of awareness, this kind of openness to a bigger world - the water we all swim in - and that things may be different.

Possible Venues, Strategies for implementation.

A module does not a curriculum make. What then is the *Bachelor of Arts in Liberal Studies in Engineering* curriculum? What are the program’s requirements? Where would it be housed? Who are the faculty?

We have been negligent. We have said very little about a curriculum, a set of requirements. We do this because we don’t want to foreclose the possibility of innovation in curricula that would fit local constraints (and opportunities). Or - another way of saying this- we believe that the core idea of infusion of engineering in with the liberal arts can be accomplished at a wide range of institu-

20. David Wallace, who according to *The Guardian*, was `the most brilliant writer of his generation' began his commencement address to graduates of Kenyon College in May, 2005 with this story. https://www.theguardian.com/books/2008/sep/20/fiction

tions of higher education. community colleges, liberal arts colleges, as well as research universities are all possible venues.[21]

Development of a full program would best be done in stages.The end goal is to put in place a sequence of courses, rooted in the humanities, arts and social sciences, with engineering infused that is open to all students, some seeking to enroll in a program that keeps open the possibility that they might pursue a degree in engineering; others recognizing the pervasive influence of technology in changing the ways we work and play and seeking an engineering-enriched program in the liberal arts that might better prepare them for pursuing a professional degree in management, public policy, or even education, law, or medicine.

Because of this dual nature, the "pathway" might be housed in a school of humanities or in a school of engineering. We see the former as the better choice to insure that the transformation in student ways of seeing the world that we propose is achieved.

The required core sequence of liberal arts courses infused would allow ample time aside this core for students interested in engineering to elect courses that would prepare them for admission to a masters level program in engineering, in computer science, in technology and policy, in management, or the like. For those students whose interest lie elsewhere, they could choose their electives concentrated in a field in the humanities, the arts, or the social sciences in preparation for say medical school or law school.

The core sequence itself would be designed, courses chosen, to satisfy the university's or college's general education requirements. Both of these possibilities would require extensive negotiation among faculty concerned. The aim is not educational innovation by "adding on" but by transformation of what exists.

Whatever the final form, collaboration among faculty of the liberal arts and of engineering will be required - at least until the program is established and its main goals met as measured by the sense of community evident in program participants - faculty and students - and by its record of attracting students and graduating individuals who value, in retrospect, their choice of a program rooted in the liberal arts as a foundation for their life, life's work.

21. Development of a program at a liberal arts college would require the participation of engineering faculty recruited from a neighboring institution or hired directly by the liberal arts college.

Reflections

In the wake of the January 15 workshop, attendees were invited by Gary Downey, editor of the journal *Engineering Studies*, to submit commentary on our proposal to establish a BA in *Liberal Studies in Engineering*. These, together with our lead article *Liberal Studies in Engineering - a Design Plan,* were published together as volume 7, numbers 2 and 3 of the journal.[22]

Several commentators, as did we, found fault with the presumption that preparation for the engineering profession requires but four years of undergraduate study. Karl Pister, Chancellor Emeritus, Univ California, Santa Cruz and Judson King, Professor Emeritus of Chemical and Biomolecular Engineering wrote[23]

> ...recognize up front that the essential confining problem is the fact that engineering in the USA places the professional degree in engineering at the bachelor's level. The present lack of breadth in engineering education is a manifestation of the constraints that come from squeezing everything into a nominally four-year degree. All other major professions place the professional degree at the graduate level and thereby build upon a broad, less-specified undergraduate education.

Likewise, Susan Silbey, Professor of Sociology, Anthropology at MIT, viewed the constraints of the four year undergraduate degree as the “elephant in the room”.[24] She points to features of the four year degree that move critics to advocate reform.

> ...(in its embrace of instrumental reasoning), the degree becomes a magnet for those who want education to be an instrumental activity with a clear means-ends relationship – it should pay for itself through immediate lucrative occupation.
>
> ....the four-year degree encourages tightly packed curricula with limited opportunities for random exploration and inquiry....
>
> ...because it is a four-year degree lacking general educational cultivation, engineering is conventionally relegated to lower ranks in prestige hierarchies than law or medicine...

Sharon Jones, then Dean of Engineering & Professor at the University of Portland, writes that an AB pre-professional degree leads her to imagine

> ...an outcome that allows students to progress through their curriculum, while maintaining their motivation and confidence, and gaining a full range of competencies needed to both frame and solve engineering problems...Imagine their satisfaction when told that a pre-professional AB Engineering degree can be used to either help their success in just about every other career path, but if they decide they like engineering enough, they can practice professionally after completing a one- or two-year graduate degree program intentionally designed for them.

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22. Engineering Studies, (2015) vol 7, Issues 2, 3; https://www.tandfonline.com/toc/test20/7/2-3?nav=tocList

23. C.Judson King & Karl S.Pister, *How best to broaden engineering education*?, Engineering Studies, op. cit. pp.150-152.

24. Susan Silbey, *The elephant in the room: constraints and consequences of a four-year undergraduate engineering degree,* Engineering Studies, op.cit. pp.164-167

But this “the revolution that is needed in engineering education”

> ...can only happen if there is seamless entry from the AB Engineering degree to professional graduate programs in traditional engineering disciplines[25].

Throughout the workshop, frequent note was made of the overwhelming emphasis in engineering education on instrumental methods and problem solving skills. How, if Liberal Studies in Engineering aims to move students (and faculty) to pay serious attention to cultural context and to critically reflect on questions of equity, of sustainability, of robustness, security, privacy, bias - to take seriously the competing interests of so-called “stakeholders” - how to manage the tension between the drive to solve the (engineering) problem and the recognition that context matters and sometimes can seem to overwhelm? Peter Kroes, Professor of Philosophy at Delft, the Netherlands, argued

> ...any program in Liberal Studies in Engineering (LSE) should first and foremost be based on *intrinsic goals*, which can go hand in hand with *instrumental goals.* In particular, LSE has to critically reflect on the increasing dominance of precisely instrumental thinking in and outside engineering, a kind of thinking that appears to lock us up into an Iron Cage.[26]

He goes on to discuss the nature of pedagogical collaboration at Delft University of Technology, which takes the form of co-teaching.

> Co-teaching means that the development of the content and the teaching of these courses is done by staff members from the engineering and philosophy departments. Since engineers and philosophers are jointly responsible for these courses, they have to enter into a dialogue about teaching goals and about how they can be achieved

So,as we concluded in the previous section, collaboration between faculty of engineering and faculty of the liberal arts will be essential in both planning and teaching. We hold that intense collaboration of this kind can go a long way in changing the culture of engineering education. Gary Downey, in a concluding essay to this special issue, says as much

> Perhaps the mutual learning that might result from systematically juxtaposing engineering and the liberal arts could indeed achieve transdisciplinary moves that transport instructors and learners alike beyond existing forms of knowledge and expertise, producing new images and practices of engineering formation that just might travel[27].

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25. Sharon Jones, *The need for intentional graduate pathways for students in liberal studies and engineering pre-professional programs* Engineering Studies, op.cit. pp 214-216.

26. Peter Kroes, *Critical thinking and liberal studies in engineering,* Engineering Studies, op.cit. pp 126-128

27. Gary Downey*, Opening up engineering formation,* Engineering Studies, op.cit. pp 217-220