PRINCETON UNIVERSITY

I CEE 102 – *Engineering in the Modern World -* Michael Littman

Michael Littman, an engineer with a background in physics, has been teaching CEE102, *Engineering in the Modern World* at Princeton for the past 20 years. The course has wide appeal, attracting ~100 students every semester taught, and deep antecedents as well, having been introduced in the mid-1980s by David Billington, one of the earliest proponents of engineering enhanced liberal education. Billington is the author of two of the texts Littman assigns: *The Innovators* and *Power, Speed, and Form.*

The course is one of several that introduce science and technology to Princeton students. There is a companion course (also originally created by Billington), CEE 262, *Structures and the Urban Environment* (see *infr*a). There is a technology and society course (EGR 277) taught by historians and sociologists of science, but under an engineering label. There are also courses in various departments at Princeton that, as Littman puts it, could be considered by students to be a follow on to CEE 102, except that since none of these lists his course *as a prerequisite*, they are not counted as upper level.

As Littman notes, "Princeton offers a healthy suite of courses for non-scientists that range from molecular biology, to physics, to psychology, computer science and including – what is far less common in other institutions – *engineering.*"

Here's how Littman describes his course:

> Engineering in the Modern World focuses on great works of engineering, ones that caused a radical shift in American society, and on a small number of successful key innovators. Three perspectives are used to view engineering: scientific (natural sciences), social (social sciences), and symbolic (humanities). At the same time, engineering is defined through its own categories: structures (civil engineering), machines (mechanical engineering), networks (electrical engineering) and processes (chemical engineering).

II Course Mechanics

CEE 102 was designed to attract liberal arts students as well as engineers. When Littman joined the course, he contributed a laboratory to go with it, but not a laboratory for *all* the enrollees. Those students taking the course for science and technology laboratory (STL) credit, nearly all of whom are liberal arts students, perform laboratory experiments in small groups and complete four lab reports in order to get credit for the course. Meanwhile, STEM majors, seeking "Historical Analysis" (HA) credit, attend discussion groups (called "precepts") and are required to write a 15-20 page paper.

Princeton University

CEE, EGR & MAE 102: **ENGINEERING IN THE MODERN WORLD**, Fall 2015
Prof. Littman LECTURES: Mon. & Wed. 11:00 AM, James S. McDonnell Hall A02

Week	Class	Lecture	Assigned Course Reading* (A&B sections)	HW due in lab/precept
		I. Independence, Iron & Industry		
	Sep. 16	Modern Engineering and Transformation of America	I Ch 1	
1	Sep. 21	Telford and the Iron Bridge	I Ch 2	
	Sep. 23	Watt and the Steam Engine		
2	Sep. 28	Fulton, Livingston, and the Steamboat	I Ch 3	HW 1
	Sep. 30	Lowell, Francis, and Water Power	I Ch 4,5	
		II. Connecting the Continent		
3	Oct. 5	Henry, Morse, and the Telegraph	I Ch 7	HW 2
	Oct. 7	British and American Rail: George & Robert Stephenson, and PRR's J. Edgar Thomson	I Ch 6, 8, 9	
4	Oct. 12	Carnegie, Holley, and Steel Making		HW3
		III. Rise of Great American Industries		
	Oct. 14	Edison, Westinghouse: Centralized Power and Electric Light	I Ch 10, PS&F Ch 1, 2, 3	
5	Oct. 19	Bell, Vail, and the Telephone		HW 4
	Oct. 21	Rockefeller, Burton, and Oil Refining	PS&F Ch 4	
6	Oct. 26	Prep. for Midterm Exam	**	
	Oct. 28	In-class Midterm Exam	**	
7	Nov. 9	Ford and the Automobile	PS&F Ch 5	
	Nov. 11	The Wright Brothers and the Airplane	PS&F Ch 6	
		IV. Regional Restructuring		
8	Nov. 16	Ammann and the George Washington Bridge	PS&F Ch 8	
	Nov. 18	Frank Crowe and the Hoover Dam	PS&F Ch 9	
9	Nov. 23	Arthur Morgan and The Tennessee Valley Authority	See blackboard	HW 5
		V. Information, and Infrastructure (Power, Water, Transportation)		
10	Nov. 30	Marconi and Wireless Telegraphy; Sarnoff and Radio	PS&F Ch 7	
	Dec. 2	George Washington Goethals and the Panama Canal	See blackboard	
11	Dec. 7	Modern Electronics: Vacuum Tube, Transistor, and Microchip	Reid, T.R., The Chip	
	Dec. 9	Douglas/DC-3; Whittle/Jet; Goddard/Rocket	PS&F Ch 10	
12	Dec. 14	Von Neumann and the Digital Computer	See blackboard	
	Dec. 16	Jobs, Gates, and the PC; Course Review	See blackboard	

* I = The Innovators   ** No precept or lab during Midterm week   PS&F = Power, Speed and Form

Thus, both populations are expected to enlarge their competencies. Everyone attends the twice-weekly lectures.

Course enrollment

In the year in which Princeton's CEE 102 was being reviewed for this case study, there were 67 students enrolled from STEM fields (required to do a historical analysis paper) and 42 from fields other than science (required to do the science and technology lab). The Total enrollment in that semester was 22 seniors, 27 juniors, 43 sophomores, and 17 freshmen. So this is not a freshman course. The class was one-third female.

Course Exams

There are two exams – a 50 minute mid-term and a three-hour final. The mid-term exam is the *same for both* the STL students and the HA students, and (worth noting) 80% of the final exam is common to both groups. Together, the mid-term and final exams comprise 40% of the final grade. Liberal arts students enrolled in the Lab, are expected to complete 4 lab reports (36% of their final grade). In their Precept, STEM students write a 15-20 page term paper (30% of their final grade) for HA (historical analysis) credit.

Labs for some; Papers for others.

For the Lab, the mostly liberal arts students are expected to complete 4 historical re-creation type labs and write lab reports for each. In their Precept, the mostly STEM students read scholarly essays or primary documents (such as autobiographies of various innovators) and write a 15-20 page term paper

Preceptors (section leaders)

The course attracts preceptors (elsewhere: section leaders) from other departments who volunteer to teach the history precepts. They like the subject and keep coming back. Graduate students in civil engineering direct the laboratory sections and some also serve as preceptors. Some of the graduate students become disseminators, taking the idea for the course to the universities where they become professors after earning their PhDs

Course Evaluation

From the students' point of view, the course is known as a "good choice" to meet requirements, not too tough and always "interesting." Even when some students find the course materials "hard" or "ridiculously easy," they agree that the material was valuable – by which we can infer – it was *new* to them, from whichever side of the campus they come. Their advice to incoming students, given the scope of the distance covered and the newness of the questions posed: not to fall behind.

Occasionally, but only occasionally, one or two students in CEE 102 will switch into engineering because of the course. More common is a shift – among those students who have already chosen engineering – into another subfield of engineering. But there are no wholesale "conversions" to engineering from the liberal arts.

The Unique Character of CEE102

It is easy to see why Littman's course "counts" as an HA (historical analysis) course. He describes himself as always having had an interest in the history of science. But it is through the "lens of engineering innovation" that he presents the course:

Through the lens of engineering innovation, the growth of America is presented as a developing progression: First, as a colonial nation designed to provide natural resources to Britain; then, adopting ideas from Britain in order to carry out its own manufacturing of cotton cloth and steam boats; then proceeding to connecting its borders through information (the telegraph) and transportation (the railroads). Finally, to a position of dominance in the world industries, starting in the late 19^{th} century and continuing through the 20^{th} century, with oil, steel, the automobile, the airplane, electric power, telephone, radio, and the computer.

"The unique character of CEE 102," as David Billington reaffirms in a recent e-mail to this author, "is the integration of numerical understanding with narrative history, essay writing, and visual analysis. We want each student to] understand each object or system as a work with an efficiency aspect (involving scientific forces or actions expressed with numbers, economic aspects (private or public utility measured in costs), and aesthetic and ethical aspects. Students learn that in the best engineering works, all of these aspects are mutually reinforcing."

III CEE 262 – Maria Garlock

Until the early 2000's David Billington, who had launched both CEE 102 *Engineering in the Modern World* and CEE 262, *Structures and the Urban Environment*, was still teaching CEE 262 assisted by preceptors, some of whom were inspired to create or participate in courses like CEE 102 and CEE 262 after they left Princeton to make their own careers. But the engineer who would become Billington's teaching successor (as well as collaborator on a major architectural history book) arrived at Princeton in September 2003, as an Assistant Professor in the Department of Civil and Environmental Engineering, today an Associate.

Maria Garlock is unusual both because a woman in civil and structural engineering was uncommon when she graduated *summa cum laude* from Lehigh University in the early 1990s and because her current work includes structural art and structural artists as well as their comparative philosophies of design. Some of these interests derive from four years of work as a practicing structural engineer prior to returning to Lehigh University for her PhD in structural engineering. "Practicing engineering," she recollects, was where she watched "design ideas, collaborations, discussions, and calculations made on paper come to life on a real structure." She continues to be involved in real-world structures: the BDNI Center (Jakarta), the Baltimore Convention Center, Megaworld Place (Manila), and the Berlin Historical Museum.

Not having been a Princeton undergraduate, Garlock only became acquainted with Billington's Structures course after arriving to be a faculty member. At first, she was entirely taken up with her own research and teaching. Once she started to audit certain lectures in CEE 262, she slowly began to be more and more involved: several years as a preceptor; then doing one lecture per semester on a topic she was comfortable with; then two. At the same time, she and Billington were becoming collaborators on articles and on a 2008 book about Felix

Candela, which was top of the list of "Best Architecture Books of 2008." When Billington retired in 2010, Maria Garlock took over CEE 262, "Structures and the Urban Environment."

The prosperity of our nation and the well-being of its citizens greatly depend on the efficiency and safety of our civil engineering works, which give us shelter (building), enable transportation (roads, bridges, ports, airport) and being us water and power (dams and reservoirs).

So begins Maria Garlock's "Welcome" to her web site. After explaining why engineering works have to be designed for extreme forces (the subject of her research work), she adds another dimension: engineering and the arts, explaining:

There is more than one solution to an engineering problem and this reality opens the door to creativity and the arts in engineering.

The themes of CEE 262 are the same as when Billington taught the course. But Garlock has made some additions: "The Origin of Structural Art in Reinforced Concrete" is one, "Earthquakes and Ethics," another. Much of the focus, however, is on technical comparisons of familiar structures, known visually to Princeton students, but not known much about: the Brooklyn Bridge, the Eiffel Tower the Washington Monument, the Gothic Cathedral and the Skyscraper.

Throughout the course, Garlock's theme is that structural engineers have a special contribution to make to aesthetics, theoretical and visual, within the technical constraints. Indeed, in one of the CEE 262 labs, students are challenged to build a small bridge themselves, within specific constraints. Like CEE 102, Garlock's course requires students from non-STEM majors to take a lab and there's a writing assignment for students from engineering and STEM. Again, like CEE 102, enrollees from either side of the campus are present in about equal numbers and provide in her words a "nice diversity pool." Do many students change their majors? "Not many," reports Garlock, "since it is difficult to switch *into* engineering once a program of study has begun." But some students do graduate and then return to another college or university to do a full course in engineering.

CEE262: STRUCTURES AND THE URBAN ENVIRONMENT, Spring 2015

Princeton University: Dept. of Civil & Environmental EngineeringL

LECTURES Mon. & Wed. 10:00 AM, 10 Guyot Hall

Wk	Class	Lecture	Assigned Reading*	HW due
1	Feb. 2	Introduction to Structural Art	T&B Ch. 1	
	Feb. 4	The Origins of Structural Art: Telford, Brunel, and British Metal Forms	T&B Ch. 2, 3	
2	Feb. 9	John Augustus Roebling & the Brooklyn Bridge	T&B Ch. 5, 8	
	Feb. 11	The Eiffel Tower and the Washington Monument	T&B Ch. 4 (first part) SS 1	
3	Feb. 16	The Eads Bridge, Eiffel's Bridges, and Baker's Firth of Forth Bridge	T&B Ch. 4	HW 1
	Feb. 18	Othmar Ammann and the Bayonne and G. Washington Bridge	SL Ch 3; SS 2	
4	Feb. 23	Wind, Suspension Bridges, and the Verazzano Narrows Bridge		HW 2
	Feb. 25	The Golden Gate Bridge	SS 3	
5	Mar. 2	The Origins of Structural Art in Reinforced Concrete: Robert Maillart	T&B Ch 9;SL Ch 1,2	HW 3
	Mar. 4	Origins of Prestressing: Freyssinet, Magnel and Finsterwalder	T&B Ch 11	
6	Mar. 9	New Bridge Forms: Christian Menn	SL Ch 6	
	Mar. 11	**MIDTERM EXAM**		
7	Mar. 23	New Bridge Forms: Jorg Schlaich and his Team		
	Mar. 25	The Politics and Art of Spanish Bridge Design	SS 4	
8	Mar. 30	The Gothic Cathedral and the Skyscraper	T&B Ch 7	HW 4
	Apr. 1	Fazlur Khan and Concrete Buildings	T&B Ch. 13; SS 5	
9	Apr. 6	Baker, Khan, and the SOM tradition of structural art in buildings		HW 5
	Apr. 8	Structural Design for Modern Buildings	SS 6	
10	Apr. 13	Earthquakes and Ethics		HW 6
	Apr. 15	The German vs the Spanish Tradition of Thin Roof Forms	FC Intro, Ch 2, FC Ch 3	
11	Apr. 20	Felix Candela and the Hyperbolic Paraboloid	FC Ch 6	
	Apr. 22	Finding Steel Forms: Laurent Ney		
12	Apr. 27	Heinz Isler and “Natural” Forms for Shells	T&B Ch 10	
	Apr. 29	Nervi and the Italian Tradition of Ribbed Vaults	SL Ch 5	

As for propagating the model, Sanjay Arwade and Ben Schafer, teach the equivalent of CEE 262 at U-Mass, Amherst and Johns Hopkins respectively. But now, Garlock, Arwade, and a colleague from Virginia Tech are trying to disseminate the model more systematically. They are funded by the National Science Foundation to facilitate “dissemination, adoption, and continuous improvement” of the CEE 262 model.

As part of their dissemination, they recently hosted a workshop at Princeton to assist colleagues in preparing to teach such a course. Where it is not possible for an institution to import CEE 262 in whole cloth, the team recommends that an institution might be able to situate parts of “Structures and the Urban Environment” in other existing departmental offerings such as history, art, and design.

IV Engineering Enhanced Liberal Education

Michael Littman and colleagues have done their share to propagate the Princeton course (Maria Garlock, as noted, is similarly engaged.) They have held summer workshops with faculty who, in turn, have initiated similar courses at Smith, Toronto, Johns Hopkins, Syracuse, and Lafayette. Some of these institutions have faculty, Littman says proudly who were once “our” graduate assistants. But the first effort to formulate and to propagate engineering-enhanced liberal education came three decades earlier at Princeton, when four Princeton professors, each coming from a somewhat different specialty, joined forces to invent courses about engineering, technology, and art and architecture designed to be accessible and appropriate to students in the liberal arts.

Professors David Billington and Robert Mark began to do research in civil engineering and the humanities centered in structures. Billington’s research led to a 1983 book, *The Tower and the Bridge*, on modern structural engineering, and Mark published on the engineering of older historic structures and taught a course, “Structure in Architectural History.”

In 1974, Billington introduced the first version of CEE 262 as an introductory engineering course that presented great works of structural engineering to first-year engineering *and* liberal arts students ”…in a way that art historians teach the history of art, by focusing on great works and the personalities and ideas of their creators.” The success and popularity of CEE 262 led Billington to create an introductory course in all of modern engineering (CEE 102) that Mike Littman teaches today, with its focus on the great works in the history of American engineering innovation.

Michael Mahoney in Princeton’s program in the history of science was also pioneering in the field. He premiered a course on the *history of technologies* ranging from cathedrals to computers, “with stops” as David Billington recalls in his report to the Sloan Foundation in the late 1980s, “at the textile industry in the early Industrial Revolution, and assembly-line production in the 20th.”

Although the course kept its focus on history, it also introduced students to a range of structures, machines, processes, and systems. They learned what held a cathedral up, how a steam engine works, how to avoid accumulation of errors to the serial machining of parts, and why software is hard to produce.

With no technical prerequisites, the course attracted a mixed audience of science, engineering, and liberal arts majors, who learned something about one another in the course of class discussions.

Finally, John Mulvey, an engineer at Princeton, began to collaborate with a philosophy professor to study ethical issues related to large-scale computer programs.

When the Sloan Foundation's New Liberal Arts (NLA) program began in 1983, with a focus on teaching quantitative reasoning and technological literacy, these four turned to serious propagation, preparing teaching materials about what they called "The Engineer's Experience and the New Liberal Arts." *Structures and Machines in Urban Society*, the original title of the 102 course, became part of this effort. Intended to inform the wider effort, were their *organizing ideas* developed and promulgated in the Princeton summer Seminars (1984-1988), sponsored by the NLA. Among these organizing ideas were the following:

- Engineering has its own set of controlling ideas which can be comprehended by liberal arts college students without any prerequisite college-level study of science of mathematics.
- Simplified numerical studies are a first essential part of any attempt to communicate to liberal arts students the essence of engineering.
- Engineering is an evolving social process conditioned by and in turn acting on politics, economic, and cultural traditions. Analyzing this process can best be approached through studies in the history of technology.
- Engineering is a human activity, which often reflects the thoughts and feelings of individual engineers. Thus, a third essential part of this program in engineering education is the study of the lives of pioneering engineers.
- The crucial importance of visual images in the teaching of technology to liberal arts students.

Today, David Billington takes the position that engineering literacy, not technological literacy, should be an integral part of liberal education. The same literacy should also be part of how engineers are introduced to engineering. Engineering education today, he says, teaches "best practices," which refer to standardized knowledge and methods of solving problems.These are the kind of knowledge essential to the work that most engineers actually do. But they do not encourage deeper innovation or explain how it comes about.

Deeper innovation, by its very nature, changes the boundaries. Which is why "best practices" should be enhanced by the study of "best works."

source: Alfred P. Sloan Foundation, *A New Liberal Arts Program*, Ed. Samuel Goldberg, 1990, p. 179