

# Bachelor of Arts in Engineering

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I think we have to de-emphasize narrow disciplinary approaches, particularly in our curricula and in the way we teach students to think. We need to pay more attention to the context in which engineering is practiced,... This sounds simple, but we're finding it, at least at my institution, very challenging.<sup>1</sup>

## 1. Preface

My purpose is to explore and provoke discussion of the possibilities for establishing an undergraduate program leading to a bachelor of arts degree with designation “liberal studies in engineering”.<sup>2</sup> The program would be intended for, but not limited to, students inclined toward pursuing an accredited engineering degree at the master’s level. It would *not* seek ABET accreditation, serving, for those so inclined, as a “pre-engineering” program. Yet students would be free, indeed encouraged, to consider a variety of career options - management, law, medicine, education, finance.

The core idea is this: 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. The method is to build on the content and form of instruction in today’s engineering program but dramatically transform both content and form to achieve the goals of a liberal arts program - “critical thinking” is the key phrase in this regard - while preparing students inclined toward engineering with a solid basis in the fundamentals of the traditional engineering course of study. To do this, “fundamentals” must necessarily be redefined.

In what follows, I first review prior proposals for “broadening” engineering education<sup>3</sup>, then, curious as to why such calls for reform have persisted over the past century without comprehensive, substantial and long-lasting effect, I analyze faculty perspectives and ways of thinking about the engineer in practice, what one must learn to be one - ways which Vest suggests need to change - to see what’s holding us back. I then get down to specific proposals about subjects for study drawn from the engineering sciences, laboratories, and design studios. Drawing upon my own experience in attempting innovation of this kind, I will describe how this transformation might be accomplished.

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1. *U.S. Engineering Education in Transition*. President Charles M. Vest's address to the annual meeting of the National Academy of Engineering, September 28, 1995. This address has been published in the Winter 1995 issue of the NAE journal *The Bridge* (Vol.25, No.4)

2. Or “liberal studies in technology”; or “technology studies”; or ... No matter. The key word is “Arts”, as in Bachelor of Arts, emphasizing the leading and dominating perspective of the humanities in the program’s operation. There exist several unaccredited degree programs - e.g., “BA in Engineering Arts” at Smith; “BA in Engineering Sciences” at Yale; “Liberal Arts and Engineering” at WPI; “Engineering Studies” at Lafayette - with similar intent but a comparison with what is proposed herein is not pursued in this document.

3. The term “broadening” is meant as a cover term for the wide variety of proposals and critiques that have found engineering education lacking with respect to learning outside the bounds of traditional, scientific/technical content.

## 2. Antecedents

History reveals a number academically inclined engineers and others who have found engineering education lacking. While the motivations for broadening are varied, my hypothesis is that there is, and remains, a fundamental barrier to reform rooted in what we hold of value as teachers (and researchers) of engineering.

Several themes thread throughout the historical record: There is a perceived need in *practice* for students of engineering to study subjects outside the bounds of engineering technique; e.g., subjects that enhance the graduate's management - especially communication - skills, ability to work in teams, understanding of ethics, etc. Many authors express concern with the *status* of engineers in society and recommend a program of study akin to that followed in medicine and law. In part this is motivated by the desire to establish the professional identity of the engineer and, in particular, differentiate the professional from the labors of the technician. Still others, recognizing that one can't possibly "cover" all that an engineer needs to know wherever his or her professional career might lead, emphasize broadening as a way to prepare the student for *life-long learning*.

These three themes are not unrelated but their motivations differ: The first aims at improving the skills and competencies of the engineer qua engineer; the second at improving the engineer's professional standing in society and/or in the firm, the third can be read as a concern for the student as maturing individual whose future may lie outside the field of view of engineering faculty. (This is where I would locate my proposal.)

### Holistic Engineering Education

A recent collection of essays *Holistic Engineering Education, Beyond Technology*, exhibit all of these themes. Holistic education is defined by the editors as:

...a more cross-disciplinary, whole-systems approach to engineering that emphasizes contextualized problem formulation, the ability to lead team-centered projects, the skill to communicate across disciplines, and the desire for life-long learning of the engineering craft in a rapidly changing world<sup>4</sup>.

Each of the essays offer powerful arguments for broadening citing the "...complex technological, social, environmental, and economic challenges facing today's societies." The demands placed upon today's engineer require more than the application of science and mathematics to solving of problems in a specific domain of engineering. Our "solution spaces" must extend beyond "... those that contain only technological answers"<sup>5</sup>

Priscilla Guthrie recounts our failure to prepare graduates to expand their "solution spaces" to cope with complex systems<sup>6</sup>. Echoing Vest, she argues

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4. *Holistic Engineering Education, Beyond Technology*, Grasso, Domenico; Burkins, Melody (Eds.), Springer, 2010. The volume includes the contributions of industrial as well as academic people.

5. "Holistic Engineering", Domenico Grasso, David Martinelli, Chapter 2, in *Holistic Engineering Education*.

6. "Beyond Systems Engineering – Educational Approaches for the 21st Century", Chapter 8 in *Holistic Engineering Education...* op cit.

...the engineering education community should foster holistic engineering curricula that broaden students' understanding of, and ability to work within the social context.

She recognizes that there are not enough hours available in an undergraduate program to add new requirements and so employers will have to share responsibility for developing a graduate's ability to deal with systems. As to reform of the engineering curriculum itself, she asserts that we cannot teach everything an engineer needs to know but is that necessary? "...it is unlikely that any single engineer has all the knowledge required to work a typical effort."

She emphasizes that the need to prepare graduates to solve problems in collaboration with experts from a wide range of disciplines will require fundamental change "...within the engineering education community".

ABET will need to consider the requirements of basic engineering education. Educators may need to consider whether existing engineering segmentation, for example, electrical, mechanical, industrial, is still useful. Educators will need to develop new and/or different topics and materials, and continually evolve the materials to meet the needs of our changing society. They will also need to introduce or mainstream new teaching methods, some of which may appear difficult to scale. Students will need to accept the requirement to learn skills that are considered non-technical, e.g., collaboration, communication, interfacing with other disciplines. Employers will need to embrace new employees with less specific technical skills (e.g., ability to use certain tools), but who are better prepared to collaborate with others to solve problems in complex environments that go well beyond technology.

Because of the rapid change in the social environment as well as in the scientific disciplines, expecting to teach students all the technical skills they will need now and in the future is misguided. Better to teach "... about the environment, how to tackle complex problems, and how to collaborate with others to understand what is required in the design and implementation of innovative solutions."

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James Duderstadt, like Priscilla Guthrie, describes how the "complex mega systems challenges" place new demands on the engineer<sup>7</sup>. Today's graduate must be prepared to work on "highly interdisciplinary [teams] characterized by broad intellectual span rather than focused practices within traditional disciplines". He sees engineering practice shifting "...from traditional problem solving and design skills toward more innovative solutions imbedded in a complex array of social, environmental, cultural, and ethical issues."

*Status* of the engineer as a professional is a key concern. Duderstadt proposes

*Engineering professional and disciplinary societies...should strive to create a "guild-like" culture in the engineering profession, similar to those characterizing other learned professions such as medicine and law, that aims to shape rather than simply react to market pressures*

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7. "Engineering for a Changing World", Chapter 3 in *Holistic Engineering Education...* op cit

The need for graduates with distinction is exacerbated today due to the availability of “.. high-quality engineering services in developing nations with significantly lower labor costs, such as India, China, and Eastern Europe...” No longer will competency in particular technical skills, education tailored to an engineering career in a well defined discipline, suffice. We need “... new paradigms for engineering practice, research, and education.” Duderstadt acknowledges that there will be resistance to change. In particular,

Many companies will continue to seek low-cost engineering talent, utilized as commodities similar to assembly-line workers, with narrow roles, capable of being laid off and replaced by offshored engineering services at the slight threat of financial pressure.

He would shift the professional, and accredited, part of engineering education to the post-graduate level. But engineering schools would retain control over both undergraduate and the graduate, professional degree programs. This move opens the door to redoing engineering education at the undergraduate level. Duderstadt proposes:

*Undergraduate engineering should be restructured as an academic discipline, similar to other liberal arts disciplines in the sciences, arts, and humanities, thereby providing students with more flexibility to benefit from the broader educational opportunities offered by the comprehensive American university, with the goal of preparing them for a lifetime of further learning rather than simply near-term employment as an engineer.*

He recommends the infusion of design and team projects throughout the curriculum. Engineering design requires a highly integrative approach in contrast to the reductionist methods of specialized engineering majors as they now stand. The reductionist approach is fine in basic research; it is “certainly not conducive to the education of contemporary engineers nor to engineering practice”. For like reasons he advocates the use of the case method as in business and law education and internships ought to be a formal part of the engineering curriculum. This “... new 21st century liberal arts core curriculum”, would lie outside any particular engineering discipline.

Duderstadt stresses life-long learning and, in order to prepare students for such, he claims that the emphasis in engineering education must shift from “the mastery of knowledge content to a mastery of the learning process itself”. Finally

The academic discipline of engineering (or, perhaps more broadly, technology) should be included in the liberal arts canon undergirding a 21st-century college education for *all* students. (emphasis mine).

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Guthrie and Duderstadt raise several issues that merit highlighting as they provide justification for the core of the reform I propose. First both see the need to break from the discipline-bound organization of learning of the traditional undergraduate engineering program, i.e., the silo structure of mechanical, electrical, chemical, etc., engineering departments and to establish a more general program structure.

Second, and closely tied to this first, they both argue for broadening studies beyond the traditional regime of reductionist, analytical problem solving. In Guthrie’s case, the social dimension of sys-

tems challenges would be a central focus of undergraduate study. Duderstadt emphasizes the importance of design and synthesis and would remake engineering as a discipline within the liberal arts.

Third, both recognize that undergraduate study can not provide all the competencies a graduate will need in engineering practice. Guthrie states that employers will have to play a larger role than they do now in preparing graduates to deal with complex systems challenges. It is impossible to provide all the student needs to know within the bounds of the traditional curriculum. Duderstadt proposes internships be made a formal part of the curriculum. His call to shift award of the professional engineering degree to the post-graduate level again reflects the recognition that the undergraduate program can not possibly provide a student with all the learning he or she will need in practice.

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Aware that “those who cannot remember the past are condemned to repeat it”<sup>8</sup>I turn to the historical record, (so enriched by Google and Gutenberg!) to explore in what ways we may be doing just that. The few selections summarized are as much about making a place for science in the curriculum as they are about broadening engineering education.

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8. George Santayana, *Reason In Common Sense* Vol. 1, “The Life of Reason” [http://www.gutenberg.org/files/15000/15000-h/vol1.html#CHAPTER\\_XII\\_FLUX\\_AND\\_CONSTANCY\\_IN\\_HUMAN\\_NATURE](http://www.gutenberg.org/files/15000/15000-h/vol1.html#CHAPTER_XII_FLUX_AND_CONSTANCY_IN_HUMAN_NATURE)

THE  
**Mechanic's Text-Book**  
AND  
**ENGINEER'S PRACTICAL GUIDE:**

CONTAINING  
A CONCISE TREATISE

ON THE NATURE AND APPLICATION OF MECHANICAL FORCES; ACTION  
OF GRAVITY; THE ELEMENTS OF MACHINERY; RULES AND  
TABLES FOR CALCULATING THE WORKING EFFECTS OF  
MACHINERY; OF THE STRENGTH, RESISTANCE,  
AND PRESSURE OF MATERIALS; WITH  
TABLES OF THE WEIGHT AND COHE-  
SIVE STRENGTH OF IRON  
AND OTHER MATERIALS

COMPILED AND ARRANGED  
**BY THOMAS KELT,**  
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To which is added  
VALUABLE HINTS TO THE YOUNG MECHANIC ON THE CHOICE  
OF A PROFESSION; MISDIRECTION OF INDUSTRY;  
INTELLECTUAL CULTIVATION, AND THE  
STUDIES AND MORALS OF THE  
MECHANICS, ETC., ETC.

**BY JOHN FROST, LL. D.**

**BOSTON:**  
**CROSBY & AINSWORTH**  
NEW YORK; OLIVER S. FELT.  
1866

The Mechanics Text-Book was first published in 1860<sup>9</sup>, mid-century - a time when the industrial revolution was in full flower in the United States. It was the year of Lincoln's election to the presidency and the founding of MIT. Darwin's, *The Origin of Species*, was published November the previous year and Joe, the blacksmith, made his first appearance in *Great Expectations* in December the same year.

It was a time when the character of the work force and ways of work were changing. The ties of journeyman to master, employee to employer, were taking on a different nature; There was less 'putting out' and more 'factory made'. New immigrants, primarily Irish, found relatively unskilled employment in the new factories. Labor was seen now in some communities as explicitly opposed to capital. 1860 was the year of the shoe strike in Lynn.

*The Mechanics Text-Book* is really two books in one: The first part, "...an Engineer's Practical Guide containing a A Concise Treatise on the nature and application of mechanical forces;... of the strength, resistance, and pressure of materials," was authored by Thomas Kelt of the Gloucester City Machine Company of New Jersey. It provides the reader with a collection of rules for the making of beams and boilers, how to figure sizes and shapes of structures, but little explanation of the "scientific" source of these relationship<sup>10</sup>.

**RESISTANCE TO LATERAL PRESSURE, OR TRANSVERSE ACTION**

The strength of a square or rectangular beam to resist lateral pressure, acting in a perpendicular direction to its length, is as the breadth and square of the depth, and inversely as the length; - thus, a beam twice the breadth of another, all other circumstances being alike, equal twice the strength of the other; or twice the depth, equal four times the strength, and twice the length, equal only half the strength, &c., according to the rule.

**Valuable hints to the young mechanics..." by John Frost LL.D**

The second part, "Valuable hints to the young mechanics..." by John Frost LL.D, was intended to advise young men in the choice of a profession as well as enlighten the already skilled craftsman - men we would call "tradesmen" who labored as housewrights and painters, distillers and bricklayers, cordwainers and engravers, printers and hatters, tailors and sail-makers, bakers, comb-maker, stair-builder, blacksmith, bookbinder, rope-maker as well as machinists. All learned their trade through a seven year apprenticeship, indentured with a master. It is this part of the text-book that fits our purpose.

Master mechanics believed in the superiority of their trade, of making useful artefacts for meeting life's needs. One historian speaks of a "Mechanics Ideology"<sup>11</sup>. But while their value to society and industrial progress was recognized their status was perceived as less than noble by, not just the lawyer, the doctor and the minister, but the merchant and the commercant too saw themselves as superior.

Frost finds it preposterous that one should deem that "the learned professions of law, physic and divinity are more respectable than the pursuits of commerce, mechanics or agriculture.

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9. The "Mechanics Text-Book and Engineer's Practical Guide ...", Thomas Kelt, To which is added, "Valuable Hints to the Young Mechanic..." by John Frost, LLD., Boston, Crosby, Nichols, Lee & Company, 1860. The frontspiece shown is from a second edition, available now at: <http://books.google.com/books?id=LiwIAAAA-IAAJ&printsec=frontcover&dq=thomas+kelt&lr=&cd=1#v=onepage&q=&f=false>

10. Today's textbook derives this relationship of beam failure load to the beam's dimensions from a fundamental conceptual scheme - "engineering beam theory" - and requires knowledge of the concept of stress and operations in integral calculus. At mid 19th century, this more "fundamental" knowledge was not required in practice - the rule sufficed - but, as we shall see, critiques and promoters of mechanics encouraged the mechanics's more scientific understanding.

11. Faler, Paul, G., *Mechanics and Manufacturers in the Early Industrial Revolution: Lynn Massachusetts 1780-1860*, SUNY Press, Albany, 1981.

The prejudice against the mechanical trades is a relic of feudalism unworthy of our free country. Considered with reference to those old feudal prejudices, all the pursuits by which bread is earned in our country are equally base. Considered in the light of republican philosophy, they are all equally honourable.

To mitigate this situation, Frost recommends the study of science, the fine arts, literature - he recommends taking advantage of the Mechanics' Institutes Lyceums and Libraries. Then the mechanic and the clergyman, doctor or lawyer, sharing topics of conversation, having common tastes and pursuits, could meet "... frequently upon some common ground of science or the fine arts, in their leisure hours, recognize each other's natural equality and become familiar companions..."

An appreciation of science *and* literature should be implanted early on. The teacher of the future apprentice needs to "... instill into his opening mind the most liberal and exalted views of the real beauty, as well as utility, of science and literature." Science would satisfy a liberal curiosity and possibly lead to fortune and fame.

By making himself master of those principles of science which are most intimately connected with his trade, the mechanic, while he is satisfying a liberal curiosity, may possibly be approaching some brilliant discovery, which will speedily conduct him to fortune and fame; and if the lighter reading, generally termed literature, promises no such result, it affords him the most dignified and innocent means of amusement and preserves the vigor and increases the brightness of his intellect.

Frost goes on to urge the mechanic to honor his trade, "... devote his leisure to the general interests of his trade" and, as a dutiful Christian, "...remain attached to his trade". Such is "...good for the mind, for the body, and for the estate of every man. It tranquilizes the spirit, it preserves the health, and it promotes that steady economy which leads to competency; often to affluence".

The man who is satisfied with the position which Providence has assigned him, and endeavours to make himself useful in that position, presents a vastly more respectable figure than one who is constantly struggling to place himself in a different position. The fruits of this struggle are harassing cares, jealous heart-burnings, hazardous enterprises, and often debt and ruin..."Keep your shop, and your shop will keep you."

### **The Massachusetts Charitable Mechanic Association**

Frost's concern for the respectability and mutual improvement of the artisan, the journeyman, and the small manufacturer reflected that of the master mechanics themselves. Earlier on, a "Massachusetts Charitable Mechanic Association" had been established in 1795 - Paul Revere was one of the organizers - to promote "... mutual good offices and fellowship by assisting the necessitous; encouraging the ingenious; and rewarding the faithful." Candidates for membership were to be twenty-one years of age, the usual age when the apprentice obtained a certificate, but only the master mechanic was eligible "...if a mechanic, he shall be a master-workman; if a manufacturer, he shall be a proprietor of a manufactory, or a superintendent thereof: He shall be a person of good moral character, who shall have fulfilled his engagement as an apprentice..."

It was under the auspices of associations like this, established in the major cities of what then constituted the industrial US, not just in Boston, that the libraries and lyceum and lectures that Frost urged upon his reader were established. While only the master mechanic and/or



manufacturer could be a full voting member of the Mechanic Charitable Association, their apprentices could take advantage of a school opened for them as well as a library<sup>12</sup>.

At the beginning of the century, the lectures given under the auspices of the association were quite general; entertaining but evidently of little utility. With time, the association, with an eye toward explicitly promoting the mechanic arts, recommended that a more formal, regular course of lectures be delivered on subjects "...connected or collateral with mechanic science..." especially those useful in the arts and manufactures. Two of the most important of these were mechanics and chemistry. Knowledge of the sciences would advance the mechanics "worldly wealth and comfort.." But, not only is such a person more likely to succeed in his business and "...less liable to be unsuccessful in any of his operations", such knowledge can act as an elixir, freeing the mechanic from drudgery

His occupation becomes more agreeable to him in proportion as he applies his scientific knowledge to his local business; and what was before, at times, irksome, will now be his pleasure. As he becomes more acquainted with this knowledge, it exalts his mind, and elevates his faculties above low pursuits, teaching him to look upon all subjects as below his notice, which are not useful in the pursuit of knowledge or the cultivation of virtue<sup>13</sup>.

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In these early concerns for the welfare of the proto-engineer we see the origins of themes still present in today's discussions about engineering education. Status was a major concern. Frost would have the mechanic develop his conversational skills on subjects of common interest with those already respectable - but be content with the station in life that Providence has provided for him. Both Frost and the Mechanics Association urged the study of science. While Frost's promoted the cultural development of the individual through the study of science (and literature), the Mechanics Institute associations viewed science as contributing directly to the skills of the mechanic as useful - and enlightening - in their daily work.

The Mechanics Institute had their heyday in the first half of the 19th century, a period during which the handcrafted gave way to the manufactured. As the factory displaced the journeyman and cottage production, there was a growing need for technically cognizant and competent individuals in industry. In all of this the question of the mechanic's role as well as status came to the fore as the system within which he labored moved beyond his control. Whereas, as a master mechanic he might have a shop, some dozen or so workers, come mid-century he was laboring within a different, corporate regime.

### **Early Engineering Programs**

Frost is writing prior to the enactment of the Morrill Land-grant act, when there were but a handful of formal programs in the US meant for the education of engineers. These formal programs were oriented toward the production of a more generally capable individual, more scientifically

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12. Here they could read the Mechanic's Magazine, Silliman's Journal or that of the Franklin Institute.[Reference efforts of Timothy Claxton here].

13. Annals of the Massachusetts Charitable Mechanic Association, [1832] p. 241.

educated, better prepared to design and make the railroads, buildings of grander scale, machinery and factories for the production en mass of tools and weapons, powered by energy systems of steam and water.<sup>14</sup>

One of the first institution of this kind was the result, not of government policies, but of the efforts of two individuals: In 1823, Stephan Van Rensaleer, a public figure of some note, together with Amos Eaton, a lawyer, civil engineer versed in the earth sciences, set the groundwork for what was first called “the Rensselaer School” in Troy New York:

for the purpose of instructing persons who may choose to apply themselves in the application of science to the common purposes of life...to qualify teachers for instructing the sons and daughters of farmers and mechanics, by lectures or otherwise, in the application of experimental chemistry, philosophy and natural history to agriculture, domestic economy, the arts and manufactures<sup>15</sup>

This became, after a decade or so, a professional school of civil engineering (the phrase first appeared in the school’s catalogue of 1828). It was B. Franklin Greene, Eaton’s successor as director who, beginning in 1846, reorganized the school to be a comprehensive polytechnic providing a technical education that went beyond narrow utilitarian concerns<sup>16</sup>. According to Wickenden, “Greene found his models in the highly developed technical schools of Paris, chiefly the Ecole Centrale des Arts et Manufactures”.

The curriculum of 1850 included courses in english, foreign languages, and philosophy spread out over the program’s three years. Mathematics, physics and chemistry were studied in the first two years. The third year was devoted to practical courses including descriptive geometry, mechanics, industrial physics, metallurgy, practical geology, mining, geodesy, machines and construction (structures, bridges, hydraulic works, railways). Wickenden notes as a distinguishing feature “...the parallel sequences of humanistic studies, mathematics, physical sciences and technical subjects which have marked American engineering curricula to this day.”

Harvard and Yale started schools of applied science in 1847. Harvard College was “openly hostile to technical studies” and this “...appears to have been a major factor contributing to the establishment of the Massachusetts Institute of Technology on an independent foundation in 1860”<sup>17</sup>.

The lack of respect on the part of faculty at Harvard and Yale for programs and course that might have utility in the arts, agriculture, manufactures, or commerce derived from their equating the liberal arts with the classics, valued in and of themselves for their “..separation from daily life”.<sup>18</sup>

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14. James “Francis’ turbine” dates from 1848. See Patrick M. Malone, *Waterpower in Lowell: engineering and industry in nineteenth-century America*, Baltimore: Johns Hopkins University Press, 2009

15. William E. Wickenden, “A comparative study of engineering education in the United States and in Europe”, The Society for the Promotion of Engineering Education. June, 1929.

16. According to David Noble, Amos Eaton had nothing but scorn for ‘cultural studies’ and the established liberal arts colleges. Experimental science with direct application to the ‘business of living’ was Eaton’s dictum. Greene evidently saw things differently. David Noble, *America by Design, Science, Technology and the Rise of Corporate Capitalism*, Alfred A. Knopf, Inc., 1977.

17. Wickenden, op. cit.

The author of my next selection takes the classicist to task for their haughty attitude toward the useful.

### **The Liberal Education Of The Nineteenth Century<sup>19</sup>**

William P. Atkinson gave this talk before the National Teachers Association<sup>20</sup> in August, 1873. A Professor of English at MIT, 1868-1869, he was educated, then taught the classics at Harvard prior to moving down river. His primary concern is with the inadequacies of the prevailing system of liberal education. He condemns the narrow focus on Greek and Latin; finds fault in the way the subjects are taught (disciplined, rote learning); and, beyond that, sees the whole system as a form of education that relies upon and enforces class distinctions and, as such, is irrelevant to the ongoing and energetic development of the new republic and its peoples of all caste and class.

He sees science as an essential ingredient of a reformed, liberal education for the nineteenth century and argues for the respectability of “...those pursuits in life which are concerned with material things, and a distinct recognition of them as included among the liberal professions”

He characterizes the prevailing classical liberal studies, as barren - a “grindstone system” - fixed on the learning of Greek and Latin. He condemns those - he quotes several at Oxford and Cambridge - who overrate “...the educating value of the process of acquiring the mere form of foreign languages...” and see discipline alone as the basis for education.

The whole system is elitist, self-serving, disdainful of all subjects other than those contained in the classics. It is a system inherited from Oxford and Cambridge and ought be recognized for what it is, i.e., one geared for “... the education of certain privileged classes and protected professions”. Liberal education ought not be viewed this way, i.e., as meant for the aristocracy and contrasted with “popular education” appropriate for the masses. Rather

A liberal education is that education which makes a man an intellectual freeman, as opposed to that which makes a man a tool, an instrument for the accomplishment of some ulterior aim or object.

He holds that the only truly liberal system of education is that which can be applied to a whole nation and available to all...

...to make the education of the whole people liberal, instead of merely the education of certain privileged classes and protected professions. And when I say the whole people, I mean *men and women*. Nothing, I will say in passing, to my mind so marks us as still educational barbarians, so stamps all our boasted culture with illiberality, as

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18. Karen Simons “Classical Antiquity”, *Encyclopedia of the Romantic Era, 1760-1850, Vol. 1*, By Christopher John Murray, Fitzroy Dearborn, 2004, NY., London, p. 194.

19. William Parsons Atkinson, 1820-1890; Professor of English, MIT, 1868-1889. “The Liberal Education Of The Nineteenth Century” was a talk given before the National Teachers’ Association, August, 1873, Elmira, New York, *Popular Science Monthly*, November, 1873. A version, lacking footnotes and with substantial sections removed, is included as Chapter XIX of: *English and Engineering: A volume of essays for English Classes in Engineering Schools*, ed: Frank Aydelotte, McGraw-Hill, New York. Hill Publishing Co., Ltd, London, 1917.

20. The Association was organized in 1857 in Philadelphia. In 1870 its name was changed to the National Educational Association at a meeting in Cleveland.

an exclusion of the other sex from all share in its privileges. No education can be truly liberal which is not equally applicable to one sex as to the other<sup>21</sup>.

Science will have a place in this new liberal studies and on a par with literary studies. But one must be careful. While science is worth a place in the curriculum, he is concerned about the excessive enthusiasm for the utility of science shown by men who "...are carried away with the contemplation of its lower uses, even sometimes to the making them the sole end of education."

.. we are in danger, on the other hand in this new country of ours, whose vast material resources are waiting for development through its instrumentality, rather of overrating than underrating its purely educational function.

Atkinson sees it as an indispensable complement to ethical and linguistic studies "...which have heretofore monopolized the title of a liberal education and which, from the absence of science from that form of education, have been reduced to their present effete and impotent condition."

Classicists would have none of this; they claimed science degrades the dignity of true leaning "...by making it subservient to mere utilitarian aims" Atkinson, in reply, claims that "... any knowledge that cannot make good its claim to such usefulness is worse than utilitarian, for it is useless knowledge." but then notes:

It is not a difference in studies that constitutes them liberal or illiberal; it is a difference in the spirit in which all studies may be pursued. The study of chemistry and the study of Greek particles may be equally base or equally noble, according as they are pursued worthily or unworthily, with a selfish eye to the loaves and fishes, or with an aim at the higher rewards of true culture, and the higher advancement of man's estate....leave aside this stupid charge of utilitarianism...<sup>22</sup>

Finally, Atkinson acknowledges a problem common to all attempts at curricular reform. If one is to add new subject matter to the requirements, in this case science to a liberal studies curriculum, how do you find the room to accommodate the new?

Now, if the study of physical science is to play a vastly more important part than it has hitherto done in all future schemes of liberal education, the first and most obvious consideration is that room must be found for it. Bearing in mind, as we must constantly do, that the word education stands for a strictly limited quantity, a limited amount of time, a definite amount of mental effort, is that time and mental effort have been wholly absorbed in one set of studies, it is very obvious that these must undergo modification and curtailment in order to make room for another set. And yet no error is a present more common or more disastrous than the attempt to introduce the new, without any disturbance of the older studies.

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Atkinson was a classicist, promoting a "liberal education for the 19th century, arguing for the inclusion of science in the curriculum. The vision of the sciences as *useful* as well as *enlightening* was voiced by Frost as well. The value of science was naturally a concern of faculty of the ever

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21. Atkinson, McGraw-Hill op cit., p.253.

22. Atkinson, McGraw-Hill op cit, p. 271, The miracle of science may yield us a surplus of loaves and fishes but its real value is in leading us to the 'higher rewards of true culture'.

growing number of engineering schools and colleges in the last quarter of the 19th century. Its identification as a *necessary* ingredient of engineering education is evident in the presentations at the very first and formative meeting of the Society for the Promotion of Engineering Education in 1893 - an organization whose members, in the main, were teachers of engineering.<sup>23</sup>

William H. Burr, a Professor of Civil Engineering at the Columbia College School of Mines in New York titled his talk:

#### **The Ideal Engineering Education<sup>24</sup>**

Burr “unhesitatingly places...as the first and fundamental requisite in the ideal education of young engineers, *a broad, liberal education in philosophy and arts*, precedent to the purely professional training.” As justification, he cites the sequence of a broad and general cultivation prior to, and forming the foundation of, the subsequent professional training in law and medicine

By means of a liberal training, the requisite powers of observation and a sound judgment are more symmetrically developed and far more accurately applied in consequence of truer conceptions of the object on which they are brought to bear, and a correspondingly enhanced power of healthy mental assimilation is acquired. The broad cultivation, it matters little when or where it is obtained, is the only effectual corrective for that narrow and malformed excellence in some special direction, which, while it is certainly much better than no excellence at all, falls lamentably short of the vigorous and well-rounded product of the ideal education in engineering.

Liberal education’s main purpose “should be such a cultivation of human qualities as will subsequently enable engineers to meet men as well as matter.”

He observes that the nature of the questions the professional faces require “profound and solitary thought”; consequently, “much of his purely professional activity removes him from all cultivating influences of a forensic or rhetorical nature through which men are most moved.” So it is all the more important - since once he enters practice the engineer will not have any inducement to “fill the void” - that liberal training be a required part of an engineer’s education<sup>25</sup>.

As to the engineering sciences (he uses the term in a critique of British universities):

The second fundamental characteristic of the ideal education in engineering, a thorough training in what may be termed the natural philosophy of engineering, which embraces all that body of mathematical and scientific knowledge constituting the pure theory of engineering operations.

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23. Terry S. Reynolds, Bruce E. Seely, “Striving for Balance: A Hundred Years of the American Society for Engineering Education”, *Journal of Engineering Education*, vol. 82, no. 3, July 1993, pp. 136-151.

24. W.H. Burr, “The Ideal Engineering Education”, Proceedings of the Society for the Promotion of Engineering Education, vol. 1, Section E, Chicago, July 31, Aug. 5, 1893.

25. Like Duderstadt, he is “very strongly inclined to believe that those engineering schools of the future which are to supply the highest grade of professional instruction will, for the most part, be found connected with our greater universities”.

He contrasts the “handbook method of construction” with work grounded in “an intelligent appreciation of the principles or laws which govern the physical sequence of the things that he is to control and adapt to the use and convenience of that part of mankind served by his clients or directly by himself.

In one case he imitates and in the other he creates. In the former he is defenseless against his own ignorance, while in the latter he is equipped for perfect safety, even though he may occasionally err.

He goes on to make a sharp distinction between the scientific training of the student of engineering and the corresponding instruction given to the student of pure physics. The focus in engineering should be set in terms of his future as a professional...

...affording a foundation for his mechanics and for the subsequent analytical treatment of such subjects as the elasticity and the resistance of materials, hydraulics and the general theory of machines, the theory of bridge structures, water and wind motors, thermo-dynamics and the steam engine, electrostatics and electro-dynamics, and every other branch of engineering physics. These are intensely practical applications of pure mathematics, and engineers cannot hope in the future to attain to a high grade of professional success without facility in their use.

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The main medium for studies, critique, and proposals for reform of engineering education throughout the 20th century has been meetings and publications fostered by the American Society for Engineering Education (ASEE), a direct descendant of the Society for the Promotion of Engineering Education. The first report that has relevance to our concern was the uneasy product of a joint committee on engineering education, chaired by a physicist, C. R. Mann, and funded in part by the Carnegie Foundation (both factors a source of the uneasiness on the part of engineers).

The report is in three parts: The first part is a review of present conditions, including a brief history of aims of engineering education and curricula. In the second part he lays out “the problems of engineering education”. The third part suggests solutions. He advocates some school-supervised contact with real engineering work under real conditions; running parallel with this a certain amount of engineering laboratory work in the school; and theoretical work in mathematics and science<sup>26</sup>.

Even when you have done all this, “...you still have not answered the question of how you are going to develop the man as a man and what you are going to do for the humanistic side of the engineer”. This is a fourth element, an essential component of the curriculum. He recommends the study of English literature, philosophy, sociology and economics and the like spread throughout the student’s entire course of study, courses “...occupying possibly a quarter of the man’s time. In elaborating on this fourth element, he cites a specific course in English literature taught by a Professor Aydelotte at MIT meant “...to develop in connection with the engineering work an apprecia-

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26. David Noble, *op cit.*, citing Monte Calvert, describes the tension between “shop culture” engineers and those of a newer “school culture”. Mechanical and civil engineers populated the former; the newer science based chemical and electrical engineers populated the latter. Mann’s proposals seem intended to bridge the two cultures.

tion of the human relation involved in engineering and the humanistic values he must understand if he is going to be a real man”.

### **The Problem of English in Engineering Schools<sup>27</sup>**

Frank Aydelotte, Professor of English at MIT, did not teach “engineering english” or ‘business english’ nor did he “cover” the great books. Rather he adhered to the dictum that students study literature to learn how to think and argue critically.

To engage students he asks questions:

...what [do you mean] by engineering?... What is the difference between a trade and a profession? What is the meaning of professional spirit? What should be the position of the engineer in society in this new era of the manufacture of power, that of mechanical, hired expert, or that of leader and adviser? Is the function of the engineer to direct only the material forces of nature, or also human forces?<sup>28</sup>

... What is the aim of engineering education? What kind of education will produce the ideal engineer? What is the relation between power of memory and power of thought? Is there any connection between a broad and liberal point of view and capacity for leadership? What qualities do practical engineers value most highly in technical graduates?

What is the relation of pure science to applied? What is the relation of science to literature?

Students read essays relevant to the subject - Huxely, Tyndall, Arnold, and Newman<sup>29</sup> - and actively participate in discussion in which “No orthodox point of view is prescribed; the student’s own reason, not the opinion of his teacher or the pronouncement of his text, is the final authority....our aim is to raise questions which it may take him a half a lifetime to answer...”

He claims that student work of this kind has “..more value for strictly technical purposes than a course occupied exclusively with what is called ‘technical writing’. The student who can think straight...handle complicated ideas, ...balance opposite arguments and marshal them convincingly...can handle any technical subject within the range of his technical ability.”

If the engineer, who has created this new epoch of the manufacture of power, is to fulfill the promise made to society by his achievements hitherto, he must view society broadly, must address himself to the solution of its problems, which are human problems no less than material. ...it must be a training in thought, the influence of which is to clarify and humanize the student’s character and his aims of life.

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27. Frank Aydelotte, “The Problem of English in Engineering Schools”, chpt. X, *The Oxford stamp, and other essays...*, Oxford Univ. Press, 1917.

28. *ibid*, pp 202-203.

29. Frank Aydelotte, ed. *English and Engineering, A Volume of Essays for English Classes in Engineering Schools*, McGraw-Hill, NY, London, 1917. Atkinson’s essay is one of the chapters in this volume.

Our selections show a recognition on the part of those responsible for establishing the first programs in engineering education that to prepare students for the profession, some measure of the humanities must be an integral part of the curriculum - and this whatever motivation we read into the policy, whether the perceived need to prepare the graduate for corporate management or to 'humanize the student's character'.

In this sampling of the concerns of individuals for the professional status of the proto-engineer, the respectability of science within the liberal arts curriculum as well as the place of liberal studies in the engineering curriculum, we find the origins of themes that thread throughout the 20th century. We must be careful not to go overboard; origins, yes, but the proposals and polemics were exchanged among academicians standing on quite different ground overlooking different vistas than today. (Still something in all of this smells the same).

We do not report on the contributions of each and every individual moved to address the question but some further sampling is necessary to convey the concerns of engineers as members of professional organizations if only to show that the issue, while not central, continued to nag, to surface, and provoke debate until this day.

#### **Aims and Scope of the Engineering Curriculum et al.**

It wasn't until 1939, with the H.P. Hammond Report, *Aims and Scope of the Engineering Curriculum*,<sup>30</sup> that the Humanities and Social Sciences received explicit and significant institutional status as a "stem" to be offered in parallel with the student's technical track. The report recommends that the humanities and social sciences be given "...a minimum of approximately 20% of the student's educational time. This allotment should be at least the equivalent to one three hour course extending throughout the curriculum, and on the average somewhat more.

The importance of "liberal education" as part of the engineer's "professional identity" was reinforced in the oft cited Grinter *Report on the Evaluation of Engineering Education*, done for the ASEE and published in 1955<sup>31</sup>. Like Frost, the Mechanics Association, William Burr et. al., the humanities are to be valued for their enrichment of the engineer's life as citizen as well for their contribution to his professional development: "... a person whose living expresses high cultural values and moral standards..."

Recognizing that "...many engineers progress into managerial and top executive positions in industry and government...", the relevance of courses in the Humanities and Social Sciences to engineering management was emphasized:

The foundation may be built more solidly in humanistic and social courses than in highly applied studies in management."

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30. "The Hammond Report", Access at <http://mit.edu/~jwk/www/docs.html> [Nov. 2011]

31. "Report of the (ASEE) Committee on Evaluation of Engineering Education", *Journal of Engineering Education*, September, 1955 pp. 25-60. (Grinter Report)



The Grinter report was quickly followed by another titled *General Education in Engineering*<sup>32</sup> in which the authors explored, through visits to approximately 60 engineering schools, how the schools had fared in incorporating study in the humanities and social sciences into the curriculum. Their focus was “..on the crucial problem of how to develop and maintain an effective programme of humanities and social sciences in the very limited time usually available in an undergraduate engineering curriculum”.

The committee found that some faculty embraced the notion of including the Humanities and Social Science because they might contribute to the professional competence of the engineer “...on narrow utilitarian grounds...” through “...the improvement of technical efficiency”. These engineering faculty claimed that students “...should take courses in composition, technical writing, speech, applied psychology, and business administration.” Some along this line argued for the study “...of literature and philosophy as subjects which will enable the engineer to manage people more effectively as a result of an improved ability to analyze their motives and points of view.” The committee rejected this rationalization:

The committee believes that the humanities and social sciences are, in a deeply serious sense, practical and useful..... What we object to is an essentially frivolous definition of practicality that limits its attention to the development of a few surface skills, while failing to recognize that literature and philosophy and social organization are, like science itself, basic aspects of human activity in which depth of understanding provides the only sound foundation for the student’s future growth. The emphasis upon immediately useful techniques narrows the scope of the humanities and social sciences and seriously diminishes their educational value.<sup>33</sup>

The committee went on to denounce (“less defensible”) the “finishing school concept” which holds that the humanities and social sciences provide a “...cultural veneer designed to make the engineer acceptable in polite society.” From this perspective “literature and the arts are primarily conversation pieces, or aids to smoother family and social relations since they give the engineer something to talk about besides transistors, strain computations, and fluid flow.” They sum up “...A statement of objectives which fails to respect the centuries of solid scholarly accomplishment represented by the humanities and social sciences can scarcely provide the requisite intellectual framework for a sound programme of study (in the humanities and social sciences)”.

The authors of the General Education report presumed that the 20% humanities and social science content would be contained in a sequence or set of courses taken over the students’ four year undergraduate studies but standing apart from their engineering course requirements. This indeed is the structure that endures to this day.

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32. *General Education in Engineering* (ASEE, "Burdell-Gullette Report", Report, 1956) refers to the Hammond Report of 1939. Access at <http://mit.edu/~jwk/www/docs.html> [Nov. 2011]

33. *ibid*, p.4.

### 3. The Fundamental Problem.

My purpose is to explore possibilities for establishing a bachelor of arts of liberal studies in engineering. I seek a fusion of the subjects of the traditional undergraduate engineering program and the ways of thinking and learning characteristic of the traditional liberal arts program. Before describing the form and content of such a program, I conjecture why - in spite of the persistent calls for broadening - it has been so difficult to make the connection and affect reform in this regard. I claim there is a fundamental problem at the very core, in what we value as engineering faculty. The problem's source lies in too narrow a view of what engineers do in practice and, consequently, too limited a vision of the "fundamentals" we insist our students must learn.

#### The Fundamentals

Prerequisites to enrolling in the engineering science courses required by the student's chosen major - mechanical, electrical, chemical, etc., engineering - are the courses in the calculus, physics, chemistry, now biology. These are seen as fundamental. And they are in the way that they provide the student with the vocabulary, the tools, the concepts and principles upon which the engineering sciences base their development of more concepts and principles and methods - enabling students to solve the problems assigned in mechanics, thermodynamics, electronics, etc. The engineering sciences in turn are held as fundamental to practice, e.g., engineering design<sup>34</sup> and to further study and research at the graduate level.

The purpose of assignments and exercises within the engineering core of the student's major, whether mechanical, electrical, civil, chemical, etc., is to convey a well established body of instrumental, disciplinary knowledge from faculty to the student. The abilities stressed are problem solving within the discipline's paradigm using its concepts and principles alone. Here, for example, is an excerpt from a well-know textbook in engineering mechanics.

The main objective of a basic mechanics course should be to develop in the engineering student the ability to analyze a given problem in a simple and logical manner and to apply to its solution a few fundamental and well-understood principles<sup>35</sup>.

The mechanics problem is *given* - not to be formulated by the student; it demands a *simple and logical analysis* - not a conjectural, inferential thinking up and about; and is to be solved using a *few fundamental and well-understood principles* - not by trying several, alternative, perhaps conflicting, approaches and perspectives. The work-life of an engineering student, hence graduate, from this perspective is neat, well posed, deductive and principled.

Solving well posed, single-answer, problems is the dominate learning experience of the undergraduate. It is a solitary activity; engaged in competition with one's peers. It is, as Burr noted, an essential activity in engineering practice, but it is not all. Solving problems is part of what I call "object world work" - work within a bounded discipline, e.g. structures, electronics, etc., with its own particular resources including concepts, principles, heuristics, metaphors, methods, codes, standards, supplier catalogues, instruments, techniques of fabrication, and more. It is necessary work but it

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34. This sequence, culminating in a "capstone" design course has been challenged; now, at many schools, design is a subject of study (and action) the first year.

35. Beer, F. P., Johnston, E. R. Jr., & DeWolf, J. T., *Mechanics of Materials*, McGraw-Hill, 4th ed., 2006, p. xiii

does not suffice. For example, in design, many with whom engineers must work may not see the world in the way they do. The (over)emphasis on solving well-posed, single-answer, problems with its reductionist, deterministic ideology works against taking the social and constitutive features of engineering seriously. Indeed, it can be dysfunctional as this quote from a summary of observations made by an MIT Corporate Advisory Panel in 1992 suggests:

MIT Graduate: Not as perfect for industry as before. Typical product of MIT education - an excellent individual performer but often considers it *just about unethical* to use results of other people's work. This attitude must change. (emphasis mine).

If we agree that mathematical and scientific knowledge and know-how is necessary to doing engineering but not sufficient, i.e., that other modes of knowing and thinking are necessary too, then we must immediately confront the question: How do we fit this other learning into an already crowded curriculum? Recall that Atkinson in 1873 asked this question. He observed that there was nothing more disastrous than attempting to introduce the new "without any disturbance of the old" - which then prompts the question: What do we leave out?

I will not respond, not go down this path. Something is fundamentally wrong with this way of framing the challenge of reform. The source of our error lies "... in the way we teach students to think.", indeed, in the way we think. I reflect on our very own mode of thinking.

### **Instrumental Rationality**

I will use the phrase *instrumental rationality* as a label for the way we think as engineering teachers. Instrumental rationality is evident in the ways we describe a "problem" to be "solved" and what is deemed a legitimate "solution". Beer and Johnston's definition of the main objective of a mechanics course provides an example. It's evident in the ways we quantify costs and benefits and the risks of failure due to an extreme event. It's evident in the probabilistic quantification of acceptable limits in a mass production process, enabling quality control of the process. Evident too in the words of faculty who speak of students as "products for industry" and see nothing wrong in grading on the curve, ensuring that a certain, small percentage of students receive a grade of "D".

The exercise of instrumental rationality requires abstraction and simplification. This is key to methods for problem solving in all fields of engineering.

[Abstraction requires] Simplification of a complex problem by breaking it down into manageable components. Specifically modeling in *quantitative terms* critical aspects of the physical and human world, and necessarily simplifying or *eliminating* [my emphasis] less important elements for the sake of problem analysis and design...<sup>36</sup>

For a problem to be treated as an engineering problem it must be expressed in quantitative terms. Only factors, aspects and feature of the "real" world that can be construed as measurable and quantified matter. Numerical measures of inputs, outputs, parameters, variables, behavior and performance, costs and benefits are the essential ingredients of a problem. One might wonder what criteria are used in eliminating, (or deforming), more qualitative elements for the sake of problem analysis and design. Is it perhaps the case that only those "elements" that can be quantified are

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36. "From Useful Abstractions to Useful Designs - Thoughts on the Foundations of the Engineering Method, Part I, Draft, 7 May, 2005, Engineering Council for Undergraduate Education, MIT, p.4

considered at all? Anything that can't be measured is, ipso facto, irrelevant, not of interest or significance?

This way of thinking is evident in the desire to make engineering design into an engineering science. It's this way of thinking that leads us to claim that, in order to broaden engineering education our "solution spaces" must be extended.

And it's this way of thinking that leads us to write and speak of knowledge as if it were some kind of material stuff; e.g., We *gain* knowledge, *store it away* somewhere in our head; *transfer* it to our students; students claim that my course is "like taking a drink from a fire hydrant". Our research contributes to the *body* of knowledge and we measure this in large part by the *number* of our publications. We know *more* now than before.

The "knowledge as stuff" metaphor leads us astray - in our case, down the path of curriculum reform that constrains our discussion to what material we must *cover*, what we must *leave out*, what we should *keep in*. I refuse to go that way. Instrumental rationality is essential to engineering but it fails when taken too far, when presumed a basis all of our thoughts, for dealing with events and features, phenomena and people, beliefs and values, that can not, ought not, be reduced to quantitative measure.

### **Attitudes, Values and Vision**

The way we think is one thing; what we want and will is another. Instrumental rationality structures our methods and means. Attitudes, values and vision inform our goals, our ends. My claim is what we value as knowledge and know-how, what we describe as engineering competence, is deficient.

This is perhaps best illustrated by citing another issue of contention throughout the history of the development of engineering education - namely the tension between those who place science first and foremost throughout the curriculum and those who advocate for the legitimacy, if not primacy, of design. At one level, this tension reflects different visions on the part of faculty (and students) of the student's career goals: i.e., practice or research. But there is more to it than that. It's as much a question of status, i.e., the perceived high status of engineering as science - as reflected in the high value placed on research publications in science-like journals by faculty in pursuit of promotion and funding - and the lack of respectability of engineering practice<sup>37</sup>. It's the old tension between a "science culture" and a "shop culture".

One noted historian<sup>38</sup> wrote how, in the 60's, many engineering faculty had concluded that the "pendulum had swung too far" toward the theoretical side. Key to redress was promoting the place of engineering design in the curriculum. For example, at MIT, a committee had been established in 1959 to study design and its place in the curriculum. Why was science valued so highly and design

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37. One must admit that perceptions are changing some. "Entrepreneurship" is now valued but this does not seem to have had an impact on the makeup of the core curriculum.

38. Seely, B. "Patterns in the History of Engineering Education Reform: A Brief Essay", *Educating the Engineer of 2020: Adapting Engineering Education to the New Century*, Appendix A, p. 117, 2005.

given short shrift? How best to teach design given its variety across different fields? What was the place of analytical technique in designing? What were the major challenges in practice?<sup>39</sup>

In the opening section on “semantics”, members of the committee noted how people “use words as weapons” as opposed “to reveal and clarify a thought”. Words take on meaning and “carry emotional content quite apart from their dictionary definitions”. Some words are “good”; some are “bad”. The committee made a list of good-bad pairs: basic-applied; broad-specialized; creative-routine; education-training; fundamental-descriptive; professional-vocational; quantitative-qualitative; scientific-intuitive; theoretical-practical. Members noted that the best way to prompt an “emotional response” is to juxtapose both words of a pair in a sentence or discourse. “We cannot communicate without being ‘descriptive’ but how much better it is to be ‘fundamental’!”

‘Bad’ words are useful chiefly as missiles to be guided to the enemy.

Members explicitly addressed the question of fundamentals, noting how many faculty claimed that is what we should teach. But they could find no accurate description of what this might mean. They then made an insightful comment on engineering knowledge and know-how:

The ostensible content of an engineering education is a body of knowledge and a set of skills which should enable a student to solve engineering problems. It is clear that education is much more than this. Whether consciously taught or not, students acquire attitudes and habits as well as information and techniques. The results of this study suggest that we have been paying far too little attention to the attitudes we instill in our students. Certain specific attitudes are required to make effective engineers, and engineering schools cannot escape the responsibility for the attitudes as well as the knowledge and skill of their students.

They listed certain specific attitudes - willingness to deal with uncertainty, to exercise judgement, to question authority, to rely on experiment - then, echoing Burr...

It is essential to inquire whether these attitudes are fostered by the kind of education we provide... We cannot dismiss the subject as something outside the province of higher education, since attitudes are slowly acquired, difficult to change and best instilled at a relatively early age.

Instrumental rationality is but one mode of thinking in engineering; we must allow that much more goes on in the classroom than the learning how to solve well-posed, single-answer problems. Normally never explicitly brought to the fore, there are particular ways of seeing the world, ways of identifying and constructing a problem to be solved, and particular ways of *not seeing* what can not be so easily included in a problem to be solved, that reside in between the lines so to speak. Attitudes, perspectives, and values - other than instrumental - pervade our engagement with students.

The attitudes and values we convey to our students are the attitudes and values appropriate to object-world work. But narrow, disciplined approaches while necessary, do not suffice in practice. Not just in design, but throughout all kinds of engineering tasks, participants’ proposals as well as

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39. The committee deliberated fall semester 1959. It’s “Report on Engineering Design” appeared in the Journal of Engineering Education, vol. 51, no. 8, April, 1961, pp. 645-660.

analyses conflict; they must be brought into harmony with one another if a task is to be brought to completion. For this, constructive critique and clarity of explanation, negotiation and exchange is necessary. In this - what's best described as a social process - traditions of the firm and of the nation matter. Norms and beliefs - about what is a 'robust' design, about the capabilities of the user, of citizens matter. Ethics matters. Culture matters. The 'context in which engineering is practiced' is value laden. Our current undergraduate programs in engineering miss all of this; we do very well at preparing the object-world worker - but pay little attention to the rich and varied and social/political contexts of engineering practice.

### Existential Pleasures of Object-world Work

The reader ought not conclude from this that thought and practice within object worlds, is mundane, done mechanically (looking up in tables...), routine or uninteresting. That's the case for some tasks but not true in general. Quite the contrary: The challenges engineers face within these worlds are never so neatly defined as problems to be solved (they first must be constructed), nor bounded so narrowly (defining interfaces requires more than a look-up table), nor devoid of opportunity for creativity (even in the smallest item) as the general public might presume.

Engineers derive great pleasure and satisfaction from getting things to work right in accord with their conjectured solutions, their proposals, their designs. Finding an elegant solution to a problem, or going from ideas, words on paper, a statement of specifications, to a device that actually does what the boss or a client says it should do is quite an amazing achievement - and it is sensed that way. For there is no rule book for doing such. Object world work is immensely satisfying, albeit constrained and instrumental, quantitative and material.

The narrowness of the domain, the instrumental nature of object world work, frees the engineer from social concerns. Working like a scientist in this regard, uncontaminated by human foibles, varying opinion, subjective judgement - or this is the way it seems - one can dream of reinventing and saving the world, through the miracle of modern technology - oblivious to what goes on in the world around (or below)<sup>40</sup>.



This fascination with technology in and of itself alone is characteristic of the exciting part of object-world work. And it is what sustains the energy and engagement of faculty in their teaching of undergraduate as well as graduate students. Here lie the roots of the value system fundamental to engineering education.

But the system is deficient. It is deficient because it ignores context - the context of practice, the context of use, the context of the individual psyche - barely acknowledged in the teaching of engi-

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40. The figure, which may prompt visions of a Renaissance painting, shows two MIT graduate students watching an un-manned aerial vehicle - one in a fleet of four they helped develop to execute surveillance and tracking tasks. Photo/Donna Coveney. MIT News Office, *MIT's intelligent aircraft fly, cooperate autonomously*, Lauren J. Clark, School of Engineering, September 26, 2006, <http://web.mit.edu/newsoffice/2006/flyingrobots.html>

neering. We rarely explore or show how social and political interests contribute in important ways to the forms of technologies we produce. We assume that engineering knowledge and know-how is universally accessible and understood by all in the same way - free of cultural variety or individual expression.

With blinders on, what is seen is only the “hard” stuff; what is discussed in earnest is limited to how to get from a well-posed problem statement to the unique solution, from a list of functional requirements in design to specifications of the product. It is a value system that glorifies the material to the extent that the system will not allow any serious discussion of values and visions other than those co-opted within itself.

The way we structure our curriculum and teach our subjects conspire to instill in the student the idea that engineering work is value-free. Object-world work might be perceived to be so, but that is but one part of engineering competence. While teaching the “fundamentals” of science and mathematics and the engineering sciences remains necessary, we must do so in more authentic contexts, showing how other than quantifiable constraints, costs, and benefits contribute in important ways to the forms of technologies we produce. We ought not as faculty imply as we do, that solving single answer problems or finding optimum designs alone, uncontaminated by the legitimate interests of others who see the world in other ways than we, is what engineers do all of the time.

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The fundamental problem and barrier to broadening then is the instrumental focus of our traditional curriculum. Teaching engineering as value-free, or what is much the same thing, teaching as though technological innovation in itself is always good and ignoring the complexities of cultural context - including who sets the ends - severely constrains opportunities for curriculum reform. The almost entire attention to means and methods to solve problems is selling students short, is doctrinaire, stifles questioning, creativity, reflection and debate, can be hazardous to society and borders on the irresponsible.

But what to do?

#### **4. Bachelor of Arts in Engineering**

Recall, this is a proposal. I do not have a listing of course requirements not even the syllabus of a single subject. I do have examples of exercises, some I have engaged with students, others chosen from what other faculty in existing programs with similar objectives have implemented. With these, I hope to convey a sense of what I mean by dramatically transforming the content and form of the traditional engineering undergraduate curriculum to make it a liberal arts program - liberal studies in engineering.

To this point I have not said a thing about the organization and structure of such a program. I do so now so that the reader has an idea of the context for the examples and proposals that follow. The guiding principle is that the humanities and social sciences should dominate -it’s a bachelor of arts degree - in perspective, class-room ambience, choice of content, as well as credit hours. Restricting attention to a semester, three fourths of the semester hours would be devoted to the liberal studies of engineering/technology. The remaining one fourth being designated “free elective” - though

we might consider requiring the student to “take” 25% of his or her total credit hours in the sciences - just as engineering students are required to take roughly the same proportion in the humanities and social sciences. More important than credit hours is, as Atkinson claimed, the qualifications, attitude, and perspectives of the instructional staff. Teaching assistants or full professors - all must engage students in open discussion and exploration, reflect on the subject at hand, encourage questioning (of authority) and critical thinking. “Tool” learning and single-answer problems may be part of this but not without reflection on limitations as well as power of instrumental reasoning and practices. Needless to say, we want active, not passive, learning; a student focused, not teacher focused classroom.

I organize my examples in accord with three kinds of learning experiences in the current curriculum - the engineering sciences, laboratories, and design projects<sup>41</sup>. I do not speak of the mathematics and science requirements as my interest is in the core of the engineering major. Research projects, study abroad, internships and the like also lie outside my field of view. Any one of these might be considered a legitimate “elective” with the proviso that faculty prepare, advise, and follow-up with the student whatever option or requirement is undertaken.

#### **4a The Engineering Sciences**

The engineering sciences carry titles like Statics and Strength of Materials, Dynamics, Thermodynamics, Heat Transfer, Controls, Electronics, Materials Science, and the like. Again, the intent would be not to cover all of this - clearly an impossible task - but to selectively choose exemplary content from the lot, do the appropriate theory, have students reflect on the relation of theory (or lack thereof) to practice, on the historical development of theory *and* practice, on the broader cultural context of that development, on the literary merits of the text-book as well as historic texts, e.g., the rhetoric, the narrative and flow of the explanation, the philosophical status of concepts and principle in the past and today. Students will be provoked to question authority, to write, to evaluate, to judge, and to construct and solve a problem or two.

##### **Engineering beam theory**

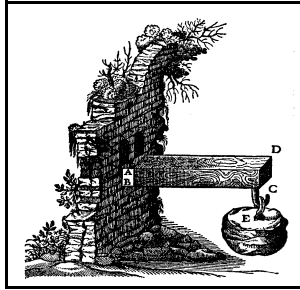
Engineering beam theory is one of the important topics of a mechanics course usually “taken” the sophomore year. Different varieties of the course are required study in different majors - e.g., mechanical, civil, aerospace. In this respect it is as fundamental as the mathematics and physics upon which it builds.

Think of what follows as describing the possible contents of a “liberal studies in engineering” module. The main purpose is to show the way the perspective of faculty of the liberal arts can be brought to bear in the liberal study of engineering, in this case, engineering beam theory and practice. The objective is to engage the student in the critical evaluation of historical precedents that are bound to appear “foreign” yet familiar in the sense that the questions posed and addressed are the same as found in today’s mechanic text book.

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41. This tri-partite structure is *not* meant as a rigid template for a liberal studies curriculum. My organization is patterned on Sheri D. Sheppard, et al., *Educating Engineers: Designing for the Future of the Field*, San Francisco: Jossey-Bass, 2008





The module would begin with Galileo's analysis of the 'resistance' of beams to fracture, an analysis found in the 'Second Day' of his "Dialogue concerning "Two New Sciences". Allowing the anachronism, Galileo is very much in the mold of contemporary engineering science thought and practice in his attention to the different materials of the world of construction, in his logical analysis, in the overall flow of his treatment of different kinds of beams, in the generality of his results obtained proceeding from but a few fundamental concepts and principles.

His text might strike the reader as bizarre; there are no equations; his analysis is throughout in terms of ratio and proportion. In contrast to the box of the scaling rules for beams taken from the Mechanics Text-Book published two centuries down the road, Galileo provides a derivation of the resistance of a cantilever to fracture due to an end load. His analysis relies on the principle of equilibrium of the lever; his result expresses the fracture load in terms of the ratio of the length of the beam to its thickness and a property of the material - its resistance when subject to tension.

But, when compared to today's theory, his result is wrong! The constant of proportionality in the relationship of end-load to the dimensions of the beam is wrong.

He goes on to deduce results for beams supported and loaded differently. And these scaling laws are correct! In fact, we can claim that Galileo provides justification for the rule governing the "RESISTANCE TO LATERAL PRESSURE, OR TRANSVERSE ACTION" found in the Mechanics Text-Book of the 19th century! We can ask the student to explain all this. How can a theory in the engineering sciences be both wrong and correct?

At this point we go through the analysis of beam behavior as found in today's text-book - i.e., the consideration of displacements and deformation, the concepts of stress and strain, the principles of equilibrium, continuity, how the properties of the material out of which the beam is made enter the picture, etc. We compare assumptions, concepts, principles and methods of analysis with Galileo's treatment. We assign a single answer problem - a cantilever, a steel I-Beam, so students, upon finding the solution, get a taste of the pleasures experienced by their colleagues majoring in engineering. The reality of today's steel I-beam - uniform in dimensions, and properties - provides a way into comparing the technological infrastructure of the late Renaissance and today.

We can not leave Galileo aside until we say something about the dialogue form of his treatise. Who are these three discussants? What different roles do they play? Who does Simplicius stand in for? We ask the students to recast the text-book derivation of engineering beam theory in dialogue form where the wrongly intuited student takes on the role of Simplicius.

Galileo is better known for his defense of Copernicus. So the students can read selections from the "Two World Systems" - for the power of his scientific narrative. We ask the student's to compare how Simplicius is treated in the two treatises.

Clearly, we could go on with a study of the period, starting with Galileo's trials and tribulations with ecclesiastical authority.<sup>42</sup> Or a tangential connection to Descartes and his style of writing, of reasoning in natural philosophy, can be made reading his letter to Mersenne in which he "reviews"

Galileo's "Two New Sciences"<sup>43</sup>. Philosophy and history and literature - and engineering science conjoined.

### Comparative Engineering Science

The preceding is meant to show how liberal studies in engineering might work - how the "hard" content of engineering science might be approached from the perspective of the historian, the philosopher, faculty in literature *and* in engineering. Just how this would really work, whether it would appear as a montage or coherent picture, would depend on the degree of collaboration among all responsible for the module. My description rambles; is opportunistic and undoubtedly needs an organizing structure but I hesitate to recommend breaking up the module into a philosophy unit, a historical unit, a "great books" unit, an engineering unit for there is educational value in contrasting the different approaches, bringing students to recognize the boundaries of scholarship, how what one sees depends upon the traditions, methods, and interests of scholars.

This is particularly important if the discipline is an engineering science and our intent is to make it a subject for liberal studies. "Contextualizing" engineering beam theory in this way enables consideration of the fundamentals of an engineering science above and beyond the instrumental analysis one finds in the text book, e.g., the complex relation between theory and technique throughout history; the critical role of language, especially mathematical expression, in instrumental reasoning; the fundamental importance of rhetoric, of narrative, in establishing meaning and a connection with the reader. Along the way we see what's left out, what's kept in; what's a laughing matter, what's a legitimate question; what's not a solution, what's a good outcome.

I am not the first to suggest that these subjects are important for students of engineering to address. Gary Downey<sup>44</sup> has proposed "to adapt pedagogies in engineering science courses to emphasize the limitations of the knowledge they convey along with their strengths" He asks "How can one teach engineering science courses so that students come to understand what they are not learning?" What are the boundaries? What is a legitimate question in thermodynamics? How does thermodynamics connect up with heat transfer? What is different about how thermo is taught in Chem E and in Mech E? And why are they different?

This immediately suggests an entire course (or two) centered on the comparison of the various engineering sciences. So a module on engineering beam theory might be followed by another on the second law of thermodynamics. Here too we have good original sources, e.g., Carnot on "The Motive Power of Heat" - altogether different ingredients (the steam engine), different mathematics, different audience, different cultural context - and a different kind of "error" (Carnot relies, in part, on a material theory of heat). Through comparative, liberal studies, we not only test and explore what is fundamental, fundamentally different, but show students how arduous a task it is to construct a functioning, paradigmatic, engineering science that has practical import. Uncovering

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42. Giorgio de Santillana, "The Crime of Galileo".

43. Oeuvres Complètes de René Descartes. Electronic edition., Correspondence 1619-1650, Descartes To Mersenne: 11 October 1638

44. G. Downey, "Are Engineers Losing Control of Technology?" *Trans IChemE, Part A, Chemical Engineering Research and Design*, 2005, 83(A6): 583-595.

and exploring these roots reveals something important about the nature of what is taken to be “basic”.

The comparison would also extend to include contrast of contemporary text-book narrative. What tropes, what metaphor are relied upon? Does the logic stand independent of narrative? That is, is the mathematical expression of concepts and principles and deduction complete in itself, make sense on its own, when freed of the narrative within which it is embedded? How does empirical data, the values of “constants” play a role in the argument? And *ceteris paribus*?

The social/political context should be a part of each module. Two centuries separate Galileo and Carnot; contrasting the sameness, the differences of their settings provides a way into broader considerations of a more wide-ranging cultural history.

#### **4b. Engineering Design/Design**

Engineering science, design and laboratory learning experiences provide a framework for recasting the form and content of engineering education under the rubric “liberal studies”. The engineering sciences present fodder for the cultural historian, the philosopher interested in the status of engineering knowledge and know-how, the teacher of literature whose critique of texts includes those bearing on science and technology.

Design caters to a wider spectrum of scholars, calling into play faculty in anthropology/sociology, psychology, political theory, economics as well as systems engineering. For design tasks, while dependent upon object-world work, are broader in scope, multi-disciplinary, more open, and must explicitly attend to the vagaries of human likes, needs, abilities and disabilities. Doing design, in itself, generally requires the collaboration of participants from different disciplines (different object-worlds) - individuals with different responsibilities, competencies and interests. And participants in design generally work within an organization which, if not motivated by the need for profit must respond to the whims and dictates of a capitalist society. In all ways, beyond its reliance on object-world work, engineering design is a social/political process.<sup>45</sup>

The historic tension between engineering science and engineering design is explained by differences in breadth of scope, in degree of openness, uncertainty of outcome; and especially in their social nature. Engineering science requires solitary effort; designing is a social/political process. It is the latter, in particular, that makes designing seem less than “rigorous”, devoid of reliable “fundamentals”. “Politics” in particular is suspect, a “bad” word in engineering discourse.

In order to get over this, a program in liberal studies in engineering needs to challenge students with, not shield them from, the social complexities and cultural implications of engineering work from the start and throughout. (A seminar/studio course each semester<sup>46</sup>). A framework of “fundamentals” drawn from the social sciences needs to be constructed and fleshed out, preferably in association with the engagement of exemplary design/planning tasks. The latter would not be lim-

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45. Louis Bucciarelli, *Designing Engineers*, MIT Press, 1994.

46. RPI, STS *Design, Innovation & Society*, <http://www.sts.rpi.edu/pl/design-innovation-society-dis>.

ited to tasks that might be addressed in the traditional engineering domains but be drawn from urban planning, architecture - even political systems might be seen as the products of design.<sup>47</sup>

The scope and complexity of design tasks will vary in accord with instructional objectives but in all instances a liberal studies perspective is to be maintained. To illustrate I build upon a design assignment I have some familiarity with - one assigned in a capstone design course in Civil and Environmental Engineering at MIT - one on the complex end of the spectrum. I first describe the design task as it was presented to students. I then remark on the ways this “problem statement” differs from that assigned in an engineering science course. I reflect on the open nature of the task and how this requires directing and limiting the student’s focus - usually to consideration of the technical parts of the task alone. But this need not be. The same problem statement allows for a much broader perspective, one that focuses on problematic social features.

### **A Capstone Design Task: South Florida Water Management – Coastal Structure Upgrade**

The Central and South Florida Flood Coastal System (C&SF) provides flood protection for the 16-county region of the SFWMD. The system was built in the 1960s and consists of a series of canals, pump stations and gravity flow structures. It has reached its design life and also needs to be enhanced because of changed conditions. The main objectives of the C&SF are a reduction of saltwater intrusion into the underlying aquifer and discharge of flood waters from highly urbanized areas. The discharge capacity has been decreased because of the rising sea level.

In terms of scope and complexity, this effort borders on the extreme. In technical terms, the student’s task is to re-design the system of canals, pump stations and gravity flow structures to enable sufficient discharge of flood waters in urban areas when needed while all the while reducing salt-water intrusion into the aquifer.

To bound the student’s efforts, four more limited and specific tasks were listed and students, in teams, asked to choose one to address. One called for a system approach; another was concerned with setting specifications on the design; a third limited attention to one critical structure; the fourth focused on policy and management practices. Even with this narrowing of scope, the tasks still require effort on the part of faculty to guide and constrain the students in their work.

Contrast this with the abstract nature of an exercise in an engineering science course where the faculty need only specify the number of the exercise at the end of the chapter and a due date; and the student need only consult his notes and the textbook to address and solve the problem. Interaction with the instructor, if any, is generally limited to how to “do” the problem if the student encounters difficulty. That is not the case with this capstone task; significant effort is required to establish an appropriate context for the task that enables students to construct “the problem” so to speak.<sup>48</sup>

There is no text book of much use in this respect. The internet provides an (over)abundance of source materials, reports, legislation, power point presentations, data, proposals, descriptions of

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47. Langdon Winner, “Political Ergonomics”, in *Discovering Design: Explorations in Design Studies*, eds. Buchanan and Morgolin, Chicago: Univ. of Chicago Press, 1995, pp 146-170.

48. In Downey, op cit, the author emphasizes the importance of the problem definition in engineering work. The challenge faculty face is to set the stage for problem definition phase but not over constrain the student’s freedom.

stakeholders, etc.<sup>49</sup> These must be culled, selected sources summarized, and a digital resource constructed for student access. With a project of such scope and complexity, not to mention its contemporary relevance, the burden is on faculty to shape the task, set limits on expectations, guide students in their search of online resources relevant to their particular task.

In doing all of this, faculty are bounding realms of thought; bringing some features to the fore, backgrounding or ignoring others. A vocabulary, not just acronyms, is under development in the give and take with students. Ways of posing legitimate questions are learned, and what will constitute a competent “deliverable” implicitly acknowledged, if not explicitly stated.

This openness, this lack of a priori specification of what matters, what students ought to take into account, is what allows for making liberal studies the dominating perspective. Ordinarily, in an engineering design course, the technology - the “hard stuff” - attracts, captures and holds fast the attention of students (and faculty). Complexities of process, including the conflicting agenda of “stakeholders” while noted - indeed impossible not to notice in many cases - usually is not made matter for study, reflection, or debate. To break from the norm, we can ask: Are there value conflicts, latent or expressed, in the contributions of all stakeholders?<sup>50</sup> How are these resolved? How have decisions bearing on the forward progress of the effort been made both apart and in concert?

Because the social/political features of the challenge matter as much as the technical features, the former can justifiably be given the lead; the latter remaining of interest and attention in so far as a grasp of the essential principles of operation, sophistication, and costs of the technology is necessary to understanding the proposals and counterproposals of real world participants in the task.<sup>51</sup> If we *do* pick up the other end of the stick, see and proclaim the social/political features as primary, then opportunities for the liberal study of design abound.

We might, for example, key to a study of government relations; states rights and federal authority in regional matters. This requires schooling in certain “fundamentals”. Relevant readings may be drawn from those ordinarily assigned in a basic course in political philosophy and social theory, e.g., Plato, Aristotle, Machiavelli, Hobbes, Locke, Rousseau, Marx, and Tocqueville<sup>52</sup>. The writings of the Federalists, together with review of key challenges to the constitutional authority of the central government over the years would be relevant. Along side of this, a history of the development of water as a resource, its uses and treatment, should be included. Reading and analysis of

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49. See, for example, “The Central and Southern Florida Project Restudy, Item (7)”, *C&SF Final Integrated Feasibility Report and Programmatic Environmental Impact Statement Restudy, 1999*. <http://www.sfrestore.org/crogee/ra7/ra7.html>

50. For the South Florida design exercise, parties include the US Army Corps of Engineers, the US Geological Survey, the National Water-Quality Assessment (NAWQA) Program, and the EPA. Other stakeholders include state agencies, environmental groups concerned with the restoration of the everglades, and the Sugar Cane Growers Cooperative of Florida.

51. Here again the question concerning “fundamentals” arises - not just with respect to the engineering sciences but more broadly. Raising the question in this context frees us from the felt necessity of responding in terms of the engineering science in itself alone and forces us to consider the relevance of engineering science particulars to engineering practice.

52. 17.03 Introduction to Political Thought, MIT, Dept. of Political Science, <http://ocw.mit.edu/courses/political-science/17-03-introduction-to-political-thought-spring-2004/>

contemporary tensions, e.g., the federal regulation of surface mining,<sup>53</sup> would also contribute to student's understanding of context.

Through this study of the politics of federal state relations, the reading and discussion of the writings of political theorists, treatises of the founders, and case studies of more recent contested issues, students acquire a language and a framework for analysis and evaluation of the arguments and proposals of parties to contemporary environmental issues e.g., as they arise in the South Florida Water Management re-design effort. Only after this schooling in the "basics", would one introduce the design task as vehicle for both re-designing the technology and for reflection on context. In this way, political processes and theories take center stage; engineering design becomes a subject of liberal studies.

### **Liberal studies of design fundamentals**

There are other approaches to the fundamentals for designing. Rather than keying off a particular design exercise, we can look across disciplines to search out and explore themes common across design domains and engage students in illustrative design tasks only when they are prepared to recognize and deal with the other-than-technical ingredients of the task. I consider three possible themes: the *organization of work*, *methods for making of decisions*, and *representations of users*.

All designing requires the *organization of work*, the setting of channels for communication both informal and formal, the acceptance of a particular hierarchy - who is an authority, who a serf - and good designing requires a healthy esprit, among all participants who, despite their different interests and responsibilities, must work together in harmony. Schools of business, in recognition of this need, have anthropologists/sociologist on their faculty - "ethnography" is not a bad word in an MBA program. If we are truly interested in what drives a "culture of innovation" - in architecture, in policy making, in urban planning, as well as in the domains of engineering - then the kinds of questions scholars in of anthropology/sociology address, their field of view, the methods they use, and the insights they prompt, provide another collection of fundamentals for design studies<sup>54</sup>.

The particular proscriptions and *methods for making of decisions* in designing in different domains, methods intended to provide confidence in the integrity of the process as well as the final product, are also worthy of study. Here philosophy is fundamental. Take, for example, the methods promoted in engineering design textbooks for choosing among a set of design options in accord with a given set of design criteria. The methods that seek a best design option in accord with a set of criteria, relying on an aggregation of weighted criteria, have been shown to lack rigor<sup>55</sup>. Here

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53. UDAY DESAI\*. *The Politics of Federal-State. Relations: The Case of Surface. Mining Regulations* lawlibrary.unm.edu/nrj/31/4/04\_desai\_politics.pdf

54. Vaughan, D., *The Challenger Launch Decision: Risky Technology, Culture and Deviance at NASA*, Univ. of Chicago Press. Such learning is essential to moving beyond simplistic analyses of failure as well. To understand events, to move beyond myth-making about whistle-blowing, to prepare students for recognizing the antecedents of, and sociology of mistakes, one might start with Vaughan's summary analysis, contained in her final chapter. There she talks about "paradigm" and "structural" (not engineering structure, but sociological), and "script" and "social construction" and "culture" and how to do good history (ethically), and calls upon the insights of authors like Kuhn, Latour, Geertz - so they need to be read and evaluated if one is to grasp the full force of her analysis.

55. M. Franssen; 'Arrow's theorem, multi-criteria decision problems and multi-attribute design problems in engineering design', *Research in Engineering Design* 16 (2005), 42-56.

Arrow's impossibility theorem is fundamental; here the distinctions among different kinds of scales of measurement must be understood if the methods are to be applied "correctly". Yet the fundamental basis, or lack thereof, of these methods is rarely addressed in the engineering design classroom where the rush toward quantification provides an unwarranted confidence in the scoring of options.

While these methods have a generality in that they might be applied to the problem of (social) choice in dramatically different domains their grounding in anything that might be labeled "fundamental" is fragile. This is not to say they ought not be taught and used but if so, then their limitations ought to be part of the lesson - and prerequisite to teaching design. Otherwise, in the words of Burr, our student is but following the "handbook method of construction" leaving him "...defenseless against his own ignorance".

There are designers - then there are user's, clients, customers, inhabitants, .... society and culture. The different *representations, images and treatments of users* implicit and explicit in the work of participants in design in different domains is another feature worthy of study. The *impacts of technology* can be considered as part of this, though I am uncomfortable with the phrase<sup>56</sup> Literature and history can provide fundamental insight into the understanding of the relationship of the products of design to society whether it be contemporary fiction or cultural studies. The study of narratives of designers themselves when "speaking" of their users requires a broader schooling in literature than is customary, even an understanding of how "deconstruction" might help in this regard (horrors!!). Sociology and psychology are relevant too. Study in these domains can provide a solid basis for consideration of user images and impacts - whether ergonomic models, open-source ideologies, focus groups, marketing methods, modes of social interaction - or lack thereof<sup>57</sup> - and extend to include the meaning of movements and ideas bearing the labels "environment", "ecology", "sustainability", "mitigation" and the like<sup>58</sup>.

Whatever array of fundamentals and/or domains of knowledge are deemed relevant to designing, learning the basics in this broad sense would be prerequisite to engaging in specific design exercises. The latter would provide a grounding and vehicle for critical reflection on the fundamentals in themselves.

#### 4c. Engineering Laboratory

I have, as a way of structuring this proposal, considered engineering educational experiences to consist of three kinds - engineering science, design, laboratory. In another paper, I offered a similar tri-partite analysis of the *texts* engineers read and write, publish and circulate, and require of their students. I said that such are a mix of *logic* and *data* within a *narrative*. Whereas engineering science texts stress the *logic* of analysis and designing requires the construction of more open and

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56. The phrase suggests the technology is made independent of culture, put out on the market, then does its work, has impacts - like it had a life of its own. A "softer" vision of the interaction of technology and culture is required.

57. E.g., Sherry Turkle, *Alone Together, Why We Expect More From Technology and Less From Each Other*, Basic Books, 2011.

58. A. Takala, K. Korhonen-Yrjañheikki, "A National Collaboration Process: Finnish Engineering Education for the Benefit of People and Environment", *Science and Engineering Ethics*, Nov. 2011 - an excellent report on the challenge of introducing sustainable development into engineering education.

multi-vocal, and multi-media *narrative*, both engineering science and engineering design eventually depend upon *data* mined and refined from the world. I include under the heading all experiments where measurements are made of people, places, and things - whether the purpose is to determine a universal constant, picture a trend, test a theoretical conjecture, or categorize a set of things, ideas, ....whatever.

As an example of liberal studies in an engineering laboratory, I recall a course developed and taught at MIT with Jed Buchwald titled “Historic Experimentation”. It was listed as a laboratory carrying “Institute Laboratory Credit” housed in the STS Program - making it the one and only “hard” laboratory science course offered within the school of Humanities, Arts and Social Sciences. In the course, students (and we faculty) attempted to replicate several historic experiments using only the materials, methods, and knowledge available during the historic period. Coulomb’s thorough set of experiments on the torsional stiffness of wires and his not-so-thorough test of the way the force of electrostatic repulsion varied with distance were two of three experiments done one semester. In a second offering, optics took center stage: Replicating Ptolomy’s experiments on the refraction of light; Huygen’s on the double refraction of icelandic crystals; required, as with Coulomb, students to craft, operate and interpret the data obtained from apparatus relying solely on our reading of the infrastructure - ways of knowing, texts, data, materials - of the time.

This proved no light task. To consciously strive to forget all that one knows about these phenomena and today’s experimental methods, instrumentation, and ways of testing is a challenge. The challenge is sharpened by the “foreign” nature of the texts we had to rely upon. Even after translation into english, the identification of materials, measuring in accord with outdated systems of units, and understanding metaphor and scientific expression no longer viable was no straight forward matter. This is no surprise to historians; they face this kind of challenge in their everyday encounter with texts (and artifacts) of the past. It is surprising to the student of engineering (and science) who are accustomed to making use of the latest analyses, methods and materials in today’s air conditioned, electrified, wireless laboratory. Historic Experimentation is as much a course in historiography as it is in experimental methods, an adventure in a different land, a different language. In the course, the students *do* serious and “hard” experimental work, though the fundamentals we seek to bring to life go beyond those stressed in the ordinary scientific or engineering laboratory.

### **Liberal Studies in the Laboratory**

In the ordinary engineering lab, as in design, the focus is on the technical ingredients in a well defined, bounded, and constrained setting. Learning to design of an experimental approach, the testing of the relationship of theory to experimental outcomes, the analysis of data, the learning of principles of operation and uses of instrumentation are the primary objectives<sup>59</sup>.

To further our discussion of fundamentals, we ask what knowledge and know-how is prerequisite to developing these competencies in our students, irrespective of professional domain? (Recall that

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59. Lyle D. Feisel, George D. Peterson Colloquy on Learning Objectives For Engineering Education Laboratories” Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition, Copyright. 2002, ASEE



our new BA program is intended to attract students interested in medicine, law, finance, education, or just plain technological literacy for the 21st century).

For example: most all domains *data analysis* relies upon statistical methods. Immediately probability and statistics appear fundamental. The methods for testing significance, setting confidence limits et al need to be learned. But much more than learning the use of these “tools” is required if we claim to be teaching the basics. Here history again comes to our aid.

The histories of the development of probabilistic and statistical thinking themselves, as in the work of Ian Hacking, reveal how cultural attitudes mix with mathematical quest mix with application in measuring society and predicting the future<sup>60</sup>. Even in engineering applications, the acceptance of probabilistic ways of viewing and talking about, say the success of a mass production process and what quality of the process means, has not been above debate.<sup>61</sup> The liberal study of the historical development and cultures of probabalistic thinking provides a rich context for the discussion of questions the use of such methods provoke when the results of such thinking are made the basis of policy and practice in, for example, medicine and health policy. Think of the question regarding the costs and benefits of periodic screening for breast cancer.

Constructing experiments that require probabalistic reasoning and statistical analysis is, obviously, not a realistic option if we strive to replicate a professional evaluation of the effectiveness of a new pharmaceutical product, say. But it is possible, in all domains, to mimic what’s done in practice with regard to data analysis and, in this way, make students sensitive to the issues the use of such methods raise.

In a similar way, we can explore the nature and ways-of-use of *instruments* and systems of instrumentation in different domains. Here we have a rich resource in the work of scholars allied with programs in STS<sup>62</sup>. Study ought not be restricted to the apparatus of scientists and engineers but extend out to include the *survey as instrument*, e.g., to “measure” the beliefs, values, attitudes of heterogeneous groups of persons. Such diversity of concerns can increase the sensitivity of students to issues like “bias” - e.g., is bias is only a real concern in the writing of a survey but not important when using a generic, standardized instrument for the measurement of a physical quantity? We can ask how anomaly is treated in different domains. We can ask how data processing defines the “picture” we see as “results” of an experiment.

Again, we can construct experiments to bring these issues to the fore in a way that generates critical reflection on the characteristics of instruments, whether survey or sensor - their transparency, robustness, reliability and the like.

What is a good (or bad) *experiment design*? The criteria for answering this question are different in different domains. A control group is essential in some; not so when you only have one artefact to put to the test. Who sets the rules that state when you have taken enough data? Who sets the speci-

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60. I. Hacking, *The Emergence of Probability*, (1975); *The Taming of Chance*, (1990)

61. Bayard, D., “How to Make Chance Manageable: Statistical Thinking and Cognitive Devices in Manufacturing Control” in Levin Miriam R. [ed.] *Cultures of Control*, Harwood Academic Publishers, 2000, pp. 153-176.

62. Lartour and Woolgar, Peter Galison, Terry Shinn, Davis Baird all tell different stories but in each case the instrument is an agent of more than measurement.

fications of the test for behavior of the material under such-and-such extreme conditions? What qualifies as a “failed” experiment? What do you learn from failure? How does the cost of an experiment “trade-off” against the reliability of the results? The STS literature addressing questions such as these is sparse compared with that concerned with measurement and instrumentation. The questions themselves are not well formed, perhaps, suggesting that they might be worthy of research from a perspective that sees beyond the scope of the dictates of the engineering textbook to include the social constituents of experiment design. The development of experimental tasks that would bring these kinds of questions to the fore should not be difficult.

In all cases of laboratory learning, we construct tasks that serve as a vehicle for critical reflection by leading the student, in the course of designing an experiment, taking measurements, analyzing the data, to think about and respond to questions about the soundness of method, the transparency of the instrument, the relation of experiment to theory, the justification of claims made on the basis of results. Questions about ethical behavior should arise naturally, prompted by this broadened view of the context of experimental work.

## 5. Sum Up

I hope, at this point, the reader has gained some understanding of how the traditional content of engineering education might be made the subject matter for liberal studies - how it might be studied from the perspectives of the humanities, arts, and social sciences, transfigured, questioned, probed, reflected upon in the hands of the historian, the philosopher, the ethnographer, the scholar of literature working/teaching in collaboration with faculty of engineering and science. The aim is to broaden the undergraduate education of, not just the student inclined and/or committed to engineering but any individual who recognizes the essential role science and technology play in our lives and sees such learning as a first step in pursuing a professional degree in law, medicine, business, education, finance or simply as preparation for “lifelong learning”.

### **But would anyone come?**

To boost its marketability I suggest a program duration of 3 years, 6 semesters in residence<sup>63</sup>. Furthermore, while roughly 75% of the program would be “fixed” - e.g., Comparative Engineering Science; Design Across Domains; The Meaning And Uses Of Experiment - the other 25% would be truly free elective. Earlier on I suggested that a student might concentrate in an engineering discipline; further study in the Humanities and/or Social Sciences might work for some; but the requirement might well be satisfied by study abroad, or a coop experience, or internship with the provision that this experience is supervised by a mentor who has bought into the ideology of the program.

For admission, prospective students would have to have studied the calculus; physics, chemistry and biology too would be required and students tested prior to admission to see if they qualify. Does this make the program “elitist”? Perhaps, but it also might encourage pre-college private as well as public schools to see science and mathematics as universally desirable for all students pursuing a college degree.

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63. Three years is a common duration for an undergraduate program in the countries of the European Union.

The program would make no claim that its graduates are fully prepared professionals; it is a liberal arts program. Yet it is meant to provide a pathway to membership in the professions, e.g., as in the thinking of William Burr, an essential first step in the ideal education of the engineer. At the same time, if a graduate of the program has devoted his/her elective study to engineering and a firm, not beholden to the dictates of ABET, offers his/her employment as such, so be it. In fact, students so inclined would be encouraged to test these waters. Industry might be interested in taking on the responsibility of training the graduate with a more general background.

**But would anyone choose to teach in the program?**

The logical place to house a liberal studies in engineering (BA) degree granting program is within STS. Active participation of faculty from other domains would be welcomed, if not necessary. In many of the subject areas I have described above, collaboration will be required in teaching as well as the development of course materials (and exams). As one with significant experience in attempting to collaborate across disciplinary boundaries - efforts with mixed success - I do not want to belittle the challenge of teaching with another who sees the world differently than you, who is uncomfortable with the way you approach the subject but lacks the confidence to question your authority. This is perhaps the greatest barrier to making liberal studies in engineering real and effective.

All faculty, all instructors, adjuncts, teaching assistants responsible for developing course content as well as teaching should be imbued with the spirit of research. The active collaboration of faculty from different fields of scholarship should provoke new questions, fresh perspectives, and new methods for addressing an individual's research agenda.

The development of curricular content will present a research frontier in itself; the best situation is when the research activities, thinking, and projects of faculty are *not* be disjunct from the development of the content of the program. The characteristics that mark the thinking and doing of the creative researcher are very much the characteristics we ought to seek to develop in our students doing liberal studies<sup>64</sup>.

Active learning should be the goal throughout all student learning experiences; students should be seen as participants in a kind of research within the comparative engineering science class, while working on a team assigned a design project, or de-bugging the instrumentation in a laboratory. Aydelotte's promoted questioning, self criticism; he saw the classroom as "... a place for the development of ideas and points of view by discussion..." and individual conferences to foster "... the gentle art of refutation." All of this is fundamental to doing research and to learning that lasts beyond the final exam.

This discussion of administration, admissions, faculty, research, none the less the resources required to establish and run a program of liberal studies in engineering is far from complete. I keep this section intentionally short: It's recommendations are certainly negotiable depending upon context. The important, non-negotiable idea is that the humanities rule.

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64. Indeed, we might ask - what are the fundamentals of doing research? - and develop curricular experiences accordingly.