

Inquiry-Driven Engineering: One of the Liberal Arts
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Delivered at the University of Delaware
5 October 2011

Summary:

From their ancient roots through their medieval history, universities came to define liberal learning as that which helps students, by broad exposure, to identify and refine their most natural learning style and then, having experienced the thrill of learning, to fuel a life of the mind, to enjoy for a lifetime the pursuit to satisfy an insatiable desire for knowledge. Engineering thought was not welcomed in the academic community until late in the modern period, and that welcome is still incomplete. When focused too narrowly on the professional nature of our discipline, we as engineers often exclude ourselves from thought and discussion about those matters that address why we live, not merely how we live. Understanding engineering, and inquiry-based engineering in particular, as a "liberal art" opens possibilities for engineering to contribute and be counted among the essential ways of thinking for those who would consider themselves fully educated in the future.

It is an honor to be invited to return to my alma mater to share with you a few thoughts about the discipline of engineering and the future of engineering education. And I have been honored by the generous amounts of time afforded me for conversations with President Harker at his home, with Provost Tom Apple, Interim Dean Babatunde Oguinnaike, and ECE Chair Ken Barner. Especially interesting and exciting have been conversations with faculty, tours of laboratories, and engagement with students. Thank you for your hospitality.

It seems, as has been observed before, that the only constant is change. That constant of change was evident even in my time here. It has been amusing to reminisce about some of the changes and transitions that took place during the time I was a student here in what was then the Department of Electrical Engineering during the early 1970s. **We were expected to arrive on campus in the fall of 1971 having mastered the use of one of two approved models of slide rules** with which we were expected to do simple multiplication and division as well as trigonometric, exponential, and logarithmic calculations. It was not until our senior year that those who could afford them were permitted to use electronic calculators in certain approved classes. We arrived freshman year with slide rules in hand to encounter a first course working with the equations to calculate the criticality of an enriched uranium fission reactor of the sort that was actually physically housed in DuPont Hall. That same course taught the fundamentals of Fortran IV programming including program compiling and data entry using decks of punch cards to be processed by the university's single central mainframe computer. Again, **by our senior year, we and the world had gravitated away from punch-card technology to remote data entry at any of a number of hardwired keyboards stationed around campus.** The

electrical engineering department, of course, was well ahead of the rest of the campus, having its own Digital Equipment Corp. PDP 11, although available mostly for research purposes.

Resistor transistor logic and diode transistor logic had been replaced by TTL (transistor transistor logic) with logic gates and flip-flops able to operate at speeds of up to 40 MHz. CMOS was being introduced, and as soon as the passivation issues could be addressed, gallium arsenide would be the semiconductor material of the future for large-scale digital integrated circuits. As far as I can tell, gallium arsenide for this application still remains a material of the future.

In the classrooms and laboratories, analog systems still were king and asynchronous logic held its own with the synchronous world. There was even a smattering of philosophy and ethics. Fourier theory was understood to be an alternative way to view a world of time domain signals, and to study stability criteria we were assigned such problems as: **If animal A eats animal B and animal B eats grass and the land produces so many pounds of grass per acre, what are the singularities in the solutions to the developed differential equations that indicate the average stable carrying capacity. It was a question about the environment!**

We had professors who had worked in secret labs developing noise reduction theories and systems to improve radar technology. A professor Robinson wrote a paper entitled "If Newton and Leibnitz Were Alive Today," hypothesizing that the developments in digital computation were so powerful that there would not be a recognized need to pursue analytical solutions to differential equations; after all, such closed form solutions are so rare that we name them in honor of those who were able to develop them.

But with all of that change and our continuing eagerness for newness for the next great thing, we sometimes looked beyond the potential to insist upon and improve upon delivering more lasting and stable educational objectives that only universities can deliver. **My topic today asks us to focus on one such deliverable—that our engineering students might also be liberal learners.**

You might suspect that in choosing the topic – building a case that the engineering disciplines, particularly inquiry-driven engineering, be counted among the liberal arts – I may simply be trying to rationalize how it is that an engineer like me could claim any right to be serving a liberal arts university like Emory, a university lacking an engineering program altogether. But that is really not the case. Instead, my purpose is to offer a broader perspective on our discipline and its ramifications for how we approach pedagogy and how we engage with society.

The power of the discipline of engineering thought needs to be better appreciated for its ability to prepare the mind for broad-minded citizenship, for the appreciation

of beauty and achievement, for the establishment of integrity in one's identity, as well as for agility in problem solving. It is in accomplishing those things that engineering can and should claim to be shaping the intellect and the character of its practitioners every bit as well and as much as the more traditional liberal arts curricula that have been around for literally over a millennium. Having said that, however, it is clear that the degree to which the fuller potential of engineering education and practice is able to achieve these things could be enhanced by some attention to pedagogical practices.

For too long we engineers have accepted and even enjoyed the description given to us as "problem solvers." The implication is that when someone else envisions a technological goal or encounters, stumbles upon, or otherwise engages a problem, especially one with a technological solution, the project can be assigned with great confidence to the engineer and his or her team. But to imagine that the role of the university is to educate problem-ready engineers waiting for society to dream dreams of opportunity or to encounter problems born out of issues is to imagine too little of our universities and the engineers that we educate. **An engineer driven by inquiry more than mere utility understands the opportunity and responsibility** is not merely to solve problems recognized, defined, and framed by others, but instead to be engaged in society, **to become the dreamer**, the problem recognizer, definer, and framers and then ultimately problem solver. Yes, we do want our engineers contemplating possibility and process as well as pursuing specific goals and accomplishments.

But old assumptions die hard (and ironically we engineers may be the very ones providing life support for these outdated assumptions). Engineering education has long been understood (incorrectly) to be inadequate preparation of the mind fully to enjoy and contribute to the human experience in the same way as those minds that benefit from a traditional liberal arts education. History certainly confirms that bias.

From ancient and medieval times through the late 1800's, there were only two kinds of engineering—military and civilian (or civil). Entrée into those professions did not require academic certification. Instead, to become a military engineer, one volunteered or was conscripted into military service. Civilian engineers, on the other hand, entered the profession through the guild and apprentice systems. As a result, there was little interest in expecting that engineers might be candidates for education from within the formal academic system of universities wherein the liberal arts reigned supreme.

C.H. Cramer chronicles some of this history of academic engineering in the introduction to his 1980 history of the Case Institute of Technology (now CWRU). He tells the story of the breakthrough of the engineering and applied sciences discipline into the academy, introducing what had been called the mechanics arts into the halls that had housed for so many years only those pursuing the study of the liberal arts.

Initially, the French were the most progressive adopters of engineering education for civilians. In 1747, they established the first of many Ecoles Nationale (National Universities), with the first one focused on bridges and highways. Soon the Germans and the Russians followed suit. And for nearly a full century, these continental European institutes were alone in their pursuits. During the same period, **the British pursued and perpetuated the classical liberal arts education. They agreed with Plato that the “mechanics arts were not a fit occupation for the educated citizen.”**

In America, the first colleges and universities were established on the models of Oxford and Cambridge and thus became similarly bound to a classical definition of university education—to prepare a literate clergy, educated gentlemen, and a necessary supply of lawyers and doctors. Only in the United States Military Academy at West Point, established in 1802, was engineering taught—military engineering, of course. Nevertheless, engineers were in high demand for design and construction of harbors, roads, and soon, the railroad. Soon civilian demands for engineering talent outstripped supply, and military engineers began to resign their commissions early in order to take more lucrative civilian employment. Still, American universities resisted the demand to educate engineers and scientists.

Jeremiah Day, president of Yale for 23 years, defended the classical approach to university education in a report of 1828: “The young merchant must be trained in the accounting room, the mechanic in the workshop, and the farmer in the field.” Science might be taught for “the discipline and the furniture of the mind” but it was not acceptable to aspire to become a practitioner of science, a physicist or an engineer. He even commented on how troubling it was to contemplate teaching such subjects, noting that “those whose researches have carried them so far beyond these simpler truths...come back to them with reluctance and distaste.”

Even when Yale did open what became the Sheffield Scientific School in 1847, its students were not permitted to sit in chapel with regular academic students. At Dartmouth, students studying science and modern languages attended classes in the wintertime, when the students of more “noble” disciplines were off campus making money as tutors.

The pattern began to change through partnership between wealthy corporate leaders and progressive educators. Thus Stephen van Rensselaer saw to the birth of RPI in 1824—the first such institution in the English-speaking world. Similarly, Yale and Harvard began programs, but apparently only half-heartedly. The first graduate of Harvard’s program did not emerge until nine years after it began. Indeed, Cramer reports **that prior to the Civil War, only six institutions of applied science existed in the US, producing only 300 graduates.** Our place in the academy continued to be resisted.

Even after the doors of the academy grudgingly opened to our ilk, use of the words “science” and “scientific” was avoided. Scientific equipment was referred to as philosophical apparatus; scientific laboratories as philosophical chambers. The Bachelor of Arts (BA) degree was king. Heaven forbid that there should be offered a Bachelor of Science degree, and so Bachelor of Philosophy degrees were offered by some institutions instead. (The doctor of philosophy degree is still the terminal degree given by most universities in disciplines of science and engineering.)

The Lincoln administration and the Civil War brought recognition of the need for education in science and engineering. The 1862 Land Grant Act provided federal funds to support the study of agricultural and mechanical arts at universities. During this same period, a cluster of technology-focused institutions was established: Boston Tech (later MIT) in 1861; the School of Mines at Columbia in 1864; Cornell and Lehigh Universities in 1865; the Stevens Institute in 1870. Here at Delaware, civil engineering was part of the science curriculum in 1850, but degree programs in engineering were not established until 1891.

Although the doors were open, attitudes were slow to change. The disdain for science and engineering within the academy is illustrated in a story told about a promising classics major at Oberlin College in Ohio in the 1880s. The student’s name was Robert Millikan. Yes, this is the fellow that would go on in the early 20th century to win a Nobel Prize in physics for a body of work that included establishing the coulombic charge of an electron. The story goes that while at Oberlin in the late 1880s, Millikan’s Greek professor approached him to teach an introductory physics course. When Millikan protested that he was not prepared to do so, his professor stated confidently, “Anyone who can do well in my Greek can teach physics.” In this case, it turned out that that the professor was right, but his disdain for the sciences and engineering was typical.

Eventually the role of our universities in pursuing science and engineering education and research accelerated. It was Vannevar Bush’s report in 1945, *Science – The Endless Frontier*, that convinced the Truman administration that the US Science and technology agenda should be pursued through our universities rather than through additional national laboratories or science cities. This was to be a policy unlike those in other developed nations and led to the birth of the NSF, the NIH, Defense research funding offices and, thus, the burgeoning of the American research university.

Today, **now that the mechanics arts of engineering are not only admitted into but expected to function in the realm of what was traditionally the space exclusively for the liberal arts, do we merely coexist with the liberal arts, or do we bring anything to the liberal arts realm?** Should we be drawing something from it? To begin to answer those questions, let us consider just what we mean by the liberal arts and how engineering may overlap with them.

Let's recall first **what liberal learning is all about**. It has nothing at all to do with political persuasion or cultural attitudes. It is not "liberal" education as opposed to "conservative" education. Ancient accounts go back to Cicero's time in the first century BC. It was a time when the citizenry and especially the aristocracy, the freed persons, could pursue a cultivation of a life of the mind—when attention to matters of survival could, for some, take a back seat to matters cerebral. And so there arose **education 'liberalis' —"appropriate for free person," liberated both from a political perspective and from the pursuits of mere survival: the education of the liberated, liberal education**. It was necessary in those times that slaves and servants should be trained in the so-called "servile arts," and that those employed in the trades would be educated in the "mechanics arts." But the free citizen would have the expectation that they might pursue an education, beyond training, in the liberal arts.

Liberal education had (and still has) only **two primary purposes**. First, **liberal education is intended as a means for the student to identify and hone a personal learning style**. We as engineers tend, most often, to be linear and logical thinkers. Humanists tend more often than not to follow more parallel paths of thinking to form opinions and express thoughts.

Once students develop an understanding and command of their own learning style, they are still only half educated, because, you see, **the second purpose of liberal learning was, and still is, to instill an insatiable thirst for more knowledge**, slaking that thirst by means of the learning style that most suits you.

I like the way Stephen Roche, former dean of the Dame's College of Arts and Letters at Notre Dame University, describes the characteristics of a liberally educated person. In addition to being free to pursue an education, in our modern times those pursuing a liberal education may expect to experience **freedom from ignorance and inability and freedom to understand** with confidence and to act with consequence—to exercise critical analysis and reasoning, awareness of context and scale, engage multiple disciplinary perspectives, and incorporate moral dimensions of issues in their actions—to be able to listen, process, and communicate. **Liberal learning when effective imparts a deep and durable and transferable set of knowledge skills suitable to facilitate creativity and agility**. By seeking to develop the whole self, the individual seeks to engage in teamwork with others. At least with regard to Roche's first set of abilities characteristic of the liberally educated, it would seem that we would want and even expect our engineers to be possessed of these.

In addition to having acquired skills of mental acuity and agility to listen, discern, reason, and communicate, Roche asserts that **the liberally educated exercise their abilities also to enjoy beauty and possibility and process** as much as accomplishment. We may or may not agree that this is a necessary or even desirable thing for our engineers and other professionals to master. After all, part of what places biology among the liberal arts but not medicine; part of what places economics among the liberal arts but not business; and part

of what places applied math and physics among the liberal arts but not engineering is that we expect that the primary focus of professional education is to address problems, to be goal oriented. As patients, we do not want our physician to be pursuing new understandings about the basic biology of our cancerous tumor. Instead we want them to address it as best they can with the understanding that exists already. We wouldn't expect any more than that of our practicing engineers would we? Or would we?

The **third characteristic of the liberally educated, Roche asserts, is that of a character based on an acquired and internally synthesized and owned set of virtues**, virtues that express themselves in action, in vocation. This characteristic has a great deal to do with identity and principal. In this regard, the liberally educated person is one who not only can quote extensively from the thoughts and works of others but, more importantly, can say with conviction ideas that they themselves understand and believe. It is **less about being a walking encyclopedia and more about being an author**. Until we are able to assert our own positions, we do not have a genuine or authentic identity. Until we are able to do so, we are not able to bring the broader perspective of humanity and ethics into our work.

This is a big deal. To the extent that the practice of ethics can be defined as making decisions based on moral **principle it is arguably the liberally educated who are best able to practice ethics**. A few of you in the room are old enough to remember Sen. William Proxmire's Golden Fleece awards. For those of you who are unaware or don't recall, Sen. Proxmire, the late Democratic Senator from Wisconsin from 1957 to 1989, had a regular habit of embarrassing government agencies by citing examples of projects and expenses that he felt wasted taxpayer money. One Golden Fleece award was given for a wrench used in space travel and another for a toilet seat that was a component of the jet bomber, both items costing the government several thousands of dollars each, but seemingly indistinguishable from items that might be purchased at any hardware store for under \$20. In defense of our engineers, I wonder if they were at first perplexed. After all, they had produced items that would meet specifications, address the purpose, and solve the problem, and may not have been told that cost, stewardship of the government coffers, was also an important design criterion. In following years addressing other of society's technological needs, engineers would learn that not only cost but also energy efficiency and eventually economic impact and other broader societal considerations would be incorporated into list the design criteria. But **should it have been necessary to point out those values to our engineers and their design teams?**

By the way, engineers are not alone in requiring training to be sensitive to decisions that call for the application of moral principle. A more sinister illustration can be made of the practice of subprime mortgage lending that precipitated our recent economic tumble. If the design driver had been to expand the mortgage business, there is no question that lucrative new markets were opened by structuring loans for which people could qualify. Never mind that at the end of the day when the loan payments ballooned, they would have virtually no

possibility of carrying the loan to its maturity. It was a clever idea and required significant intellectual capacity. Even more clever, brilliant in fact, was the ability to repackage those loans to sell as high grade investments to banks and other Wall Street investors. But had the practice of making decisions been based at least in part on moral principle, one would have discovered that the brilliantly defined processes for short-term financial gain were not ethical. Certainly that characteristic of liberal learning that develops a sense of individual identity and core virtues is something we would want not only of our financial leaders but also of our engineers.

Considering the several characteristics just described—intellectual agility and mastery of communication, ability to appreciate possibility and process as well as achievement, and development and ownership of actionable virtues—it would be a good thing, would it not, for engineers to claim to be thus educated and not merely trained, to be among the ranks of those engaging in, contributing to, and drawing from a rich life of the mind?

You might even contend that men and women educated as engineers here at Delaware already embody most or all of these characteristics and may very well have a rightful claim to be called liberal learners. But I doubt that they would self-identify as such. This brings me to my final set of thoughts. **What should we be doing in our engineering schools both to be explicit about the value of liberal learning and to educate engineers with the expectation that they will develop the capacities traditionally associated with liberal learners?** In terms of curriculum, a Delaware undergraduate degree in electrical or computer engineering already requires six general education breadth requirements (no different than 40 years ago) but notably and admirably requires also a course in critical reading and writing, a junior course in English, and a senior course in ethics and the impact of engineering. The curricula at other universities in which I have studied and taught impose a communication requirement, but neither as much nor as visibly as the curriculum here. And neither of those institutions is explicit about the value of ethics in engineering curriculum. I have now still another reason to be especially proud of my Delaware degree.

But are curricular changes really the answer to ensuring that our engineering students not only receive but also recognize and enjoy the fact that through their engineering education they may be receiving also a liberal education? We all know that there is very little if any breathing room in a modern engineering curriculum. Some of us recall that period in the 1980s when the explosion of technical information had educators at their wits end to figure out how to squeeze it all in to a four year engineering program. That was the time that MIT experimented with eliminating entirely the bachelor's degree in electrical engineering, offering only a five-year Masters. At Dartmouth the engineering curriculum was shortened to three years culminating in a general engineering degree without any specialty designation. An additional two years was required for that, and then another five-year program was proposed. Neither experiment ultimately was successful. Instead, it was decided that our students were better served by a mastery of engineering fundamentals

and using the most recent technology as much as possible to provide examples that reinforce those fundamentals.

So if it is unwise to attempt to augment our curriculum to try to accommodate every aspect of modern technological advance, what does that say about the desirability of curricular change to facilitate more effective liberal learning through our engineering curriculum? To answer that question, it is instructive to be reminded of the original liberal arts curriculum. By the time the University of Bologna had been established in 1088, so had the formal liberal arts curriculum. It consisted of two parts, the Trivium and Quadrivium. The Trivium consisted of grammar, dialectic (logic and reasoning), and rhetoric, while the Quadrivium encompassed arithmetic, music, geometry, and astronomy. Only later did the curriculum grow to include history, art, literature, mathematics, the social sciences, physics, chemistry, and biology. Lining up the curricular elements of the Trivium and Quadrivium against the characteristics that we now associate with those who receive a liberal education we see that the intellectual skills are addressed explicitly. That is to say that in those times one might have been drilled in logic and debate and grammar to hone reasoning and communication skills. But there are no courses explicitly to broaden perspectives and thought or two exercise ethics and moral reasoning. Presumably it was expected that these virtues were acquired in the aggregate experience of the education and the attitudes and caliber of the faculty as mentors as well as experts.

Beyond course requirements and perhaps without even needing to add any new subject matter to the curriculum **we should be encouraged from the earliest roots of our academic institutions that we might do more to better prepare the mind of our students and to sharpen our own.** Since, unlike in the basic sciences upon which we depend, engineering exists specifically to have a positive impact on society, **could we not entertain in our classrooms and our conversations more of the why questions?** What happens when we broaden effective design criteria as widely as possible rather than narrowing the criteria to help ensure that our student's efforts will converge to a single and simple right answer? You recall the old joke of the physicist called in to address the agriculture board about maximizing food yields, who begins by drawing a circle on the board declaring "let's assume a spherical cow." But engineers have the rich challenge of working in the real world, a challenge to take into account every dimension of reality—he physical and behavioral, the known, the unknown, and the unknowable. Is there really any course with a design component that does not also provide the opportunity to have a running conversation about ethics? Is there any laboratory course that doesn't provide almost weekly opportunities to reinforce the value of the ability to write with clarity?

Of course my entire argument today has been based on the assertion that our discipline has the potential more fully and deliberately to impart the skills and disciplines and values that we associate with the liberal learner and that doing so might better serve our students and our society. If as stated earlier the twofold purpose of a liberal education is first to help a student identify and develop how they best learn and

secondly to impart an insatiable desire to continue learning, then I personally can attest to the great value of my Delaware engineering degree and the liberal education that I received in pursuing it. It is something for which I will forever be deeply grateful.

Thank you