Making Multidisciplinary Teaching Commonplace

Abstract

The repeating cry for more campus courses containing multidisciplinary aspects begs the question "How is Multidisciplinarity to be identified and assessed?" We discuss three engineering approaches to this question:

1. "Doing it all yourself" which requires dual initial degrees or extensive mid-career retraining of self. Examples: John Lienhard, University of Houston, author "Inventing Modern: Growing up with X-rays, skyscrapers, and tailfins" and Samuel Florman, Kreisler-Borg Construction, author "Engineering and the Liberal Arts"

2. "Seeing your discipline as inherently bidisciplinary". Example: David Billington (NAE), Princeton, civil engineering as "structural art", author: "The Innovators"

3. "Cross-college Collaboration:" Example: Our NSF-funded NCSU collaboration to use an engineering device dissection laboratory to enhance achievement of student learning objectives for courses taught in our Colleges of Humanities and Social Sciences (Foreign languages: Spanish and French), Design (Industrial design studio), and Education (Technology Education track).

Introduction

Among the eleven ABET EC 2000 criteria is found the requirement that every engineering graduate have "an ability to function on multidisciplinary teams." Implied but not discussed is the notion that the corresponding instructors have a knowledge of multidisciplinarity itself, and an ability to transmit this knowledge to students in a productive manner during their undergraduate tenure. In this paper we ask the question “Through what modes of training or formats of opportunity can instructors gain the bi- or multidisciplinary comfort and expertise appropriate to the EC 2000 dictum?"

An earlier response summarized the experience reported by our NSF Engineering Education consortium, SUCCEED, in which a variety of formats for teaching multidisciplinary design (MDD) were noted. Examples included faculty from different engineering disciplines as collaborating advisors, as well as cross-collegiate and multi-university collaborations. The emphasis in these early examples was on how to search for, and find multidisciplinary design problems. Sources included industry clients, government national laboratories, and individual faculty suggestions. Intriguing as the individual design course examples were, no consensus format for teaching multidisciplinary design was evident.

In retrospect, lack of consensus strongly suggests a lack of uniformity in the individual instructors approach to design, and/or the variation in instructor background. Unfortunately, while individual instructors reported what they did, they rarely reported_
why. Thus, we know little about those design faculty who enjoy and encourage multidisciplinary instruction.

In no engineering topics except design and first year engineering is opportunity for multi-disciplinary instruction broadly available. Thus, even if faculty teaching other topics desire to teach in a more multidisciplinary fashion, their opportunity is restricted.

The present paper explores several pathways through which engineering faculty have trained themselves to think and teach in a cross- or multidisciplinary style. We will argue that while multidisciplinary instruction by an individual is achievable, the most facile, and thus transportable, approach is through cross college or cross-departmental collaborations. We illustrate examples of each mode of achievement.

We will consider three examples:

1. “Doing it all yourself, which requires either initial degrees in two different disciplines, or an extensive mid-career retraining of self. An example of the first type is Samuel Florman, and Henry Petroski and John Lienhard are exemplars of the second.
2. “Seeing your discipline as inherently bidisciplinary”. Our example is David Billington, civil engineering professor, who has defined major infrastructure forms (bridges, tall buildings, and canals) as “structural art”, a name which immediately indicates a bidisciplinary approach to his métier.
3. “Cross-college Collaborations”. Our illustrations here include multidisciplinary design and our experiences with a device dissection laboratory.

We argue ultimately that stimulating as the first two categories are, the individuals noted are singular: all have written beautiful books about engineering, books accessible to the entire undergraduate population, and all are members of the National Academy of Engineering, in part because of their book prowess. Thus, “cloning” these instructors is particularly unlikely to occur.

The third format, to the contrary, requires only the finding of a kindred collaborative spirit in another department, or college, and development of a demonstrable, if amateur, interest in that second domain. As John Lienhard, professor of engineering and history, noted, we have only to learn the vocabulary of our colleagues from the next college or department to create a collaborative atmosphere where bidisciplinary instruction can work well.

1. **Doing it all yourself**

The engineering profession’s senior conscience and explicator is Samuel Florman, whose education in civil engineering (Dartmouth) and English literature (Columbia) produced a wonderfully informed and talented writer who has, via books, explored and popularized the engineering terrains evident in his titles (Table 1):

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Works of Samuel Florman</th>
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Engineering and the Liberal Arts: A Technologist’s Guide to history, Literature, Philosophy, Art, and Music

The Existential Pleasures of Engineering
The Introspective Engineer
Aftermath: A Novel of Survival
The Civilized Engineer
Blaming Technology: The Irrational Search for Scapegoats

This exemplar has not been duplicated: the industry engineer is an uncommon author among the small group of engineer-authors writing today. Nonetheless, the “grand view” of engineering which Florman provides, illustrated through his willingness to explore aspects of history, philosophy, music, and the fine arts places engineering in a multitude of contexts.

Florman’s earliest book, Engineering and the Liberal Arts, introduces each of the latter topics (history, literature, philosophy, fine arts, and music) through the equivalent of bidisciplinary subject matter which link engineering to each liberal art. Thus, per Table 2, the history of technology is Florman’s bridge from engineering to history, utility and beauty link the utilitarian engineering to the visual arts, and sound as environment couples engineering to music.

Table 2
Chapter structure of Engineering and the Liberal Arts

<table>
<thead>
<tr>
<th>Liberal Art</th>
<th>Bridge from Engineering</th>
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<tbody>
<tr>
<td>History</td>
<td>History of Technology</td>
</tr>
<tr>
<td>Literature</td>
<td>Engineer: Protagonist in Fiction</td>
</tr>
<tr>
<td>Philosophy</td>
<td>Truth of Science</td>
</tr>
<tr>
<td>Fine Arts</td>
<td>Utility and Beauty</td>
</tr>
<tr>
<td>Music</td>
<td>Sound as Environment</td>
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These links are not only logical, they were advanced “To induce the engineer to journey deep into the world of the liberal arts”, in other words, to facilitate the acquisition of a multidisciplinary outlook. The need for this outlook is not simply for the aesthetic pleasure of becoming a Renaissance person, but for achieving the fullest potential as an actor in human affairs. Florman recalls Vitruvius a timeless statement that those who have acquired “skill without scholarship have never been able to reach a position of authority to correspond to their pains.”

Florman anticipated the desirability of a multidisciplinary training for the engineer and posed means to address the “two cultures” problem which Snow popularized. He observes tellingly that bridges between two cultures “…do not so much require building as discovery: they already exist” as Table 2 so nicely illustrates.

Henry Petroski, civil engineer and professor of history, is our second example. Petroski, as with Florman, established book writing as his avenue to bidisciplinarity. Of
his impressive series of titles (Table 3), nearly all constitute histories of particular technologies (e.g., the making of bridges, pencils, books, etc) and thus illustrate the utility and beauty of Florman’s “bridge” conceptions for bidisciplinary topics. It is easy to see that individuals or student team assignments based upon reading Florman and Petroski books as texts could lead to a bi or multidisciplinary experience, and thus presumably enable students to function on multidisciplinary teams.

Table 3  
Titles by Henry Petroski

<table>
<thead>
<tr>
<th>Title</th>
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<tbody>
<tr>
<td>Pushing the Limits : New Adventures in Engineering</td>
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<tr>
<td>The Evolution of Useful Things: How Everyday Artifacts-From Forks and Pins to Paper Clips and Zippers-Came to be as They are</td>
</tr>
<tr>
<td>Engineers of Dreams: Great Bridge Builders and the Spanning of America.</td>
</tr>
<tr>
<td>Paperboy : Confessions of a Future Engineer (Vintage)</td>
</tr>
<tr>
<td>The Book on the Bookshelf</td>
</tr>
<tr>
<td>The Pencil : A History of Design and Circumstance</td>
</tr>
<tr>
<td>To Engineer is Human: The Role of Failure in Successful Design</td>
</tr>
<tr>
<td>Small Things Considered: Why There Is No Perfect Design</td>
</tr>
<tr>
<td>Invention by Design: How Engineers Get from Thought to Thing</td>
</tr>
<tr>
<td>Pushing the Limits: New Adventures in Engineering</td>
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</tbody>
</table>

By the very writing of such books, Florman and Petroski have trained themselves, as well as their readers, in the task of bidisciplinary thinking about engineering.

A third bidisciplinary exemplar is John Lienhard, professor emeritus of both aeronautical engineering and history at the University of Houston. In contrast to Florman and Petroski, Lienhard’s “publication” venues include radio as well as books. His many presentations through his Public Broadcasting Systems (PBS) “Engines of Our Ingenuity” program “have dealt with human ingenuity and creativity seen largely through the window of history.” Such a description is easily received by the public, because it could have been penned by a designer, an artist, or a composer as well. His ability to write as “a story-teller who informs and enchants” (S. Reiser, jacket review comment) illustrates nicely Lienhard’s bidisciplinarity as engineer and communicator. Further, Lienhard’s two books illustrate different bidisciplinaryities, those of engineer-historian (The Engines of Our Ingenuity) and engineer-biographer (Inventing Modern: Growing up with X-rays, Skyscrapers, and Tailfins).

2.  Bidisciplinary professions

Recent bidisciplinary areas of research have become new “subdisciplines” or subjects in their own right. Examples include optoelectronics, bioinformatics, molecular computing, as well as genetic engineering which began in the 1970s.

An earlier, deeper example of a bidisciplinary field is “structural art” which produces from industrialized iron the modern forms of “bridges, tall buildings, and long-span roofs”, i.e. the civil infrastructure of modern societies. The ideals of structural art,
David Billington argues, are efficiency, economy, and elegance. These topics denote the husbanding of raw materials, the erection of affordable large scale artifacts, and the realization of aesthetic values in the finished structure. While material utilization efficiency and cost control for economy are common considerations in engineering, the inclusion of “elegance”, an aesthetic quality from the fine arts, places the profession of “structural art” as a discipline which is itself a bridge between the two cultures: a new bridge which says as much about modern materials as it does about modern culture. This atypical dimension of engineering, elegance, allows participation by “the conscious aesthetic motivation of the engineer”, which Billington rediscovers through his scholarship in the Swiss school of civil engineering.

Consideration of only economy and efficiency has led to “works that are faulty, excessively costly, and often ponderously ugly.” Billington argues that “If the general public and the engineers themselves are aware of the extent and the potential of structural art, the public works in the late twentieth century can be, more than ever, be efficient, economical, and elegant.”

Thus, inclusion of aesthetics allows a multidisciplinary approach to design. As engineering is frequently characterized as “design under constraints” the additional constraint of the need for elegance does not change the tenor of the activity, but rather enlarges and enriches the universe of possible design outcomes. As aesthetics often reflect the culture of the moment, design of structural art transcends the conventional boundaries of engineering character, namely economy and efficiency.

Billington’s earlier books (The Art of Structural Design: A Swiss Legacy; The Tower and the Bridge) reflect his determination to define and demonstrate structural art. His most recent issue, the Innovators, moves beyond specific civil works to focus on the evolution of American technology, organized to emphasize both key technological developments and the individuals who played central roles in their development. Thus, through a history of technology approach which includes a strong biographical character, Billington provides opportunity for a multidisciplinary representation of technology, as seen from his chapter sequences summarized in Table 4

Table 4  Engineer-Technology associations in The Innovators

<table>
<thead>
<tr>
<th>Engineer</th>
<th>Technology</th>
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<tbody>
<tr>
<td>Newcomen (steam engine)</td>
<td>British beginnings</td>
</tr>
<tr>
<td>Watt (separate condenser)</td>
<td>Steamboat/Mississippi</td>
</tr>
<tr>
<td>Wilkinson (cannon boring)</td>
<td>American industrial revolution (factory town)</td>
</tr>
<tr>
<td>Fulton</td>
<td>Industrial water power</td>
</tr>
<tr>
<td>Lowell</td>
<td>Eastern railroads</td>
</tr>
<tr>
<td>Stephenson, Thompson</td>
<td>Telegraph</td>
</tr>
<tr>
<td>Morse</td>
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</table>
Here is found the engineer as protagonist, not in fiction as Florman explores, but as immersed in history, society, and culture. Of course, such contextual examples do much to address other EC 2000 criteria, such as understanding professional and ethical responsibility, communicating effectively, understanding the impact of engineering solutions in societal and global context, and possessing a knowledge of contemporary issues.

As a side note, Alexander Calder was an early technologist trained in two disciplines: the sculptural tradition of his parents, and the mechanical engineering tradition of Stevens Institute. His famous sculptural works are exactly a mirror of Billington's dichotomy of built artifacts: structures and engines, represented respectively by his stabiles (grounded) and mobiles (floating) art forms. Inasmuch as these are composed largely from “industrial steel”, they are examples of Billington’s trilogy of efficiency, economy, and aesthetics.

Training multidisciplinary instructors?

Exemplars as they are, the examples above are not easily repeatable, clonable, or transportable. It happens that Florman, Petroski, Lienhard, and Billington are all members of the National Academy of Engineering, and their books represent pinnacles of intellectual achievement by engineers. While their multidisciplinary works address broad reaches of engineering, their impact in undergraduate education will only be apparent when their “literature” becomes required reading for engineering students. Such is patently not the case today, and thus we still seek means for identifying faculty who can teach in a multidisciplinary environment.

Lost dimensions of engineering education

The EC 2000 attribute that the engineer “be able to work on multidisciplinary teams” requires that the graduating engineer demonstrate suitable antennae for receiving, and communicating, with colleagues in related fields of management, finance, human resources, sales, and manufacturing. This communication requirement is aided by the ability to see problems through multiple lenses. Historian Eugene Ferguson argued in his tome, Engineering and the Mind’s Eye, that engineering education has lost some of its dimensionality by elimination of non-mathematical descriptions of the disciplines. Historically, approaches to engineering included artisanal, visual and mathematical methods. Ferguson bemoans the loss of this multiple characteristic approach, as first the artisanal (laboratory) component, then the visual (drawing) dimensions of engineering receded. Both artisan and artist activities allowed for inclusion of the elegance which Billington promotes. The latter would have been easier to include if drafting and hands-on creation and assembly of devices were routinely included in engineering.
multidisciplinary activity of design has involved, according to Ferguson, artisans, engineers, and inventors. We may suppose an individual engineer today alternately passes back and forth among these roles, as s/he fabricates example structures (artisan), calculates structural behavior (engineering) or creates whole new solutions to problems (inventors). Ferguson’s theme is that “The art of engineering has been pushed aside in favor of the analytical ‘engineering sciences’, which are higher in status and easier to teach”\(^9\). This claim echoes one of a century ago, where Veblen offered the view that curricula are designed more for the benefit of faculty than students.

3. **Cross-college Collaborations**

Cross college collaborations may succeed when the win-win circumstance is present. An early example of ours was collaboration with English instructors to co-present a six unit first year engineering collaboration between English and engineering.\(^3,5\). Here, a device dissection lab presented students with opportunity to use, disassemble, and teach others how modern devices work, such as bar code scanners, compact disc player/burners, digital cameras, facsimile (FAX) and scanner machines, electric and acoustic guitars, bicycles and exercise machines, video cameras and video cassette recorders (VCR), optical fiber communications, satellite television, and water purification. The device lab thus presents a good cross section of current technologies, yet fails to represent either the humans involved in technology development or the history of past technical designs responding to earlier problems.

This latter need was met by the English course created to accompany the laboratory, in which the reading materials in history of technology and biography of engineers is chosen to fill the context and social setting of prior developments. Together, these two courses fulfill a broad need for multidisciplinary explanation of technology to the undergraduate students, yet via an approach which relies on the presumed instructional strengths of the engineering and English teachers. This approach left untouched the pathways of experience and grading for each instructor, yet in combination achieved a far greater synthesis of explaining engineering to the student than either could alone.

Let us consider now the “design” of such multi-faculty instruction to provide a multidisciplinary student experience using the three-legged stool of Billington’s structural art approach: efficiency, economy, and aesthetics.

The collaboration is efficient if it makes maximum use of “natural resources”. Here the resource list includes both the expertise and the teaching time allotted to each instructor by their departments. The engineer explains how stuff works, and the English instructor still requires the standard formats of discussion and presentation, argument and analysis, as would be present when teaching from more traditional literature bases.

The collaboration is economical if it uses a minimum of financial resources to achieve it goals. For English, the majority of first year English courses at large campuses are taught by instructors, the least expensive teaching power in that department,
Fortuitously, such instructors are often of a “newer” generation than the tenured faculty, and consequently are more technology savvy than most of their senior peers, a fine circumstance for cross-collaboration with engineering. Our engineering laboratory inventoried above may be assembled for less than $10,000, which is a lower end price for a single engineering lab experiment off the commercial catalogue from professional lab companies. Thus, the two most novel aspects of our collaboration, a device lab and first year English instruction in an engineering course, are also economical.

The third leg of Billington’s structural art stool is aesthetics, the incorporation of elements of beauty and form in such a fashion as to enhance the more common elements of efficiency and economy. Here, to follow Billington’s argument, the individuality of the instructors (designers) has free play and different instructor will prefer different forms, yet may achieve equally satisfactory results. For example, in our NCSU collaboration, the first English instructor Ann Brown preferred literary referents such as the “Kafka and Concrete” of Florman, and the “Builders of Dreams” of Petroski. A second instructor, Steve Luyendyk, a science fiction fan, offered excerpts from Isaac Asimov’s I, Robot and Philip K. Dick’s Do Androids Dream of Electric Sheep? In each case, the topic has major technical components, but like other early level English courses, the student work centers on a structural analysis of the text.

So, how does elegance work here? What beauty is “visible” in the educational product? Firstly, the lab and the literature represent a balancing of what is with what was. The devices are most easily and inexpensively those of the moment, whereas biography and history are cases from the past. Intriguingly, the technology of the future may be foreshadowed by either literature (science fiction) or design (creation of future devices). There is elegance in this balance, much as there is in yin and yang, give and take, to and fro, a feeling that the “two-sides” of the subject is fully represented.

The elegance also derives from the simplicity with which existing resources are reconfigured to yield an answer to an existing problem, that of needing a multidisciplinary approach to improve instruction. The elements of the solution were pre-existing, we merely rearranged their proximity and relation.

Other bi-disciplinary faculty pairings are illustrated elsewhere, including pairings between engineering and business/management colleges, between engineering schools on different campuses, and even in different countries. While the variety of such pairings is stimulating and intriguing, one shortcoming is the individuality of such arrangements, which defy use of common instructional materials. Our engineering-English collaboration, on the other hand, offers the potential for a broadly based, easily accessible set of materials for teaching engineering in a multidisciplinary context: the use of off the shelf commercial devices coupled with technology related books from the universal modern source: www.amazon.com!

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References