Report to the Carnegie Corporation

the 2004 Symposium and Workshop at Princeton University

August 8—13, 2004

Teaching and Scholarship in the Grand Tradition of Modern Engineering

–through three introductory engineering courses:

- *Structures and the Urban Environment*
- *Engineering in the Modern World*
- *Rivers and the Regional Environment*

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Introduction to the Report

on the 2004 Symposium and Workshops for

Teaching and Scholarship in the Grand Tradition of Modern Engineering

at Princeton University on August 8-13, 2004

This report describes the symposium and workshops on the new approach to introductory engineering education initiated by three slide-lecture courses at Princeton University and being implemented now by other institutions. The Carnegie Corporation provided the principal funding for the symposium and workshops with additional support from the National Science Foundation and Princeton University.

On Sunday evening, August 8, participants gathered for a reception and dinner, received an overview of the goals for the week, and formed into small groups. The program for the next five days (Appendix B) consisted of a general symposium on Monday followed by four days of workshops, which each included morning general lectures and discussions, afternoon small group meetings, and special after-dinner presentations. Faculty from twenty institutions attended, along with participants from Princeton University including three faculty, five graduate students, three undergraduates, four staff members, and several others.

Our goals were: first, to strengthen and expand the network of teachers for the course "Structures and the Urban Environment;" second, to begin dissemination of the course "Engineering in the Modern World;" and third, to introduce the course "Rivers and the Regional Environment," which is being developed for dissemination in the future.

Since the mid-1980s, we have made available the slides for eighteen lectures in the structures course along with a slide catalogue and lecture notes. About forty schools purchased the slides and supporting materials and began to give the course or parts of it in the context of the New Liberal Arts program funded by the Alfred P. Sloan Foundation. After the New Liberal Arts program ceased in the early 1990s, the connections among its participating schools diminished, but some continued to use our materials. We invited teachers from ten of these schools to present their experiences to the workshops, and six gave papers on Monday, August 9. We include these papers along with papers from several faculty who could not attend. These papers demonstrate that the materials can be taught at a variety of schools and by many different types of faculty while preserving the same common principles: a physical understanding of structures, a grasp of their historical context, and visual analysis of form.

To accomplish our second goal, disseminating the course "Engineering in the Modern World," we presented two lectures on Monday and gave all participants a CD with a

Shared teaching experiences were discussed following each presentation

Discussions were lively and valuable

lecture-length PowerPoint presentation summarizing the course. We also gave throughout the week readings and lectures on topics that illustrate how the course presents modern engineering in terms of four great ideas: structure, machine, network, and process. The Watt steam engine and Wright brothers airplane are examples of machines; the telegraph, the telephone, and the Internet illustrate networks; steel-making and oil refining teach processes; and great public engineering works such as the George Washington Bridge and the Hoover Dam exemplify structures. Interest in this course was greater than we anticipated and we are supplying five schools with a full set of lectures so that the course can be given in the spring and fall of 2005.

On the afternoons of workshop days, we rotated each small group into a room with laboratory models to demonstrate how the course can be taught with a laboratory. The visitors worked through five experiments involving models of the Menai Straits suspension bridge, the Eiffel Tower, the Edison electric power system, the Bell telephone, and the Prony brake for measuring mechanical power. These exercises were drawn from the laboratory units used in both courses. Professor Littman in his lectures also showed how models can be demonstrated in the lectures for "Engineering in the Modern World." We plan to send interested schools the details of these experiments, some of which are now used at Stanford University.

These introductory engineering courses center on the need for students to grasp the nature of engineering as a whole, to recognize the necessity for interdisciplinary study, and (for engineers) to communicate their work to a non-engineering public. These objectives do not replace the technical curriculum but they relate engineering to the liberal arts in a new and natural way. They break down the barriers that too often isolate engineers from the broader culture and that prevent liberal arts students from graduating with an understanding of the technical foundations of modern life.

Symposium

Monday, August 9, 2004

Implementation of "Structures and the Urban Environment" at Smith College: Development of a Digital Image Database

Professor Andrew J. Guswa

Picker Engineering Program, Smith College

A.J. Guswa

Introduction

In 1999, Smith College positioned itself as a leader in engineering education by establishing the Picker Engineering Program. The first engineering program at an all-women's college, the Picker Program was motivated by a growing sentiment articulated by former President Ruth Simmons: "Engineers literally design and build much of the human environment. Women must not accept so marginal a role in so important a field." The program offers a course of study leading to a Bachelor of Science degree in engineering science, and the first class of twenty engineers graduated in June 2004. The program is notable for its integration of the liberal arts with the technical rigor of engineering, as expressed by the program's vision:

> Smith's Picker Engineering Program will be an exemplary program of national stature, emphasizing a unity of knowledge across all disciplines. The program will be marked by faculty excellence and innovation in both scholarship and engineering education, with an emphasis on students' active participation in the learning process. Graduates will be confident and creative women who bridge the traditional boundaries between the sciences and humanities as leaders in both the profession of engineering and in society as a whole. As critical thinkers and socially responsible decision-makers, they will help to engineer a sustainable future for the global community.

In support of this vision, William Wulf, the President of the National Academy of Engineering, stated: "Smith College is a pioneer in the diversification movement – helping us not only diversify our ethnic and gender representation, but also diversify the intellect of the individual engineer through a broad and rigorous education."

A course like Professor David Billington's CEE 262: "Structures and the Urban Environment" finds a natural home in such a program, and I have taught my version, EGR 101: "Structures and the Built Environment", at Smith since 2001. Drawing on our common visual experiences with bridges, towers, and long-span roofs, images are used to explain the scientific meaning and symbolic importance of significant engineering works. Following the evolution of ideas and materials, EGR 101 introduces students to the interpretation of common landmarks such as the Brooklyn Bridge and Eiffel Tower along with lesser known works such Robert Maillart's Schwandbach Bridge and Felix Candela's Xochimilco restaurant. Designed for a general audience, this course attracts students from a range of disciplines: from first-year French majors to sophomore engineers to senior chemistry majors. This interdisciplinary mix creates a richness that greatly enhances the value of the course. The history major provides insight to the impacts of the Spanish Civil War on structural designers, while the engineer helps to explain the bending moment that arises from wind effects, and the visual nature of the course provides a common experience that connects all students.

Upon completion of my EGR 101 course at Smith, I expect that each student will come away with:

1. A firm understanding of the scientific principles underlying the conceptual design of structures
2. An expanded vocabulary, including precise definitions of the following terms: force, stress, moment, load, column, cantilever, arch, cable, beam, etc.

Figure 1: Insight® presentation view showing how an image can be paired with a detail.

3. A working knowledge of a canon of structures, which are presented over the course of the semester
4. A clear and compelling term paper that addresses the scientific, social and symbolic components of a structure of interest
5. An ability to interpret structures with respect to their efficiency, economy, and elegance

These outcomes are achieved through lectures, in-class demonstrations, structural design case studies, and an individual research paper and presentation. In addition to my evaluation of the research paper, the outcomes are assessed via a midterm exam (which focuses on outcomes one and two) and a final exam (which focuses on outcomes three and five).

Use Of *Insight®*
For Images Of Structural Art At Smith College

Images have been critical to the success of EGR 101; the visual display of bridges and structures tie together all components of the course. Unfortunately, the use of 35 mm slides has some limitations: images are static, annotations are not possible, and the images are not available to students outside of the lecture. These drawbacks are eliminated if the images are converted from analog to digital format. Luna Imaging, Inc.'s Insight® (http://www.lunaimaging.com/insight) is software for digital image management and delivery.

Images and their associated metadata (creator, location, date, material, etc.) are stored in a relational database, which enables easy searching and organization. Insight® also enables the user to build presentations with multiple images, notes, links, and zoom capability. By creating specific groups of images, faculty can provide an easy means for students to preview or review images shown in lecture. Insight has been adopted by a number of colleges and universities, including Smith College, Brown, Cornell, Duke, Stanford, and Yale.

I anticipate that the integrated use of Insight® in my class will have an immediate impact on the lectures, term paper, and final exam. Since the images are stored in an on-line database, one has the capability to allow access to the images and lectures to multiple users from various locations around campus at all times. Additionally, using the presentation tool enables me to zoom in and out on images in real time, and multiple images can be displayed in the same window (see Figure 1). Annotations can be added to the images (see Figure 2), and the metadata associated with a particular structure can be recalled with a click of the mouse (see Figure 3).

In addition to enhancing the lecture component of EGR 101, Insight® will also aid students as they prepare their term papers. One important component of the paper is an aesthetic comparison of the structure in question with other similar structures. At Smith, Insight® provides access to a number of image libraries, and students will be able to search a vast number of images to find structures for visual comparison.

My final exam requires students to identify, discuss, compare, and contrast works of structural art with respect to their efficiency, economy, and elegance. In past offerings of this course, students have commented that

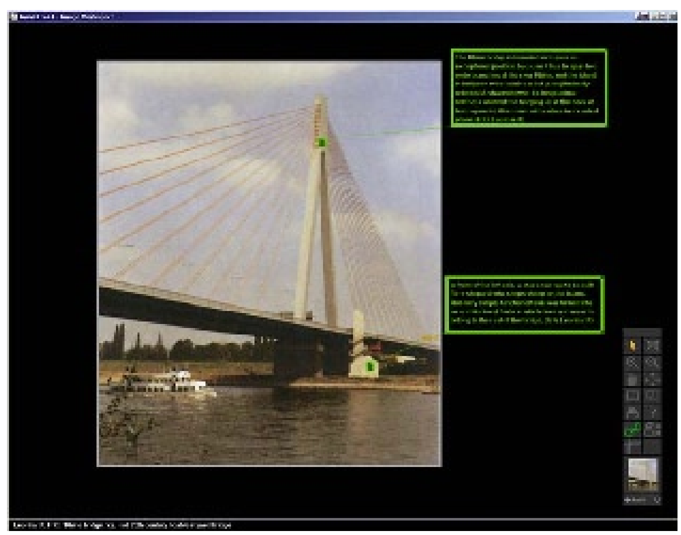

Figure 2: Images can be annotated with notes pertaining to the scientific, social, and symbolic aspects of the structure.

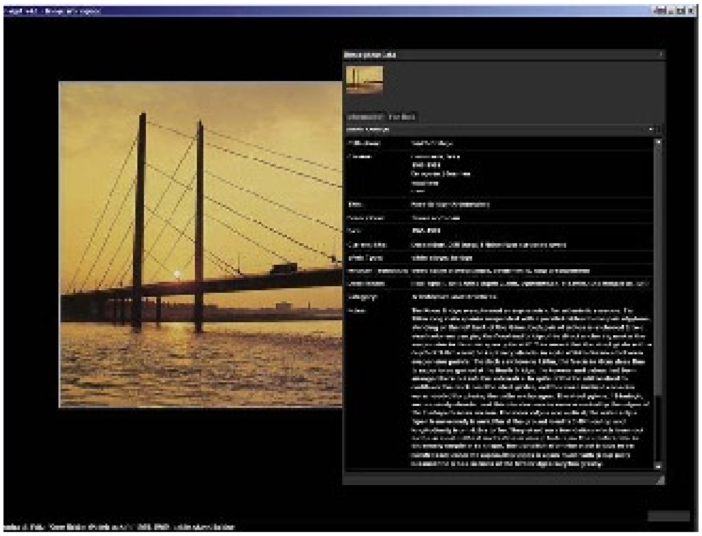

Figure 3: Metadata can be accessed with the click of the mouse.

while we spend time in class discussing these points, they would like more opportunities to practice these analyses and comparisons on their own. With Insight®, I intend to create homework assignments that mimic the kinds of questions I expect the students to be able to answer on the final exam. For example, I may create a small group of images, such as of Maillart's Stauffacher, Zuoz, and Tavanasa Bridges, and ask the students to compare and contrast them and discuss the validity of each as a work of structural art.

Dissemination

Another significant advantage of digital images is their easy transferability. We at Smith are very interested in making our database of images and metadata available to other users. Before doing so, however, there are a few logistical questions to be worked out. First, how best to share the images? Second, who should get access? Third, how will this image collection grow and evolve, and who will ultimately be responsible for its maintenance? The first question is one that is being worked out by the staff at the Smith College Imaging Center.

The second question is not so straightforward. The real value of the images from CEE 262 is in the way they have been woven together through David Billington's rich narratives. Without the organization and thoughtfulness of the lectures, the value of the images drops considerably. Therefore, it seems unwise to make the images available without a corresponding commitment to the lecture notes. I intend to work with Professor Billington to find a suitable answer to this question. Lastly, if others are interested in not only sharing the images from CEE 262, but also continuing to develop new lecture and image materials that could be used in a similar course, there will be a need for maintenance and management of these materials. It is worth keeping this issue in mind as we move forward.

Conclusion

The visual nature of structural art compels the use of images to explain the scientific, social, and symbolic themes of the course, and Insight® provides a powerful tool for managing, editing, and disseminating digital images. Use of this tool will enhance EGR 101 at Smith and has the potential to lead to beneficial collaborations among faculty offering similar courses.

Acknowledgements
The author thanks Elisa Lanzi, Jolene De Verges, Richard Fish, and Kevin Kanda of the Smith College Imaging Center for their support of this project and Emerson Taylor '05 and Honor Hingston '04 for creating the digital image database for EGR 101: "Structures and the Built Environment".

Structures and Society

Concepts for the Course (STS 297A)

Professor Harry West

The Pennsylvania State University

Harry West

General Information

Background: The general notion of the course "Structures and Society" was first conceived when Harry West was active as a faculty member in the Department of Civil and Environmental Engineering at The Pennsylvania State University, where he served as a professor in the area of structural engineering for nearly 40 years. Over the last 20 years of that time, he had an interest in developing a course in the history of structures. The obvious home for such a course at Penn State would have been in the Science, Technology, and Society Program (STS), but it lacked the funding to support such an undertaking, and West was not able to get financial support or release time from his department to pursue the matter. To bring it about would have required taking it on as an overload, and this was simply not possible with the other responsibilities in teaching and research that necessarily had a higher priority. Upon retirement from the University in 1997, however, Professor West continued to have an interest in teaching, and he offered to develop an STS course on the history of structures and to volunteer to teach it once each academic year. This arrangement was enthusiastically accepted by the STS Program.

Over the years, West became acquainted with what Professor David Billington was doing at Princeton University. He had invited Billington to visit the Penn State campus, where he gave three separate lectures to civil and architectural engineering students. During that visit, Billington shared some material describing what he was doing at Princeton. At a subsequent time, West visited Princeton and attended one of Billington's lectures and became aware of the slide series that was available. Penn State agreed to purchase these materials, and that provided the jump-start for STS 297A. Professor Billington was extremely helpful and encouraging as West was developing his course, and his materials provided a strong foundation on which to build the new course. Although the orientation of STS 297A is substantially different from Billington's Structures and the Urban Environment (CEE 262), virtually all of the material in Billington's course is woven into the coverage of the Penn State course.

Course Description

STS 297A, Structures and Society, is a three-credit course that satisfies a general education requirement at the University (engineering students take it as a humanities course as a part of the 18-credit social-humanistic stem of their ABET requirement). The course meets for either 45 fifty-minute periods or 30 seventy-five minute periods. In addition, there is a one-hour-and-fifty-minute period for a comprehensive final examination. The central thread of the course follows the historical development of structures, ranging from the ancient forms of Stonehenge and the pyramids to modern long-span bridges and high-rise buildings.

Special consideration is given to the closing decades of the nineteenth century and the new set of possibilities brought about by the Industrial Revolution. In tracing the historical timeline, attention is focused on the forces that were at play in shaping the trends—the personalities of the master designers and builders, along with their philosophical leanings; the social and symbolic aspects of structures; the cultural and environmental issues; the needs expressed by functional requirements and the art forms that were consistent with meeting those needs; the tensions between creativity, economics, and politics; and the availability of building materials.

The course has a nontechnical orientation, but there are brief discussions on some of the scientific principles that are intended to aid the student in understanding how structures carry their loads in a safe and serviceable fashion. This portion of the course requires only a background in high school mathematics and science—neither college calculus nor physics is a prerequisite.

The course follows the format of a traditional art history course with a lecture format supported by an extensive set of slides for illustrative purposes. Portions of videos are used to reinforce certain points, but rarely are these shown in their entirety. The course notes contain numerous illustrations that are displayed with an overhead projector to provide explanation or amplification of certain concepts. Although the course follows a lecture format, the class size is such that questions and discussions are encouraged.

There is a mid-semester examination, given during a designated class period, and a final examination that is administered during the end-of-semester exam period. In addition, a term paper is required of each student.

Course Content

1. Introduction

As an introduction to the course, the concept of structure is defined. Some structures in nature are then described ranging from the structures of plants and trees to those built instinctively by animals. A sampling of early structures of humans are discussed as examples: some of these are appropriated from nature, such as fallen trees over chasms, vines that could be used to bridge a span, or natural arches caused by the erosive actions of water or wind; others considered are early and crude habitats constructed by man.

It is shown how this small set of examples represents modest beginnings that merely met the bare necessities of life. But building would change dramatically from these meager utilitarian beginnings. Human imagination and effort would be channeled into monumental structures that would absorb enormous energies and resources at a time when survival on a day-to-day basis was arduous and uncertain. Much of the early monumental works were based on spiritual motivations, and these structures are the first area of concentration. As the course moves forward to examine specific structures, students are asked to consider the standard questions of who, what, where, when, why, and how. Specifically:

> Who were the prime movers (leaders, conceivers, planners, builders, users), and what were their personal characteristics?
>
> What are the physical characteristics of a given structure and some of the other distinguishing features (time to build, pertinent dimensions and other quantities, casualties in construction, etc.)?
>
> Where was it constructed?
>
> Were there unique and/or challenging physical obstacles to overcome?
>
> When (chronologically, historically, categorically) was it constructed?
>
> What were the motivating factors (desires, needs, etc.) that provided impetus for the project? Why was the structure built?
>
> What special factors (artistic, cultural, societal, symbolic, spiritual, environmental, economic, political) were involved? How did these factors interface (priorities, competition/tensions, etc.)?
>
> Were there unique obstacles (state-of-the-art, technological, materials, scale, nature of project)?
>
> How did the project lead to new innovations (artistic, technological, materials, societal, etc.)?

2. Building in Response to the Spirit

When humans respond on the spiritual level, history shows that they have reached beyond themselves and accomplished some of their most spectacular feats. This fact is demonstrated by many examples in the ancient world. And in many cases, we have no certain knowledge or understanding of how these structures were built with the limited technology that was available at their respective times of construction.

The first structure examined in this category is Stonehenge. This provides an opportunity to introduce the basic concepts of post and lintel construction and some of the other details of construction. Also, various theories are considered regarding how the structure was constructed and what its purpose was.

The pyramids of Egypt are next considered. The evolution of tomb building is briefly traced from the early mastabas to the monumental pyramids. Several pyramids are examined in detail, ranging from the "Stepped Pyramid" at Saqqara (c. 2750 B.C.) to the Great Pyramid at Giza (c. 2570 B.C.). Again, various theories regarding how and why they were built are briefly discussed. The obelisks and some of the associated temples are briefly touched upon as an extension of the temple building landscape of Southern Egypt. Here, the focus is on the on-going debate on how these monolithic structures were raised to their vertical positions. Portions of the Nova film series, Secrets of Lost Empires, is used to support those portions of the course on Stonehenge, the pyramids, and obelisks.

At the conclusion of the presentation on the pyramids, a brief discussion on modern environmental impact statements is pursued. This provides a good opportunity for class participation as the impact of pyramid building on key baseline conditions is considered.

The next class of structures built in response to the spirit is gothic cathedrals. After a brief introduction to cathedral building (early Christian basilicas, Romanesque churches), the evolution of the gothic cathedrals of Northern France is traced from the early-gothic style of the Abbey of St. Denis (1144) to the high-gothic of Amiens (1269). The structural challenges that were encountered as the designers sought to admit more light while reaching greater heights are discussed in detail. This section of the course provides opportunity to define several structural terms such as truss, arch, pointed arch, vault, rib, buttress, and flying buttress, and to explain the structural function of each of these elements.

As a conclusion to this portion of the course, a brief survey of other churches and temples throughout the world is made. Structures in the Middle East, other portions of Europe (including Greece and Rome), Central America, India, China, and Japan are used to illustrate the tendency of humans to undertake enormous building efforts in response to their spiritual needs. In sections of the world with virtually no influence from other civilizations, the same kinds of activities were underway, in which building in response to spiritual needs was the center of society and the economy of the times.

3. Building for Protection

This section of the course deals briefly with the various structural forms that were built to provide protection. A number of walls are considered: Hadrian's Wall between Scotland and England and the Great China Wall are prime examples of defensive structures; the walls of Zimbabwe and Machu Picchu offer interesting examples of the sensitivity of these early cultures to detail and aesthetics. A small set of castles from Europe and the Middle East are studied as examples of defensive and military structures.

As a final topic in this portion of the course, water barriers are considered for those who reside in flood-prone areas. The traditional technology used in Bangladesh for the Feni River enclosure is seen in sharp contrast with the highly sophisticated barriers on the Thames River and the Delta Project of the Netherlands. The latter two involve complicated structural/mechanical systems that are brought into play to protect against surges from the sea.

4. Building Up

For centuries, towers have exerted a powerful, often spiritual, influence in those who view them. As a result, there has developed a certain hubris among those who reach to build higher and higher. This was seen in the Biblical account where the Tower of Babel symbolized humankind's audacity and assumed self-sufficiency, and it is seen today as city after city, or country after country, seeks to build the tallest building in the world.

This portion of the course opens with a brief introduction to statics. The axial forces of tension and compression are described, and bending action with its associated shear and bending moment are defined. Two early towers of note are discussed: the Pisan Campanile (leaning Tower of Pisa) is studied, and the problems associated with its lean and the remedial measures that have been taken to arrest the drift are discussed; and John Smeaton's Eddystone Light is considered. Smeaton, who is considered to be the father of civil engineering, introduced iron-reinforced masonry and waterproof cement into the construction of his tower.

The industrial revolution brought dramatic changes to tower building, and this allowed builders to push higher and higher. No longer in service solely for religion and war, towers emerged as a symbol of a new age of technological achievement. At this point, the three criteria of Billington's "structural art" are introduced--efficiency (minimum material), economy (minimum cost), and elegance (maximum aesthetic expression). These criteria relate, respectively, to three societal dimensions—the scientific dimension requires that the structure safely work within the laws of nature to make the most efficient use of materials, the social dimension requires that the structure be designed and built within the political and societal constraints of sound economy, and the symbolic dimension recognizes that structures become durable monuments of a society and must, therefore, make an expression of elegance. These criteria are then used, when appropriate, to evaluate structures in subsequent sections of the course.

The Washington Monument, the Eiffel Tower, the St. Louis Gateway Arch, Seattle's Space Needle, and Canada's CN Tower are each studied in some detail and compared according to Billington's criteria for evaluating structural art. In the case of the Eiffel Tower, Eiffel's experience in designing and building his viaducts in the Massif Central is examined as a prelude to his innovatively bold and confident proposal for the tower.

5. Building Out

In "building up", humankind's first efforts to overcome vertical heights was considered. Now, attention turns to the efforts to conquer horizontal distances. Initially, a look at canal building is reviewed—from the early canals in the United Kingdom to the Panama Canal. Special emphasis is given to the Ellesmere Canal in Western England and Wales and the Delaware and Hudson Canal in Pennsylvania and New York, where some of the early works of Thomas Telford and John A. Roebling, respectively, are in evidence. Next, there is a brief look at the development of the railroads and the ways in which they replaced most inland canals. And finally, the development of roads and highways from the Roman Appian Way to the modern interstate system of the United States is examined. It turns out that roadways have structure too, and names like Thomas Telford emerge again as key figures in the advancement of road building technology.

And, of course, whether as aqueducts for canals, trestles and viaducts for railroads, or bridges for highways, the ability to bridge over depressions, chasms, and waterways is essential to "building out." Initially, a brief summary of bridge types is considered—a description of simple beam-type structures, arches, trusses, cantilever bridges, suspension bridges, and cable-stayed bridges. Then each bridge type is considered in detail. After an explanation of how a particular bridge type behaves structurally, an array of examples from simple to complex is discussed, frequently culminating in an in-depth study of some classic structure. In the case of beam-type structures, the survey begins with the simple "clapper" bridges scattered over the English country side, it then looks at Robert Stephenson's Britannia Bridge in some detail, and finally touches lightly on the typical long-span continuous structures that are commonly in evidence on modern highway systems.

For arch bridges, the study begins by examining some of the Roman arch structures, many of which were part of their extensive aqueduct system. Two in particular are considered—the one at Segovia, Spain, and the Pont du Gard in southern France. Other Roman arches are discussed, such as the Puente de Alcántara in Spain. Its engineer, Caius Julius Lacer, resided and died near the bridge, and his epitaph stands as a lasting and truthful testimony, not only to his bridge but to the enduring influence of the Empire he served: "I leave a bridge forever to the generations of the world." A few other famous arches are considered, such as China's An Ji Bridge, which is composed of multiple segmental arch ribs and haunches to lighten the load on the arch, and some more modern structures: the Tunkhannock Creek Viaduct, the Bayonne Bridge, and the New River Gorge Bridge in the United States.

Truss structures encompass a variety of bridge types. The manner in which truss-type structures carry loads is explained, and some of the earliest "draughts" of Palladio, who is generally credited with developing the truss in the 16th century, are described. He said that "because the particulars are infinite…whereby everyone, as occasion offers, or his genius is happy, may take his measure and perform what shall be worthy of praise." And over the years, countless designers have happily performed according to his prediction. Examples are shown, ranging from the multi-span Walnut Street Bridge (Baltimore through-truss) in Harrisburg, Pennsylvania, to the Lindenthal's more complex Smithfield Street Bridge (lenticular truss) in Pittsburgh, to the Kinzua Viaduct in northwestern Pennsylvania, and to some of the large cantilever spans such as the Poughkeepsie and Quebec Bridges.

Next, a close look is taken at the British metal forms and the chronological development of modern structural engineering that is embraced in this time period through the introduction of industrialized iron. One who clearly stands at the forefront of this period is Thomas Telford, the first major structural engineering artist. Telford's contributions are traced throughout his career with special attention to the Craigellachie Bridge and some of his later refinements at Galton and Gloucester. These structures are composed of rather flat, unbroken arch ribs connected together by braces, and they stand in sharp contrast with Darby's Iron Bridge, which was the first to employ iron but in a form inappropriate for the material. Telford's mastery of masonry bridges is also illustrated by examining his Gloucester Bridge and Dean Bridge. And, of course, no study of Telford's work would be complete without considering his Menai Straits suspension bridge, whose elegance continues to be recognized today.

A second contributor to the dominance of the British during this period is Isambard Kingdom Brunel. Brunel was a very productive and creative engineer who worked in a variety of activities and, therefore, did not leave the same kind of imprint on the field of bridge engineering that Telford did. However, his Saltash Bridge over the Tamar River is a classic, and it is discussed in some detail. It couples a tubular arch with a suspension chain to support two 455- foot spans. It is compared with Stephenson's Britannia Bridge, which has almost identical spans, and is found to be much lighter and less expensive than Stephenson's bridge. Even though the Saltash has a rather awkward appearance, it harbors no secrets—it is beautifully expressive with respect to how it behaves as a structure, whereas the function of the Britannia is hidden. And Brunel's masterpiece, the Clifton Bridge, is examined—a suspension bridge that rivals modern structures for beauty.

The next section of "building out" features a look at several monumental structures. The first is the St. Louis Bridge, most commonly referred to as the Eads Bridge after its designer and builder, James Buchanan Eads. This is a magnificent structure, and its design and construction were bold undertakings that challenged the profession. The design characteristics of this three-span arch structure and its construction are studied in detail along with the personality of Eads, for whom this monumental bridge would be his single accomplishment as a bridge builder. The arch spans of 520 feet were the longest in the world.

Attention is then directed to Gustave Eiffel. In contrast to Eads as a one-time bridge designer, Eiffel was a prolific structural engineer with a wide array of experiences, and he was a bridge engineer without peer. His vast experience in the Massif, which was discussed as part of the Eiffel Tower section of the course, served as preparatory work for his greatest achievements as a bridge designer. Eads' record-breaking span would reign as the longest for only three years, because Eiffel's Pia Maria Bridge over the Douro River in Portugal claimed the title at 524 feet. And then soon after that, Eiffel would complete his masterpiece, the Garabit Viaduct over the Trùyere River in France, which set a new record at 541 feet. Both of these bridges were two-hinged, wrought iron structures with a crescent shape, and the latter one is examined in detail.

The third monumental span studied is the Firth of Forth Bridge in Scotland. Its designer, Benjamin Baker, like Eads was to build one bridge in his entire career, but it would be a colossal structure—two 1710 ft cantilever spans that were the longest in the world when built. The fourth monumental span is the Brooklyn Bridge over the East River in New York between Brooklyn and Manhattan. The career of its designer, John A. Roebling, is traced in some detail, and the systematic development of his bridge-building skills is followed from his early suspended canal aqueducts to his masterpiece, the Brooklyn Bridge. Roebling's premature death, and the ensuing drama associated with his son Washington Roebling's taking charge of the construction, along with the role played by Washington's wife, Emily, in an interesting piece of history. Probably no other structure has spawned so much response from the art community as the Brooklyn Bridge, and some of those contributions are discussed.

A section on the history of suspension bridges traces their development from James Finley's first wire bridge to the current record holder for span length, the Akashi Kaikyo Bridge in Japan. Some of the early structures discussed individually are placed in context within the historical timeline, but emphasis is placed here on the aesthetic trends established by Othmar Ammann with the George Washington Bridge and the bridges that followed. The collapse of the Tacoma Narrows Bridge is discussed along with the retrofits that followed for existing bridges and the changes in design philosophy for new bridges.

Continuing with the theme of "building out," new possibilities in concrete structures are considered. A brief explanation of the mechanics of reinforced and prestressed concrete is followed by a survey of the early works of Robert Maillart from his Zuoz Bridge to the Salginatobel Bridge. Moving on to prestressed structures, the pioneer, Eugène Freysinnet, is introduced, and some of his reinforced (Plougastel) and prestressed (Luzancy) structures are discussed. In the prestressed realm, some of the contributions of Gustave Magnel (Sclayn Bridge) and Ulrich Finsterwalder (Mangfall Bridge) are considered.

The Swiss tradition in bridge engineering is introduced by relating the formation of the Federal Polytechnic Institute and the influence of Carl Culmann and Wilhelm Ritter. Ritter's impact on Robert Maillart is described, and the array of Maillart's deck-stiffened arch structures and some of his later structures are examined. Particular attention is given to the Valtschielbach and Schwandbach Bridges. The role of Pierre Lardy at the Federal Polytechnic Institute is noted and the works of one of his protègès, Christian Menn, is treated in some detail. Menn's incredibly creative designs, with prestressed, deck-stiffened arch configurations, are studied, and his Ganter Bridge is featured for its innovative form.

As a final topic under "building out," the history of cable-stayed bridges is presented. The early attempts and disappointments of this form are discussed prior to describing the re-emergence in post-war Germany. From the first crossing of the Rhine at Düsseldorf to the vast array of structures that have subsequently appeared in Germany and Japan, and most recently in other parts of the world, the history of this popular and versatile bridge style is traced.

6. Building Higher

In an earlier portion of the course, the urge to build high structures to celebrate historical events or commemorate important public figures was examined. Attention is now turned to building higher to create living and working spaces in areas where land value is at a premium. This section begins with an explanation of frame behavior and some of various structural configurations used in high-rise construction. This is followed by a discussion of the history of the skyscraper—beginning with the Chicago fire up through the current activities along the Pacific Rim.

The personalities of, and the buildings associated with, the First Chicago School are examined—William Le Baron Jenney and the Home Insurance and Leiter Building; John Wellborn Root and the Monadnock and Reliance Buildings; and Louis Sullivan and the Carson Pirie Scott Building.

The rivalry between Chicago and New York is described, and the period of dominance of New York is traced from the Flatiron Building to the World Trade Center. The re-emergence of Chicago through the activity of the Second Chicago School is examined, with special emphasis on the contributions of Fazlur Khan as manifested through the Hancock Building and the Sears Tower. In addition, the artistry of Khan is described by taking a closer look at his many innovations in both steel and concrete buildings. Finally, the many tall buildings that have surfaced along the Pacific Rim are studied, and the many new structures that are being contemplated throughout the world are discussed.

7. Building for Large Public Spaces

The first structures to accommodate large public gatherings were the Greek amphitheaters, such as those at Ephesus and Epidaurisis. These were forerunners for the stadia of the Roman Empire, where the early ones were built in depressions with the seating on the surrounding earthen banks. But the gem of Rome was the Colosseum, and this structure is studied in some detail.

This arena established the pattern that continues today to serve as a model for modern stadia, and it reigned as the largest structure of its type (a closed bowl) until the Yale Bowl was built in 1914. A survey of stadium structures covers the important structures up through the current wave of covered, domed, and convertible stadia. One stadium that is considered is Penn State's Beaver Stadium. It is not a particularly noteworthy structure, but its history provides an interesting study as the structure was enlarged, relocated, jacked vertically, and converted to a double-deck facility. It is local, can be visited, shows evidence of the incremental changes, and it is of much interest to the students.

Next, exhibition halls are considered. The early examples of the Crystal Palace, Eiffel's 1867 Galerie des Machines, and Dutert's 1899 Galerie des Machines that stood opposite the Eiffel Tower are compared. Later halls, such as Centre Pompidou and Spaceship Earth at Disney's Epcot Center are also discussed.

The emergence of vaults as a means for covering large spaces is studied, and the various national styles are compared. The early works of the German School are first considered—the market halls of Franz Dischinger and Ulrich Finsterwalder are examined and the spin-off work of Anton Tedesko in America is noted. This is followed by the lightweight, ribbed style of Pier Luigi Nervi culminating in his Little and Large Sports Palaces in Rome. The works of the Spanish School of Roof Vaults are then examined—the divergent and daring forms of Antonio Gaudì, Eduardo Torroja, and Felix Candela are examined and compared in detail. And, finally, the new vault forms of Heinz Isler are studied for their freedom from some of the constraints imposed by mathematical rigor.

Also, in this part of the course, some of the other structural forms in which Robert Maillart was again an innovating force are considered—his Cement Hall with its incredible thinness, his Magazzini Generali Warehouse, and his unique slab construction featuring the pilz deck with mushroom-type column capitals. At this point, some comparisons are made with Nervi's ribbed slabs and other more conventional systems.

8. Building to Harness

At this point, a rather brief survey of structures that are used to harness energy is undertaken. First, the various dam types are described with examples provided for each type. Next, wind mills and modern wind turbines are discussed, and finally, a few solar furnaces are described.

9. Building to Fail

The final class period is devoted, in part, to the viewing of Henry Petroski's video To Engineer is Human, which examines the role of failure in successful design. Although the reality of failure is woven into the fabric of the course by discussing specific failures over the course of history, this video takes a more philosophical view of the inevitability of failure as a part of the human design process and how we learn through the devastating and painful experience of failure.

Additional Information

Textbooks

The Tower and The Bridge, David Billington, Princeton University Press, Princeton, N.J., 1985.

Why Buildings Stand Up, Mario Salvadori, W. W. Norton & Company, New York, 1980.

Structures and Society, class notes package which includes material from Structural Studies, David Billington and Robert Mark.

Assignments There are regular reading assignments listed as part of the detailed course outline—it is expected that these will be studied in detail. There is a list of references provided that identifies material that is on reserve in the library. These materials provide additional material on topics of interest, and specific assignments are made from this list on occasions.

There are several written exercises selected from Structural Studies, by David Billington and Robert Mark, that are required. These include Column (Washington Monument), Cantilevers (Eiffel Tower), Trusses (Sheldonian Theater and Palladian Bridge), Cables (George Washington Bridge), Beam (Magazzini Generali Warehouse), Cantilever Column (Hancock Tower).

Term Paper Specifications

The student is free to select any topic that is within the context of the structures/society orientation of the course as described in the course syllabus. The paper need not touch on all of the dimensions embraced in the syllabus; however, the paper must include the interplay of structure and society. That is, it may not be one-dimensional, such as the detailed technical description of a structure or structure type nor a narrow biographical sketch of an individual that treats only his/her technical achievements. The paper must be at least 10 pages, but no longer than 12 pages (typed and double-spaced). If sketches, figures, and/or calculations form a portion of the presentation, they should be included in an appendix (not in the 10-12 page text) and cited in the text. A bibliography must be included (not part of the 10-12 page text) with no fewer that six entries, and there must be a short (not to exceed fifty words) annotation for each bibliographic entry. A one-page (typed and double-spaced) proposal must be submitted to the instructor to make certain that the topic and scope are appropriate.

Course Grading

The course grade will be determined based on the following percentages:

Structural Studies Exercises:	20 per cent
Term Paper:	30 per cent
Mid-Term Examination:	20 per cent
Final Examination:	30 per cent

Abbreviated Course Outline

Introduction

Building in Response to the Spirit:
- Stonehenge, Pyramids, Obelisks,
- Gothic Cathedrals
- Other Churches and Temples

Building for Protection:
- Walls, Castles, Water Barriers

Building Up
- Static Considerations: Structural Behavior
- Early Towers (Pisa, Eddystone Light)
- Billington's Structural Art
- Washington Monument, Eiffel Tower,
- St. Louis Arch, CN Tower, Seattle Space Needle

Building Out
- Canals, Railroads, Roads and Highways
- Bridge Forms: Structural Behavior
- Beam-Type Bridges
- Greek and Roman Arches, Other Arches
- Truss-Type Bridges
- British Metal Forms (Telford, Brunel, Stephenson)
- Monumental Spans (Eads, Eiffel, Baker, Roebling)
- History of Suspension Bridges (Ammann, others)
- Beam Behavior: Reinforced and Prestressed Concrete
- New Possibilities in Concrete (Maillart)
- Origin of Prestressed Concrete (Freysinnet, Magnel)
- Swiss Tradition and New Forms (Maillart, Menn)
- History of Cable-Stayed Bridges
- Bridges of Modern Germany and Japan

Building Higher
- Frames: Structural Behavior
- History of the Skyscraper
- The Structural Art of Fazlur Khan

Building for Large Public Spaces
- The Colosseum
- Stadia—Open, Closed, Convertible, Beaver Stadium
- Crystal Palace and Other Exhibition Halls (Paxton, Eiffel, Dutert)
- Roof Vaults: National Styles (Dischinger, Finsterwalder, Tedesko, Nervi)
- The Spanish School of Roof Vaults (Gaudí, Torroja, Candela)
- New Forms (Maillart, Isler)

Building to Harness
- Dams, Windmills & Turbines, Solar Furnaces

Building to Fail
- The Role of Failure in Design

Turning Structures and the Urban Environment into Perspectives on the Evolution of Structures

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Abstract

The objective of this paper is to describe and provide an initial evaluation of a new course in the history of structural engineering being offered at Johns Hopkins University. Perspectives on the Evolution of Structures is a study of the history of structural design to demonstrate to students the discipline of structural art and to give them the tools necessary to evaluate structures as works of structural art. The course covers structures from the Industrial Revolution to modern times with a focus on long span bridges and tall buildings. Our most ambitious objective for the students was that they be able to research the social, symbolic and scientific aspects of structures in the world around them and express their findings clearly in both written, graphical, and spoken form. Through slide lectures in the tradition of art history, combined with extensive writing and calculation assignments, the students perceived that they had indeed obtained this objective. Their performance on a final project consisting of a 20 page paper with calculations and a verbal presentation verified to us that they had achieved our objective. Further, their feedback indicated the course greatly stimulated their interest in the subject matter, and they had some fun along with the learning.

Introduction

The intellectual basis of David Billington's approach to engineering education is that humanistic thought can inform the study of engineering, while engineering thought can inform humanistic scholarship. While all engineering programs require some study in humanities or social sciences, the modes of thought introduced in those classes are rarely put to use in core engineering studies. Conversely, only in very rare instances are students of the humanities and social sciences asked to engage in the study of engineering.

Perspectives on the Evolution of Structures is closely based on the class Structures and the Urban Environment (Billington 1984), and the book The Tower and the Bridge (Billington 1983) and is designed to address both of these deficiencies by integrating humanistic and engineering scholarship in a class that is accessible to the entire undergraduate student body.

The simplest way to describe Perspectives would be as a study of the history of structural design from the industrial revolution to the present. Were that a sufficient description of the class, it would perhaps be best taught by faculty in the History of Science, but the class actually reaches much farther. Students who complete the class should have an understanding of the way that the forms that structures take are guided by engineering principles and the individual creativity of the designer, as well as social and economic circumstances. Furthermore, students should be awakened to the built environment that surrounds them and gain the ability to make critical judgments of structural form which are founded in an understanding of their engineering behavior. Perspectives was offered for the first time in the Fall of 2003 at the Johns Hopkins University and maintains a permanent online presence at www.ce.jhu.edu/perspectives where significant further information is available. Here we give an overview of the structure and method of the class, followed by quantitative and qualitative assessments of course success.

Learning Objectives

Formal learning objectives benefit the student, by making clear the expectations and goals of the instructors, and benefit the instructors by providing specific goals for instruction. The objectives for Perspectives cover a variety of cognition levels from knowledge to synthesis, as defined by Bloom's taxonomy (Bloom and Krathwohl 1984). The objectives, listed below, make clear the expectation that engineering students will expand their way of thinking to include social and symbolic significance of structures, and that humanities students must learn to support their structural criticisms with engineering calculations and reasoning. Learning objective (8) summarizes the overall goal of the class, that students examine the built environment from a range of perspectives, humanistic, engineering, and social science. The specific learning objectives are:

For the structures discussed in class, students should be able to:

1) identify from an image a structure's designer and location,
2) explain how form relates to forces in the structure,
3) explain the social, symbolic, and scientific significance of the structure (George Washington Bridge, Eiffel Tower, Hancock Tower, and Salginatobel Bridge at least),
4) explain qualitatively how the loads are transferred by the structural system to the ground, and
5) perform simple calculations to determine the forces in the main structural members.

For structures that students encounter in the world around them, they should be able to:

6) explain qualitatively the means by which loads are transferred to the ground,
7) evaluate the qualifications of the structure as a work of structural art, and
8) research the social, symbolic and scientific aspects of the structure and express their findings clearly in both written, graphical, and spoken form.

Instructional Elements

A variety of instructional tools was implemented in the course to allow evaluation of the best method of imparting the way of thinking on which the class is founded. The effectiveness of each of these tools is assessed quantitatively in later sections.

The instructional elements of the course are:

1) slide lectures,
2) writing assignments,
3) calculation assignments,
4) readings, and
5) Wednesday workshops.

Slide Lectures, held twice a week, consisted of 50-100 images per lecture of structures, the surrounding environment, and engineering diagrams such as free body and bending moment diagrams. The slide lectures, particularly for the first half of the course, follow closely the organization of The Tower and the Bridge (Billington 1985), and are composed of images provided by Professor Billington. These introduce the idea of structural art, and provide a base of knowledge for the study of the second half of the class.

Lectures taken directly from "Structures and the Urban Environment" notes:

- The Washington Monument and the Eiffel Tower
- The Eiffel Tower and the St. Louis Gateway Arch
- Telford, Brunel and British Metal Forms
- Eads, Eiffel and the Forth Bridge
- John Augustus Roebling and the Brooklyn Bridge
- History and Aesthetics in Suspension Bridges
- Robert Maillart and the Origins of Reinforced Concrete
- Freyssinet, Finsterwalder and the Origins of Prestressed Concrete
- Roof Vaults and National Styles
- The Swiss Tradition of Bridge Design
- New Bridge Forms: Maillart and Menn
- New Building Forms: Maillart and Isler
- The Development of California's Bridges

In addition to the Billington lectures a number of additional lectures were added, or revised to essentially new form. These lectures served two main purposes, to bring more contemporary content to the class, such as green design, and to provide a connection between the concept of structural art and the local urban environment of the City of Baltimore. Additional topics such as dam design and New York skyscrapers are also represented.

New or revised lectures:

- Chicago and the Skyscraper (Rev.)
- New York and the Skyscraper
- Forms and Forces (Rev.)
- Cable-Stayed Bridges
- Bridges and Structures of Baltimore/Chesapeake
- Earthquake engineering shapes structures
- Architecture and Engineering: Schlaich, Calatrava and Gehry
- High, Wide, Far (The world's newest and greatest structures)
- The Structural Art of Dams (Donald Jackson, Lafayette College)
- Green Buildings: Fathy to Yeang

Writing assignments consisted of four major exercises: a short extemporaneous essay, peer editing of writing samples, critique of published articles, and a final report. The short writing assignment was conducted in three parts. At the first Wednesday meeting of the class students were asked to spend 30 minutes writing about a structure that had personal significance to them. We encouraged them to attempt to think about any possible engineering meaning of the structure, but left the assignment very open. We provided comments on these short essays, particularly addressing ways in which the students might have extended their thinking about structural behavior.

Part two of the assignment was a peer editing exercise, in which groups of three students were required to provide detailed critiques of the others' essays. Part three consisted of a final complete rewrite of the essay. This assignment was successful in that it provided students an early opportunity to express their thoughts about a structure with which they were familiar. It was, however, disappointing in that many of them chose structures which had little or no significant engineering meaning or importance. Such an exercise could be improved by delaying it even by a week or two after students have had a basic introduction to the idea of structural art, and social, symbolic and scientific meaning.

Calculation assignments consisted of one general purpose set of "Statics 101" calculations followed by specific calculations on the Eiffel Tower, George Washington Bridge, and John Hancock Tower (Chicago). The calculations performed on actual structures were supported by detailed structural studies that were available online and discussed in detail on at least one Wednesday workshop (Billington and Mark 1983).

Readings focused on the required text for the course: Billington's *The Tower and the Bridge*. Other suggested reading for the students included:

- Gordon, *Structures: or Why Things Don't Fall Down*
- Hibbeler, *Engineering Mechanics: Statics*
- Salvadori and Ragus. *Why Buildings Stand Up: The Strength of Architecture*
- Billington, *The Art of Structural Design: A Swiss Legacy*
- Billington, *Robert Maillart and the Art of Reinforced Concrete*
- Billington, *Robert Maillart's Bridges*
- Holgate, *The Art of Structural Engineering*

Wednesday workshops contained a diverse set of supplemental educational activities. The workshops were discussion oriented and relied on group work to help students understand and interpret the writing, reading, and calculation assignments within the context of the knowledge gained from the slide lectures. The topics covered in the workshops included:

FIG. 1 - Students working on the hands-on build a bridge workshop

- Eiffel Tower Structural Study
- Writing Workshop 1
- Statics Workshop
- Writing Workshop 2
- Hancock Tower Structural Study**
- GWB Structural Study**
- Junkyard Wars: Hands-on bridge building (Fig. 1)
- Discussion of structural forms
- Final Project Workshop 1
- Review session (students lecture, professors provide slides)
- Field trip to the Chesapeake Bay Foundation
- Final Project workshop 2
- Applying Structural Art ideas, an aside on Tulsa Structures

Final project presentation.

** Through a grant from the Johns Hopkins Center for Educational Resources these two structural studies were turned into online and interactive materials.

Enrollment

This course was offered for the first time in the Fall of 2003. Thirty students total, one third each civil engineering majors, other engineering majors, and arts and sciences majors enrolled. Five engineering departments, six arts and sciences departments and all four undergraduate classes were represented. There is a commitment from the Maryland Institute, College of Art to send some of their fine arts students to the class at its next offering in the spring semester of 2005.

Student Projects

The culmination of the course and the opportunity to demonstrate attainment of learning objective (8) is the development of an independent critique of a structure documented in a written report and oral presentation. The presentations are available at www.ce.jhu.edu/perspectives/projects2003/projects2003.htm and include the following structures:

- The Xochimilco restaurant building (Felix Candela)
- Chesapeake Bay Bridge
- The works of Jörg Schlaich
- Commerzbank Headquarters (Norman Foster)
- 100 E. Pratt St., Baltimore (SOM)
- Sydney Harbor Bridge
- Bank of China (Leslie Robertson and I. M. Pei)
- Fallingwater (Frank Lloyd Wright)
- World Trade Center Baltimore (Associates of I.M. Pei)
- World Trade Center Seoul
- Woodrow Wilson Bridge, DC-VA
- Chesapeake Bay Bridge-Tunnel
- World Trade Center New York (Robertson & Yamasaki)
- Akashi-Kaikyo bridge
- Alamillo bridge (Santiago Calatrava)

Assessment

Student satisfaction of the learning objectives was assessed through graded writing and calculation assignments, one exam, and the final report and presentation. The writing and calculation assignments represent standard forms of student assessment in the humanities and engineering respectively. The exam, on the other hand, provided the first opportunity for students to demonstrate their ability to synthesize humanistic and engineering thought in response to questions such as that shown in Fig. 2. The students performed at a high level, achieving a low of 68%, a high of 94% and a mean of 84%.

Figure 2: Short essay question from the course mid-term (These images -at right- are digitized versions of those from David P. Billington's "Structures and the Urban Environment" Slide Library)

The class is a work in progress. The variety of instructional methods implemented and the variety of student backgrounds suggested that quantitative assessment of course strengths and weaknesses would provide the guidance necessary to improvement of the class. Two online surveys were conducted, one at the midterm and on at end of term. At the midterm students were asked to evaluate their state of knowledge at the start of the course as well as at the midterm.

The results of the surveys are summarized in Table 1. Questions were asked with regard to each of the learning objectives and the students were asked to rank their knowledge, experience, and confidence in achieving the objective on a scale of 1 to 5. Students were also asked to assess the effectiveness of the five instructional elements of the course in achieving these objectives.

Stauffacher

Zuoz

Tavanasa

Salginatobel

Fig. 2 - Assignment: "Using at least the above structures as illustrations describe the evolution of form in Robert Maillart's bridges, and evaluate his qualification as a structural artist. You should include your own sketches to illustrate your response."

Table 1 Several interesting features of the data point out strengths and weaknesses of the course as well as indicating the educational gap which such a course fills. Knowledge at the beginning of the class was low, averaging 2.5 on a scale of 1 to 5, where 5 indicates a high level of knowledge. Such low knowledge ratings point to the failure of the current engineering curriculum to address system level issues in structural design and the historical context of structural design, as well as the complete lack of exposure to the engineering discipline in Arts and Sciences. This course is designed specifically to address these shortcomings.

The students perceived that the learning objectives were achieved. By the end of the course achievement of knowledge in the course was above 4 on a scale of 4 to 5 for five of the eight objectives. While achievement of goals Q4 and Q5 was less successful, students did demonstrate acquisition of the new skill of structural critique through high confidence, knowledge and experience with respect to Q8.

As the course progressed from the midterm to the final, the greatest improvements in knowledge occurred with the higher level objectives related to interpreting structures in the world (Q6 – Q8). The jump in the synthesis objective (Q8) was the greatest of all increases over the second half of the class- that we believe reflects the emphasis in this part of the course. Interestingly though, the application of their new ideas on structural art seem to also increase their knowledge, experience, and confidence in the lower level objectives that were the focus of the early part of the class. The rise in experience and confidence in their new knowledge is notable.

Slide lectures consistently provided the greatest aid to the students in achieving the learning objectives. Although the mode of communication is largely conventional one-way lecturing, the extensive use of images is non-conventional for an engineering course. This method seemed to be effective for the students in learning the material. In some cases the slide lectures were regarded as a near absolute must (average of 4.9 out of 5) for learning and achieving an objective.

Writing assignments were not regarded highly for understanding load path, calculating forces, or identifying structures, (Q2, 4, and 5) but were the most highly

Table 1

Average of class response	**FIRST DAY OF CLASS - Learning objectives assessment**								
	Structures discussed in class…					***Structures in the world…***			
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	AVG
	On a scale of 1 to 5 (complete) the achievement of the learning objective is…								
Knowledge	-	**2.7**	-	-	-	**2.6**	**2.4**	-	**2.5**
Experience	-	2.1	-	-	-	2.2	2.0	-	2.1
Confidence	-	2.2	-	-	-	2.3	2.3	-	2.2

Average of class response	**MIDTERM OF CLASS - Learning objectives assessment**								
	Structures discussed in class…					***Structures in the world…***			
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	AVG
	On a scale of 1 to 5 (complete) the achievement of the learning objective is…								
Knowledge	**3.7**	**3.8**	**4.1**	**3.8**	**3.8**	**3.6**	**3.7**	**3.7**	**3.8**
Experience	3.2	3.4	3.6	3.4	3.5	3.0	3.3	3.3	3.3
Confidence	3.1	3.3	3.6	3.5	3.5	3.3	3.2	3.3	3.3
	On a scale of 1 to 5 (essential) the use of a class element in achieving the learning objective is.								
Slide Lectures	**4.9**	**4.2**	**4.8**	**3.7**	3.2	**4.3**	**4.8**	4.1	**4.2**
Writing assignments	2.6	*2.0*	3.4	*1.9*	*1.6*	*2.2*	3.2	**4.3**	*2.7*
Calculation assignments	*2.1*	4.0	*1.8*	4.1	**4.6**	3.3	*1.5*	*1.9*	2.9
Readings	3.4	2.4	3.6	2.3	2.0	2.6	3.5	3.1	2.9
Wednesday Workshops	3.1	3.8	2.8	4.0	4.1	3.7	2.7	2.5	3.3

Average of class response	**END OF CLASS - Learning objectives assessment**								
	Structures discussed in class…					***Structures in the world…***			
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	AVG
	On a scale of 1 to 5 (complete) the achievement of the learning objective is…								
Knowledge	**4.2**	**4.3**	**4.3**	**3.9**	**3.8**	**4.1**	**4.3**	**4.4**	**4.2**
Experience	4.1	3.6	4.3	3.6	3.6	3.6	4.1	4.1	3.9
Confidence	3.9	3.6	4.2	3.7	3.5	3.6	4.1	4.1	3.8
	On a scale of 1 to 5 (essential) the use of a class element in achieving the learning objective is.								
Slide Lectures	**4.9**	**4.6**	**4.6**	**4.4**	3.9	**4.5**	**4.8**	4.4	**4.5**
Writing assignments	3.3	*2.6*	3.7	*2.4*	*2.1*	3.0	3.7	**4.4**	3.1
Calculation assignments	*2.4*	3.7	*2.2*	4.1	**4.6**	3.4	*2.2*	*2.2*	3.1
Readings	3.8	3.1	3.9	2.7	2.2	*2.9*	3.5	3.5	3.2
Wednesday Workshops	2.9	3.9	3.1	3.5	4.1	3.3	3.1	2.9	3.3

regarded for performing the synthesis objective (Q8) – the large research project. We found that the non-engineering majors were more comfortable with the writing assignments than the engineering majors.

Calculation assignments were useful as a practice tool, and in understanding load path ideas – but they were the least useful for the overall synthesis objective (Q8). We chose to de-emphasize calculations in the final project to some extent – but perhaps too much, as the students did not see the value based on their response to the latter objectives; for Q7 and Q8 the calculation assignments were only given a 2.2 out of 5.

Readings were regarded well, except when it came to the specifics of solving calculation exercise (Q4, 5, and 6). The readings tailed off in the second half of the course and this is reflected in their decreased effectiveness in achieving the higher level objectives for structures in the world (Q6 – 8). Readings that relate more directly to these goals will be included in the future.

The Wednesday workshops met some needs quite well: explaining how the structures in class relate to the principles of structural art (Q3) and performing simple statics calculations (Q5) – but generally failed to connect at a high level with the larger objectives at the end of the course. The rather unstructured nature of many of the Wednesday workshops came in stark contrast to the slide lectures, and in some cases it was difficult to have the type of group discussions that we had desired in this format. In general, we believe, the use of this time offers the greatest opportunity for improving the instructional elements of the course.

Reflections

The quantitative assessment of the previous section is supplemented by narrative responses to survey questions, and anecdotal evidence from the instructors. The most striking conclusion from narrative responses is that a group of students, two thirds of whom do not study structural engineering, found the history of structural design to be intellectually exciting. 22 out of 24 respondents to the university course evaluation form responded to the question, "simulated interest in the subject matter," with the highest possible rating of 5. This is certainly not the reputation engineering classes enjoy across the entire university. Student comments include, "the material is interesting and easy to get into", "the subject was great – a good way to think about things in a new light", "evolutionary aspects of structures & designs are made explicit".

Students also identified areas for improvement including "have weekly quizzes on identifying structure's designer and location", "[the] simple calculations … are too ambiguous", "more hands-on workshops would assist students in understanding the way loads are transferred", "more in class models", "cumulative review or practice quizzes", "smaller quizzes", "split the class into two groups" [based on engineering background], "using actual numbers from the more important structures, like for the [George Washington Bridge], would be helpful."

As the instructors in the class we have several observations to add to the course assessment. The main challenge of the class was also its strength, the intellectual diversity the enrolled students brought to class each day. Class discussions were stimulated by hearing informed opinions from majors as diverse as East Asian Studies, Psychology, Civil Engineering, and Electrical Engineering. For example, in the final project presentation on the Commerzbank building, our psychology major made a convincing argument for how the structural form of the building might affect the performance and well being of the office workers.

In general, students from Arts and Sciences were stronger writers, and students from Engineering were understandably stronger in the technical aspects of the class. Our experience confirms the assessment results, however, leading us to believe that even those students with the weakest mathematical background left the course with a sense that there was more to the choice of form in structural engineering than architectural creativity.

It would be easy to consider this class a missionary endeavor; an attempt to bring structural engineering to the masses. While it very much is that, the value of the class to students studying structural engineering cannot be minimized. Of the civil engineering upper classmen in the course, two had their view of their profession entirely altered by the class experience. One will, inspired by the class, spend the summer interning for a British structural engineering firm, and researching a paper comparing early British and American railroad bridges from the perspective of structural art. For the underclass civil engineers, the course gave them their first exposure, in the midst of the standard assortment of math and physics classes, to what it actual means to be a structural engineer, designing elegant structures to serve the public good.

From our position as instructors, three things must be done to significantly improve the class. The Wednesday workshops must be improved through more directed discussion, perhaps more short writing assignments, and more hands on demonstrations using simple structural models. More reading assignments, particularly in the second half of the class, would provide additional historical context. Better integration of the engineering content into the slide lectures will provide better motivation for the inclusion of this material in the course. More use should be made of simple numerical results, such as axial force in suspension cables, and qualitative engineering concepts such as bending moment diagram shapes.

Conclusions

Perspectives on the Evolution of Structures was a success, enrolling 30 students from 11 departments spread across Engineering and Arts and Sciences, and achieving the learning objectives to a high degree. The course is among very few engineering classes at Johns Hopkins to attract significant enrollment from Arts and Sciences, and has the potential to raise the profile of structural engineering within the undergraduate population of the university. The profile of structural engineering is also raised by public student projects imspired by the class, such as that shown in Fig. 3. The production of non-engineering graduates who have experience with structural design can only benefit the profession.

All students, from Engineering and Arts and Sciences, expressed very low confidence, knowledge and experience in making rational criticism of structures at the system scale at the start of the course. All students demonstrated significant improvement in this ability throughout the semester. They were most aided in gaining this ability by the slide lectures. The calculation assignments were least helpful. The usefulness of the calculation assignments will be increased by better integration of numerical results into the lectures in coming iterations of the class.

Students from all backgrounds appreciated the synthetic nature of the course's intellectual content. To successfully complete the final project, students were asked to think qualitatively about aesthetics and historical context, and quantitatively about structural behavior and economics, finally synthesizing these approaches to a final overall critique of a structure. The inclusion of history in the engineering curriculum benefits engineering students, and the introduction of some engineering content to the experience of Arts and Sciences students opens their eyes to a new way of viewing the world around them. The historical context of engineering should be present not only in an isolated class, but throughout the engineering curriculum where design decisions of today can be informed by the experience of those who came before.

Acknowledgements

The authors wish to thank Professor D. P. Billington for making available the course accompaniments to *Structures and the Urban Environment*. The Johns Hopkins University's Center for Educational Resources provided financial support for the production of the interactive structural studies and is providing ongoing support for the project *An Engineer's Guide to the Structures of Baltimore*. Ms E. Hagar of the Center for Educational Resources assisted in the administration of surveys as part of the quantitative assessment of course effectiveness. Ms. E. Mengel of the Johns Hopkins Libraries was a tremendous resource in the historical research necessary for development of new lectures and completion of student projects.

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Fig. 3 - On a cold clear winter morning students on the Johns Hopkins campus were surprised to see this ice bubble sculpture created during a freezing night using a weather balloon and strips of cloth and water, demonstrating a concept shown in slides from Swiss engineer, Heinz Isler.

Developing "Toy Labs" for CEE 80N - The Art of Structural Engineering

Professor Sarah Billington

Stanford University

presented by Kristi Miro

Graduate Student, Civil and Environmental Engineering at Princeton University

This paper outlines the development of "Toy Labs" at Stanford University, similar in concept to the labs that are a part of CEE 262 at Princeton University. The labs at Stanford were developed for a course titled "CEE 80N: The Art of Structural Engineering."

Sarah Billington

CEE 80N is offered under Stanford's Freshmen Seminar Program. The seminar program is open to all freshmen at Stanford, regardless of their potential major. The program gives students the opportunity to get to know one or more professors well early in their time at Stanford. The enrollment is limited to 16 students and preference is given to freshmen. The small class size is meant to create a relaxed, less formal environment for the students to interact with each other and the professor. While the course is open to students of all backgrounds, there is an interest on the part of the CEE department to attract students to the CEE major.

The class meets twice a week. The first day is a 50-minute lecture and the second day is a 50-minute lecture followed by a 50-minute "class" session where basic principles of statics are taught to evaluate the efficiency and safety of structures. The lectures focus on the history of structural form as outlined in *The Tower and the Bridge*. Stanford runs on the Quarter system and so the course is ten weeks long. Roughly six weeks of the course follow the traditional pattern of two 50-minute lectures and one 50-minute class session per week. There is one homework assignment each week during the first five weeks related to a Structural Study (from Princeton's CEE 262). Newer topics of cable-stayed bridges, earthquake engineering and the collapse of the World Trade Center are given in lectures towards the end of the course. Interspersed throughout the course (and particularly toward the end) are several hands-on activities including a field trip, competitions to fabricate efficient and elegant columns out of paper and bridges out of uncooked spaghetti and epoxy. Students also spend two weeks conducting a small independent study of a structure of their choice, culminating in a brief three-page write-up and a 10-minute presentation to the class. An outline of a recent syllabus is given in Figure 1.

CEE 80N Structures
Fall 2004

Week	Day	Date	Lecture	Class/Lab	Readings*	Assignments**
			INTRODUCTION			
1	M	27-Sep	Introduction to Course		Ch 1	
	W	29-Sep	The Washington Monument and the Eiffel Tower	Columns - Analysis Part I	Handout 1	HW 1 (Introduction to Calculations - Statics)
2	M	4-Oct	Telford, Brunel, Eads and Eiffel: Metal Bridges		Ch 2,3,4	
	W	6-Oct	Chicago and the Skyscraper	Columns - Analysis Part II	Ch 7, 13	HW 2 (Washington Monument & Paper Columns
3	M	11-Oct	Cantilevers/Beams			
	W	13-Oct	Columns competition	Columns competition		HW 3 (Eiffel & Hancock Towers - includes lab)
4	M	18-Oct	The Brooklyn Bridge and Other Suspension Bridges		Ch 5,6,8	
	W	20-Oct	Maillart and the Origin of Reinforced Concrete	Cables (in first class)	Ch 9	HW 4 (George Washington bridge - includes lab)
5	M	25-Oct	Freyssinet and the Origin of Prestressed Concrete		Ch 11	
	W	27-Oct	Roof Vaults and National Styles	Arches	Ch 10	HW 5 (Salginatobel Bridge)
6	M	1-Nov	Development of Cable-Stayed Bridges		Handout 2	
	W	3-Nov	Field Trip - Offices of Skidmore, Owings & Merrill	Field Trip		HW 6 (Independent Study/Presentations)
7	M	8-Nov	Trusses and MASTAN tutorial for bridge competition			
	W	10-Nov	Testing Spaghetti Beams in Lab	Intro to bridge competition		Bridge Competition
8	M	15-Nov	The Swiss Tradition of New Forms		Ch 12,13	
	W	17-Nov	Student Presentations	Student Presentations		
9	M	22-Nov	California Bridges & Earthquake Engineering			
	W	24-Nov	WTC Collapse			
10	M	29-Nov	Final Lecture			
	W	1-Dec	Spaghetti Bridge Contest	Bridge Contest		
	W	**8-Dec**	**Final Exam (8:30-11:00am)**			

* Chapter readings are from The Tower and the Bridge (D.P. Billington). Students are responsible for reading the whole book. The chapters specified here correspond to the lectures for guidance. Students are also responsible for reading additional handouts distributed in class.

** Assignemnts 1 to 5 are due at the beginning of class one week after being assigned. The presentation and bridge competition assignments are given more time - due dates will be announced.

Fig. 1 - Recent syllabus for CEE 80N at Stanford University

Fig. 2 - Eiffel tower and Eiffel tower model built from K'nex

We have two fully developed labs (Eiffel Tower and Golden Gate Bridge) and one that is almost completed (Seattle Space Needle). The labs are incorporated into the class as part of the homework assignments related to the relevant Structural Study. Not having a long lab period to accommodate all of the students, we have the students sign up for a one-hour time slot outside of class time to conduct the lab with a TA and 2-3 other classmates.

We have created a replica of the Eiffel Tower lab at Princeton (the full tower only) shown in Figure 2. Students measure the reactions at the base of the tower resulting from a single lateral point load being applied (with a pulley system). Students then compare their calculations with the experimental measurements.

Fig. 3 - Golden Gate Bridge and model

We created a model of the Golden Gate Bridge (Figure 3) following the basic set-up and experimental details of Princeton's Menai Straits Bridge model. For the Golden Gate Bridge model, students use a series of weights to act as a distributed live load, and measure the span length and the sag of the cable (Figure 4). They then predict the

Fig. 4 - Students working with Golden Gate Bridge model

reactions at the base of the towers and the horizontal component of the cable force at the towers. Next, they load the bridge and compare their calculations to the measured values using the model. As an additional exercise, the students are asked to repeat the procedure for a partially loaded deck, while also noting the deflected shape under the partial loading (Figure 3b).

The third lab we have just recently created is that of the Seattle Space Needle (Figure 5). The objective of this lab is to make dynamic measurements of a single-degree-of-freedom structure on a table-top shake table and compare them to simple calculations. Students will measure the height and stiffness of the tower (they will be given the weight). They will then be asked to predict the acceleration of the top (lumped mass for the "restaurant") due to a given sinusoidal input motion and compare it with their experimental measurement. Finally, they will observe the difference in response of the structure to various recent earthquake records (e.g. Northridge, Kobe). Note we had to make the Needle have four legs instead of three to avoid excessive torsional response. The model is a less realistic replica of its prototype and we may modify it in the future.

The labs were developed by several undergraduate and graduate students. Financial support for these developments was provided by an internal (Stanford School of Engineering) grant called the Perin Foundation Award for enhancing engineering education. The total budget was $7,800 and a breakdown of projected expenses vs.

actual expenses is given in Figure 6. The development took place beginning in June 2003 and ending in July 2004. I ended up having a "free" undergraduate research assistant the first summer and also there was an extra PC in the lab that we could use for our models. As a result, we stayed under budget and were able to allocate leftover funds for developing a 3rd lab (Space Needle) – the original proposal was for two labs.

Fig. 5 - Seattle Space Needle and model

The Eiffel Tower and Golden Gate Bridge labs were developed by one of the students from the first group of students I had in class for CEE 80N (Lauren Schneider). Lauren was hired as an undergraduate research assistant through my department and worked for me for about two months during the summer of 2003. During the summer, she visited the Princeton lab for a few days and took numerous pictures of the models to facilitate replicating most of the details (that make the experiments work). In her two months with me she purchased all of the materials and equipment, built the two models and began proof testing them.

When Lauren's assistantship ended and the Fall Quarter began (when I was again offering the course) there were still several details to be worked out such as adding turnbuckles to the cable of the bridge (Figure 6a) and fixing the base of the Eiffel Tower to the force sensors (Figure 6b). These details were essential for the measurements to be accurate and I believe considerable time was saved by simply replicating the exact details used in the Princeton models since they had already been proven. The details were all completed within the first four weeks of the Quarter by the two teaching assistants I had helping with the course. Students in the fall course completed both lab exercises. The bridge lab was required and the tower lab was offered as an extra credit assignment. We were confident with running the bridge lab successfully based on early proof testing but this was not the case with the tower lab. Therefore we did not put the tower lab in as a required assignment in case we needed to drop it.

The Space Needle lab was developed by an undergraduate student (Stoyan Boydev) from the Ecole Centrale Nantes in France. Stoyan came to Stanford for four months to complete a "graduation project" required of all undergraduates at his university. As a final year undergraduate in the French system, his level of education was similar to that of a first year graduate student finishing up a one-year Masters degree. I offered him this project with neither of us knowing how it might turn out. We had some local expertise with our table-top shake table and several contact names for additional assistance but were otherwise in very new territory.

Stoyan was very resourceful and creative and had a calibrated, working model after about three months. However he created a lab assignment that required the students to analyze the structure as a five degree-of-freedom structure, rather than the proposed single-degree-of-freedom structure for the freshman class. His exercise therefore required the students to compute the mass matrix, the stiffness matrix and write a Matlab program to estimate the damping ratio of the five degree-of-freedom structure. I had to clarify who the "audience" of the lab would be, and further explain that freshmen at a US university do not have the same education as first year university students in France. Furthermore, a large number of my students have no interest or intention of majoring in any engineering field and most will have had no prior experience with matrices or Matlab. However, the exercise that Stoyan had developed was very good (and worked well) and it will be available for use in the graduate course on Structural Dynamics offered by our department.

In the second round, Stoyan added a mass to the top of the structure (restaurant location) and created a new exercise wherein the students can use much simpler equations to estimate the top story acceleration when the structure is subjected to a sinusoidal ground motion. Although he ran out of time (on his student visa) to proof-test this alternate version of the exercise thoroughly, preliminary tests

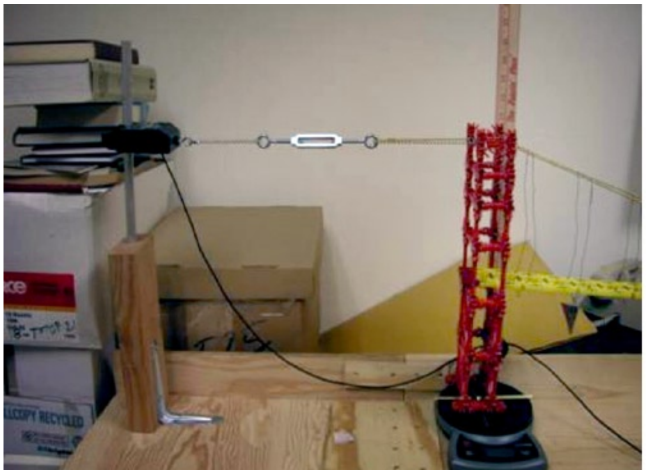


Fig. 6a - Turnbuckles for model of Golden Gate bridge

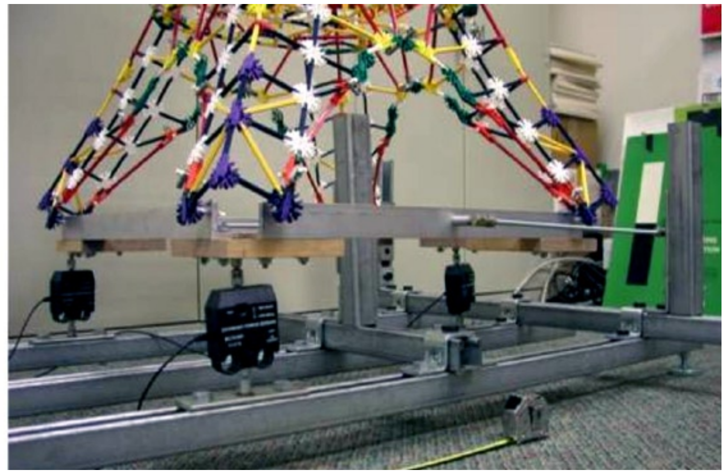


Fig. 6b - Attachment of base of Eiffel Tower model to sensors

showed good agreement between calculations and measurements. We will be further proof-testing this model this coming academic year.

In assessing the effectiveness of adding the labs to this class, the students were asked if the bridge and tower labs were interesting, challenging, too easy, or difficult. The response was generally positive from all students. Twelve of sixteen found the labs to be interesting and many noted that the labs helped them understand better the concepts behind how each structure was resisting loads. However 7 of the 16 students also added that the labs were not particularly challenging (despite being interesting) and they preferred more problem-solving rather than "plugging and chugging numbers." There were no negative comments about the labs or complaints about having to do them.

In closing, there are several issues that are worth mentioning to aid others who are planning to develop such labs. We found that each lab took 2-3 months to create and "debug" with a student working full-time. This time could be shortened if the person or persons building the new models could visit a lab with existing structures to discuss the fabrication and set-up procedures and details. While I ended up staying within my budget (Figure 7), this was only because of the "donations" of a computer and undergraduate research assistantship covered by my department. Given the length of time needed to complete these models, paying the student for this full-time work proved to be the largest expense.

We purchased the sensors and software from PASCO and had some problems with "drifting" of the sensors (also experienced at Princeton). The company was quick to replace the faulty sensors – but it did mean a delay in set-up time so it is something to consider if the models are being set up in a short time frame. Finally, we found that the accelerometers supplied with our table-top shake table were more accurate and reliable for our Seattle Space Needle model (for what we were measuring) than the accelerometer from PASCO. If we find we need to use the non-PASCO accelerometer for our single-degree-of-freedom lab, we will unfortunately not be able to use the PASCO software (which is nice, and simple to use) for the lab. We would most likely use LabVIEW for further developments.

In general, creating these labs has been a great learning experience and a lot of fun for the students, for me and even for my colleagues who are observing from outside. So far it has been well worth the effort to put these labs together.

Budget Item	Requested	Spent
K'NEX Toy Sets (6)	$600	$850
PASCO Standard Physics 500 Bundle (w/Force and Acceleration Sensors)	$1,700	$2,010
Data Studio Software2	$100	$110
Personal Computer for Lab	$1,500	$0*
Travel	$0	$700
Student assistants (3 months)	$3,000	$2,000
Lab supplies, Weights & Technician	$900	$670
Total	**$7,800**	**$6,340**

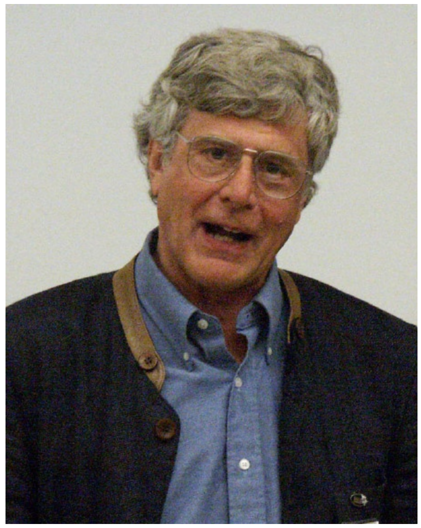
**PC donated from lab*

Fig. 7 - Requested and actual budget

Bridges, Towers and Skyscrapers

Professor William Case
Grinnell College

I first met David Billington about twenty years ago at the Waldorf Hotel. It was kind of nice. I always wanted to have a Waldorf salad at the Waldorf. I was there because Grinnell College had gotten a grant to teach a course on technology. I was going to do what any physicist would do which was teach a course on energy, basically a thinly veiled physics course. When I was there, David told me about the course he was teaching which I found very interesting. What I found particularly interesting was his book on structural studies that contains quantitative analyses of the Eiffel Tower, the George Washington Bridge and other famous structures. I decided I wasn't going to leave the room without a copy of the book. It changed what I had originally planned to do. David had this course already. It was a question of how to put myself into the picture.



William Case

This is my course description as it appears in the Grinnell College Catalog. It is very much in the spirit of what David does.

Physics 180 Bridges, Towers, and Skyscrapers.
4 credit hours

> An investigation of large man-made structures (e.g., Brooklyn Bridge, Eiffel Tower, and Hancock Tower/Chicago) considering structural, social, and aesthetic aspects. The relationship between a structure's form and its function is examined. Concepts from physics necessary for the quantitative analysis are presented. Prerequisites: one semester of calculus.

As a physicist I'm quite comfortable talking about the scientific and quantitative aspects of the structures. The historical and social parts are also not too difficult. It's not too hard to find out when it was built and how much it cost. The aesthetic parts I present by showing pictures of structures that I consider beautiful and ones which I considered less successful. After talking about them, the students generally agree.

Grinnell College is a liberal arts school. There is no engineering program on campus. Students major in subjects in the humanities, social sciences or sciences. My course is designed to attract a variety of students.

When you sit in a room almost everything you see around you is a work of engineering. To have an understanding and appreciation of this is a goal of my course. The prevailing view in many academic circles is anti-technology. The extreme view is to see technology as a disease society has caught and can't seem to shake. I don't care if at the end of the course they love technology or hate it, but I want them to understand it so they can talk about it in a meaningful way. I would like them to be able to look at a structure and say that it's a good work of engineering or a bad one.

One other thing I want to accomplish is to have liberal arts students develop a sense that they can understand a quantitative argument.

A few comments about the course: This is a standard four credit hour course, lecture format with no lab. I have offered it about ten times in the last twenty years. It draws about twenty students each time it is offered. There is a calculus prerequisite. Calculus is actually used at only one point in the course. But I want to warn students that

Fig.1 - David Billington and Bill Case inspecting a bridge pier

they will need to use algebra. At Grinnell about 80% of the students take calculus so this doesn't limit enrollment. The mix of the students is about 50-50 men and women. Their majors are roughly equal among the sciences, social sciences and humanities. Those in the social sciences and humanities will have more trouble with the quantitative parts.

I spend a lot of time in the course on bridges. One reason is that the solution to the problems of building a safe bridge is not obvious. If you simply make it bigger it will not necessarily work better. For example if you make the deck stronger and thus heavier the bridge may not be safer. A second reason is that bridges tend to be transparent. The structural aspects are not hidden, as is often the case in buildings. And a final reason is that I like them.

As part of my preparation for teaching this course I spent eight months of a sabbatical leave with Prof. Christian Menn at the ETH in Zurich. During this time I was able to work with engineers. I also had access to construction photographs, and original drawings and calculations for various major bridges, such as the Ganter and Felsenau in Switzerland.

Another thing I do in the course is something I thought of while taking a shower. I wanted to have a problem where you designed a bridge where the design was constrained by the requirement to carry a specific load. The assignment was this: Bridges, Towers and Skyscrapers

Bridge Project

Specifications

1. Span - 12 1/2" (between tables)
2. Width of roadway - 2"
3. Must carry a 1 lb. 1 oz. car at any point on the span.

Materials

1. Ivory soap bars - (99 44/100% pure)
Personal size (2" x 3" x 7/8") $20,000/ bar
2. Toothpicks - round - standard 2 1/2" $3,000/ pick
3. String (I will supply this) $600 per inch

Can cut bars, toothpicks, and any length of string. Cost is based on fraction used. The idea is to build the least expensive bridge.

I wanted a material that would take compression but no tension, so I figured Ivory soap would work. The span is about the length of four standard Ivory soap bars. In order to complete the structure I added string which will take tension but not bending and toothpicks which will take bending. All components are assigned costs high enough to make the problem interesting. With these three components the student must think about how to put them together to carry the one-pound toy car at the least cost.

The span and load are such that the most naive solution of taking four bars attached with toothpicks will be unsuccessful in supporting the load. One must use a more sophisticated approach such as using string running beneath the soap bars to support the load.

A Successful Solution

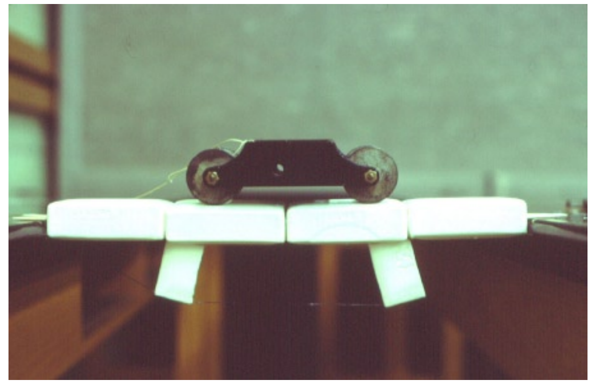


Fig. 2 - Soap and toothpick bridge with one pound car

Beyond this students have found many successful solutions. The problem is assigned early in the course before there is any discussion of forces and bending. It is done by students working on their own. No hints about possible successful solutions are given in advance. I provide the string and the toothpicks, the car, and a place to work. Students purchase the soap and often deplete the town's supply of it.

The soap bridges that are the least expensive are often the most aesthetically pleasing.

A Better Solution

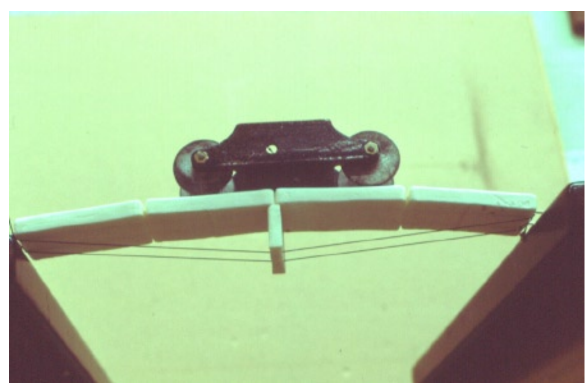


Fig.3 - Prestressed soap and toothpick bridge

In solving this problem on their own, some students invent pre-stressing. On the day the assignment is due, all the bridges are tested with the dreaded one-pound car.

At this time the Bridges, Towers and Skyscrapers course at Grinnell is established and successful. It represents, thanks to support from the Sloan Foundation, the transfer of an important and unique course from one institution to another.

ARCE 446-Advanced Structural Systems

Professor Mike Botwin

California Polytechnical Institute - San Luis Obispo

Mike Botwin

This is a three quarter-unit lab course that enrolls approximately 20 senior architectural engineering students (with an occasional senior architecture student). The course meets 6 hours per week with an additional 3 hours as "assigned time" to be used towards a final project.

Architectural engineering students come to this course with a strong back ground in structural analysis, structural design and structural intuition but all geared to rectilinear geometries. This course deals heavily with "form resistant" long-span structures—arches, tensile structures (cable nets, suspension and cable-stayed bridges, fabric structures, pneumatic structures and cable/glass structures) and shells (including grid shells, geodesic domes and deployable structures). In addition, a brief time is spent on high-rise buildings. Consequently, a significant effort is expended in breaking pre-conceived "rectilinear thinking". Geometry—form-findings and the benefits of curvature as a design parameter—permeate the course.

The engineering basics of equilibrium, free body diagrams, structural behavior and load flow are integrated into virtually all discussions. Construction strategies, structural engineering history and structural aesthetics are interwoven throughout the course.

The overall approach to the course is qualitative—as opposed to quantitative—which I feel best fits an undergraduate curriculum. The course is admittedly a superficial introduction to the addressed topics.

Basic lectures are augmented with slide presentations (using slides from both the Princeton Series and my own collection), physical model demonstrations and student projects—mostly hands-on model building.

Expanded Course Outline

Arches

Lectures: develop the concepts of funicular shapes, the pressure line, bending in arches and the influence of curvature on behavior.

Slide presentations: (1) reinforce the concepts dealt with in lectures; (2)present the techniques used to reduce live-load bending, through dead load, deck stiffening and radial cable pre-stressing; illustrate historical and aesthetic aspects.

The slides shown include the works of Roman builders, Telford, Eads, Maillart, Menn, Rice and Calatrava. Construction techniques are addressed.

Student participation: two assignments dealing with the concepts of the lectures, including funicular and non-funicular loading for trusses and two and three pin arches.

Tensile Structures

Lectures: deal with stability of hanging cables through pre-stressing by dead load, stiffening elements and anticlastic networks; the influence of curvature on behavior and forces; the influence of pre-stressing on stiffness; the transition from cable nets to fabric structures; cable and fabric structure morphologies including cable-domes and pneumatic structures; introduction to cable-supporting for glass walls.

Slide presentations: reinforce the concepts dealt with in lectures; illustrate historical and aesthetic aspects. The slides shown include the works of Roebling, Schlaich, Calatrava, Rice, Otto (including a cassette of Otto talking about his own design philosophy), Geiger and Berger.

Student participation: three hands-on models building projects are used to deal with curvature, support and prestress issues. Groups of four build string models of about 10'-15' span on the lawn; each group has a different type of cable structure to deal with (e.g. bicycle wheel, arch supported tent); a second class is devoted to variations on the first models. The third model exercise has each student build a fabric structure using panty hose as the building material (using guidance from Horst Berger's book).

Shells

Lectures: an overview of geometry and behavior of shells (with the aid of short films produced by Robert Heller); discussion of membrane and bending stresses. Load flow and behavior of synclastic shells; solution of the equations of equilibrium for self weight loading for spherical shells. Behavior and load flow for hypars. Discussion of grid shells; introduction to geodesic geometry and geodesic domes. Discussion of foldable and deployable structures.

Slide presentations: reinforce concepts dealt with in lectures; illustrate historical, aesthetics and construction aspects. The slides shown include the works of Torroja, Nervi, Candela, Dieste, Isler, Schlaich (glass grid shells) and Fuller.

Student participation: groups of four develop self-designing shells using the Isler hanging towel approach; this exercise is repeated resulting in 4-6 different configurations per group.

High Rise Structures

Lectures: general discussion of gravity, wind and seismic loads on hi-rises. Introduction to special framing systems for hi-rises—tubular, belt and mega-structure systems and discussion of control systems of dynamic behavior.

Films: while no slides are usually presented, two films are shown. "Higher and Higher" deals with hi-rise history, engineering—including structural—issues unique to hi-rise and the social/urban problems caused by these structures. "One Queen's Way" documents the design and construction of a Norman Foster/Ove Arup designed bank in Hong Kong.

Student participation: no project or homework is assigned but a classroom discussion for the impact of hi-rise buildings on society is encouraged.

Final Project

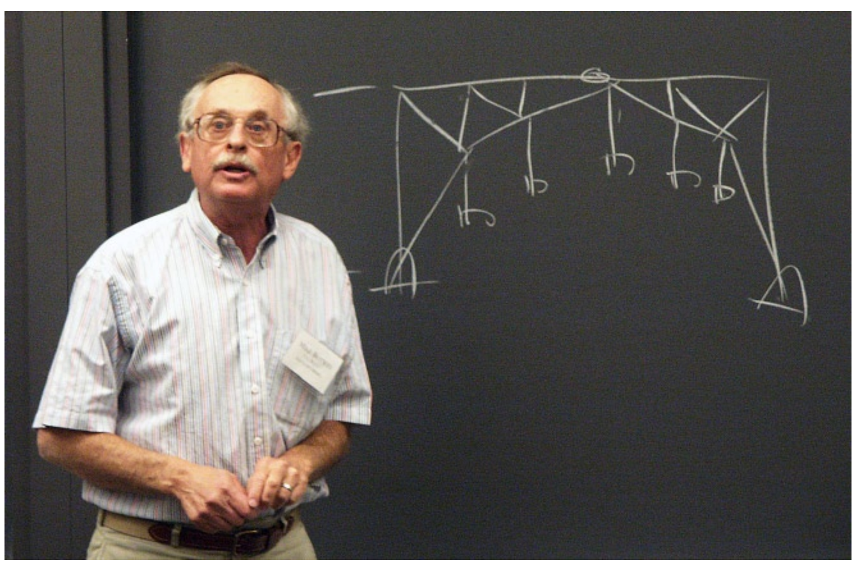
A final project pertaining to any aspect of the course is required for each student; group projects are acceptable. Commonly these projects entail models and accompanying reports of original designs or important built structures. Students are given the opportunity to make classroom presentations of their projects.

Test

A two hour short answer final exam is the only test given.

References

Billington's *The Tower and the Bridge* is required reading. A number of "recommended" books are ordered—these depend on availability—but usually include Robbin's *Engineering a New Architecture*, Berger's *Light Structures, Structures of Light*, Holgate's *The Works of Jörg Schlaich* and the ASCE *Tensile Fabric Structures*. In addition, I make available to the class my entire library of books and articles concerning the germane topics.



CEE 102 - Engineering in the Modern World

Professors David P. Billington and Michael G. Littman
Princeton University

Engineering in the Modern World, a course designed for both engineering and liberal arts undergraduates, explains the great engineering events that transformed American life over the last two centuries. The course consists of five parts, of which the first two are now written in *The Innovators: The Engineering Pioneers Who Made America Modern*. This first volume includes the steamboat and the textile mill, the railroad, the telegraph, the steel industry, and the rise of the electrical industry.

A second volume, currently in manuscript form, explains the telephone, the oil industry, the automobile, the airplane, radio, steel bridges, and concrete structures, carrying the history up to World War II. Lecture notes and other teaching materials bring the course up to the end of the twentieth century.

Early in its life the Museum of Modern Art in New York City held exhibits on photography and on modern structural engineering, portraying both as new art forms. These two products of the Industrial Revolution illustrated the artistic response of individual photographers and engineers to the transformation taking place since the introduction of steam-powered rotary motion and industrialized iron. In addition to creating these new art forms, the Industrial Revolution also transformed natural science. The steam engine stimulated the new science of thermodynamics and bridge building encouraged the science of mechanics. Moreover, American government of the 19th century was radically transformed by engineering events, from the steamboat and the textile industries to the railroad, telegraph, and steel.

In the twentieth century these interconnections are far more compelling than formerly, and emphasize the transformation of nature, politics, and art. Over the past 200 years the means of transformation has been modern engineering and the results exhilarate and confuse us; they alternately conjure up images of utopia or of annihilation; we sometimes extol progress and other times long for lost idylls.

Understanding our era will not remove all ambiguities or doubts or visions, but the paramount role of technology in modern life demands that a proper understanding of it have a more central place in a liberal arts education. Here, then, is the paradox of higher education: keep the classics and add technology. These superficially incompatible subjects relate surprisingly well, as we can see for example in the life of Samuel Morse (1791-1872).

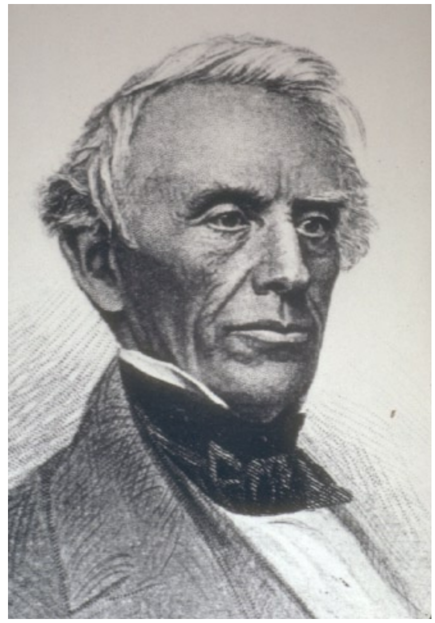


Fig.1 - Samuel Morse, both an artist and an engineer.

Morse played a central role in the transformation of society by using electricity. To understand Morse and his career, however, requires a study of Joseph Henry, America's first great 19th century physicist, who actually invented the telegraph; Morse also leads us into the early 19th century art world in which, for a dozen years, he was a leading painter, and finally the powerful and discouraging impact of the Jackson administration on the elite establishment from New England. It was Morse who introduced photography into the United States, where he trained Matthew Brady in his New York studio. Science, politics, and art are the essential coordinates of Morse's life and, in varying degrees, each plays a role in the lives of other pioneering technological innovators.

Yet in books on the 19th century history of the United States, these innovators barely appear. The general culture leaves them out for reasons that one can trace back to the first foreign observer who attempted a full analysis of the

Fig. 2 - Joseph Henry's invention - the telegraph key on display at the Smithsonian Institute.

young republic: Alexis de Tocqueville (1805 - 1859). A French aristocrat and lawyer, de Tocqueville visited the United States between May 1831 and February 1832 as an official emissary of the French government with the goal of studying American prisons.

He became so fascinated by the new world and its differences from the old that upon his return he wrote his two volume study *Democracy in America* published in 1835 (Vol. I) and 1840 (Vol. II). It remains a classic work widely read today. He understood well that the United States would soon be a world power and he connected that to its "democratic institutions...joined to the physical constitution of the country..." being "the cause of the prodigious activity of the inhabitants." He then proceeded to formulate his famous dichotomy: democracy and the pursuit of happiness versus aristocracy and the elevation of culture. Tocqueville's choice of grandeur and monarchy over equality and democracy came naturally to someone brought up in the shadow of the French revolution. In 1835, Tocqueville could not possibly visualize how these two images could be related: production of comfort and promotion of poetry; general well-being and a people fitted to act powerfully upon all other nations. What Tocqueville saw as two societies, Americans have been trying since independence to make into one.

The integration of industry and high culture can be seen in America's unique system of private higher education. Private institutions named for Carnegie, Stanford, Vanderbilt, Cornell, Duke, and Tulane were the prducts of wealth created by steel, railroads, telegraph, tobacco, and steamboats.

In our own institution, Princeton, prominent campus buildings bear names such as Firestone, McCormick, Frick, and Rockefeller, names from technological industries that built the nation, and our lake is named Carnegie. In each case the technology created the wealth which has supported the culture. One does not have to approve of all business practices to recognize that private education, which often sets the tone for liberal education, cannot be separated from private enterprise based upon technology.

Equally significant for higher education has been the landmark Morrill Act of 1862 which established the land grant state universities. These great institutions today embody the ideals of public education and also stand for the public belief in the value of education in engineering, agriculture and the liberal arts. Together with private schools, the public ones make up the best educational system in history.

Yet, like Tocqueville, we academics assume that culture means that which the Frenchman assigned to an aristocratic state. A cultured person knows about the arts and perhaps something about the sciences but not technology. Higher education can integrate technology with the liberal arts only by recognizing that one way to integrate the liberal arts themselves is through technology. Conversely, the essence of engineering lies not just in natural science, as is usually thought, but also in social science and the humanities. In order to illustrate this integration, we shall outline some stages in the growth of our country as taught in the course.

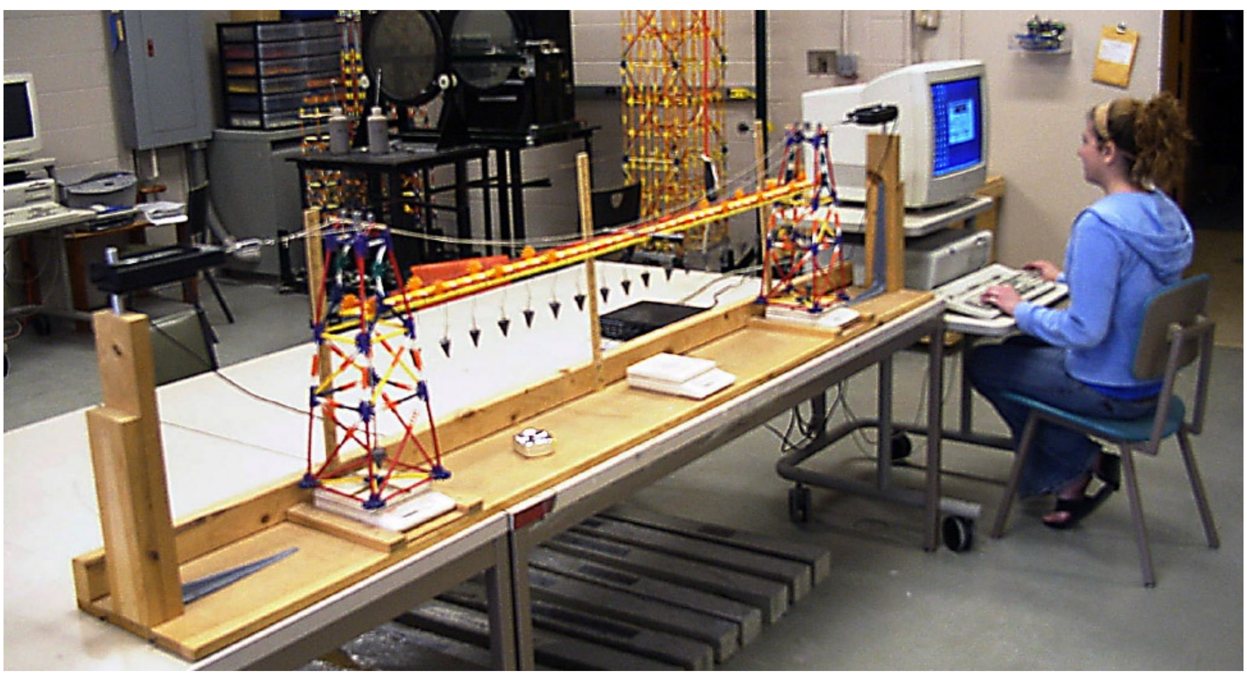
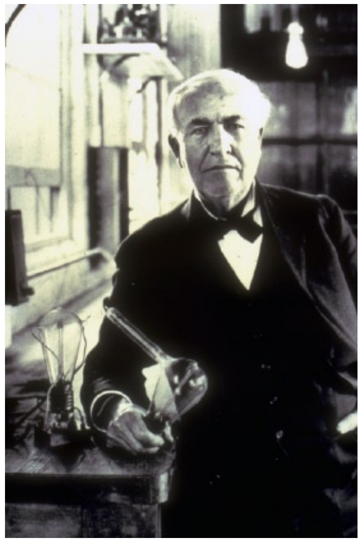


Fig. 3 - In CEE 102 students load models of real structures such as the 1826 Menai Straits Bridge with weights to measure deflections and reactions.



Figs.4, 5, and 6 - Alexander Holley, Thomas Edison, and Henry Ford were leaders in developing the great American industries.

Course Summary

"Engineering in The Modern World", a course designed for both engineering and liberal arts undergraduates, explains the great engineering events that transformed American life over the last two centuries.

Like the older course, "Structures and the Urban Environment", this course has two lectures per week which provide the political and visual context of engineering. Both do the same basic engineering calculations. The formulas are symbolic images of physical relationships. The problems are intended to introduce the students to basic calculations which help guide engineers in their designs, and to provide a means of understanding the origins of main events in our history. The goal is not to give students full expertise in engineering calculations. The students in 102A write a 3000 word term paper on an engineering object or system, and those in 102B write a series of lab reports. Both groups take a final examination on the lectures, readings, and calculations.

Some of the calculation questions may be used to stimulate more detailed discussions and additional research, but most of them are intended to have a straightforward mathematical answer. This is not to say that engineering problems all have single answers.

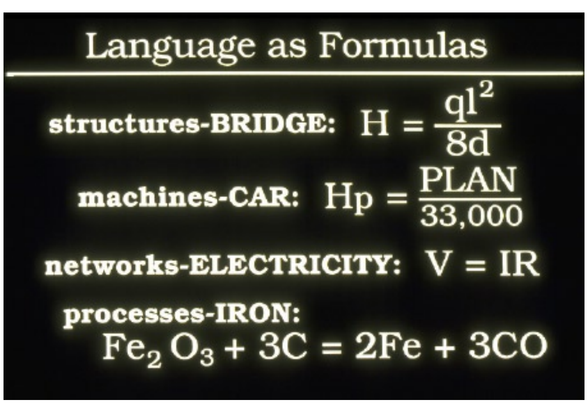


Fig. 7 - Formulas are used throughout the course to show how the leading engineers made conceptural calculations.

It is crucial for the public, politicians, and journalists to know that formulas do not solve problems; rather they suggest designs, they stimulate insights, they define limits, but they never provide ways to the best solutions as so many technologically illiterate writers on engineering suppose. Formulas never define a "one best way" or an optimum. Formulas represent a discipline, not a design; they can be used to avoid disasters but they can never insure full safety or essential elegance.

The five parts of the course are each organized around a major cluster of engineering innovations since the Industrial Revolution:

- **I. Independence, Iron and Industry: 1776 - 1855**
- **II. Connecting the Continent: 1830 - 1883**
- **III. Rise of the Great American Industries: 1876 - 1939**
- **IV. Regional Restructuring: 1921 - 1964**
- **V. Information and Infrastructure: 1946 - 1996**

Both the book and the course treat American technology as an interplay of three perspectives: what great engineers actually did, the political and economic conditions within which they worked, and the influence that these designers and their works had on the nation. A brief description of each time period will illustrate the general approach of the course.

Independence, Iron and Industry

By 1830 two engineering breakthroughs had begun to transform our society: the river steamboat and the textile factory town. Both resulted from raids on British invention and both led to innovations that surpassed the original inventions.

For his steamboat, Robert Fulton bought a Watt steam engine from Britain and proceeded to create something new that marked America's first great contribution to world technology. Fulton was an engineer in the modern sense: he made detailed calculations based upon experimental data and he synthesized the work of others into a new working object which proved profitable; in doing so, he turned invention into innovation. The students calculate the engine horsepower, as Fulton did, by using the formula developed by James Watt:

Hp = PLAN/ 33,000

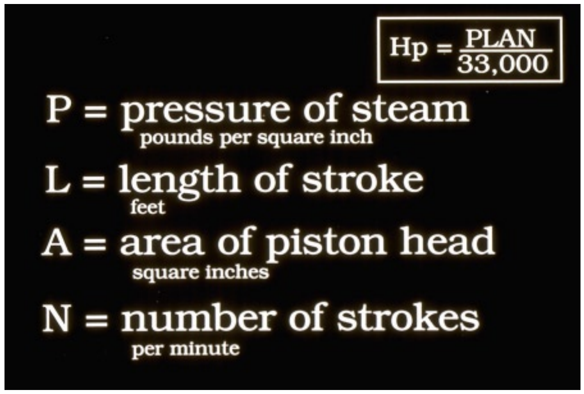


Fig. 8 - This lecture slide shows the four components of horsepower

where P is the cylinder piston pressure (in pounds per square inch), L the power stroke length (in feet), A the piston head area (in square inches), N the speed of the piston (in power strokes per minute), and 33,000 Watt's estimate of one horsepower in foot-pounds per minute. Fulton converted this reciprocating engine power into rotational power so that the paddles could provide adequate thrust, T, to overcome the drag that he estimated based upon the Deptford Dock tests in Britain during the 1790s. The drag was proportional to the velocity squared. The students work with these relationships to solve problems and to understand the elementary basis for vehicle design.

To make his boat a commercial success, however, Fulton needed help which he received from Robert Livingston, a major political figure in New York state. Livingston secured a Hudson River franchise which amounted to a monopoly for Fulton's steamboat and more importantly Livingston played a central role in acquiring for the United States the land on the west bank of the Mississippi River. Fulton's main objective of profitable commerce on that great natural waterway could be achieved after Livingston, as American Ambassador to France, signed the Louisiana Purchase of 1803.

Big government emerged over the next half century as the river business flourished and created a new set of dangers. Competition forced greater speeds, higher pressures of steam, and at alarming rates more and more boiler explosions, often killing 100 people at one time. Students learn the formula for boiler wall stress to see how this happened. In the 1820s the federal Congress began debating the issues of government intervention, something not provided for by the Constitution. After many false starts, Congress finally created the first government regulatory agency in 1852, expressly to control the steamboat industry.

But the study of engineering history is more than boiler stresses and fatal statistics, it is also personal stories. American literature found a new voice on the river.

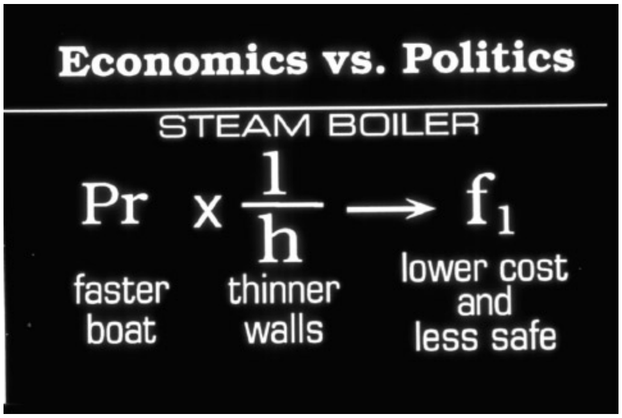
Samuel Clemens, river pilot, lost a brother in one of those explosions and his account of life on the Mississippi includes a searing account of one such disaster. Stresses, statistics, and stories - these are the components of culture and of course, representing science, politics, and art, integrated by the steamboat.

Just as early transportation was sustained by water, so early industry was powered by water. The first large scale American industry was at Lowell, Massachusetts where the Merrimack River drops 33 feet and thus provides power for textiles that by 1831 were building the huge fortunes of the Lowells and the Lawrences.

Probably no family in American history has contributed so directly to technology, education, and art as the Lowells. Francis Cabot Lowell (1775-1817) was one of the most remarkable minds of the early 19th century. Having made a fortune in shipping by the age of 35, he traveled to Britain where between 1810 and 1812 he studied the textile industry and memorized the workings of the mills. Back in Boston just before the War of 1812, he designed with his chief engineer, Paul Moody, the first integrated textile mill at Waltham but died prematurely in 1817. His partners established an expanded textile center at a new town they named after him.

The town of Lowell became the seat of the first great American industry and its wealth was poured into education, in particular to Harvard which the family has supported ever since. But the Lowells were not just philanthropists; they were also direct participants both in art and in education. Three family members were major poets: James Russell Lowell (1819-1891), Amy Lowell (1874-1925), and Robert Lowell (1917-1978). James Russell Lowell and Abbott Lawrence Lowell (1856-1943) were Harvard professors with the latter serving as President of the University from 1909 to 1933.

Behind the textile industry lay a great water power network designed by James B. Francis (1815 - 1892). In building a



Figs. 9 and 10 - Big government began in the mid-nineteenth century when the econonics of faster steamboats (see formula) resulted in many boiler explosions. Congress created the first government regulations to protect the public. This was the beginning of many Federal regulations.

network of canals, Francis created also the first American research and development laboratory in which he laid the foundations for engineering hydraulics, devised the now standard formula for measuring water flow, and perfected a water turbine which today still bears his name. Hoover Dam power, providing roughly 75% of electricity sold in Los Angeles in 1945, comes from Francis turbines.

To separate the stories of education, poetry, and engineering is to present an unrealistic picture of the development of the nation and to deprive liberal education of its central meaning as education based upon information of general cultural concern. When wealth depended upon land or trade but not engineering, culture could more easily be disconnected from commerce; but since the industrial revolution that divide has ceased to exist in practice even as it persists in education.

Even as Tocqueville traveled in America by carriage and boat, a rival vehicle had entered the continent. Imported from Britain like the Watt engine and the textile mill, the railroad started weaving its way through the former colonies in the early 1830s. No other object so dominated American culture during the 19th century. It pushed westward, spurred competition between cities like Baltimore, Philadelphia, and New York, and gave all people a means of rapid travel far faster than on rivers or post roads. The railroad remade the landscape; where its lines went cities sprang up and the biggest railroad town, Chicago, grew rapidly into the nation's second metropolis.

By the end of the Civil War railroads ruled eastern transportation and the greatest of all the lines was the Pennsylvania Railroad, then the world's largest transportation company with over 6,000 miles of track. The man most responsible for this success was J. Edgar Thomson (1808-1874), the engineer who literally built the line through mountainous central Pennsylvania and who from 1852 to 1874 directed it as president. Thomson's ideas about running a business centered upon careful building, reliable operation, and continual maintenance of its technology. Profit was crucial, but most of it was plowed back into maintenance and innovation. He pioneered the use of steel

Fig.11 - Typical Francis turbine rotor in use up to 1990.

Fig. 12 - Textile industries in Lowell, Massachusetts grew based on available water power.

Fig. 13 - J. Edgar Thomson, president of the Pennsylvania Railroad from 1852 to 1874.

rails, air brakes and an accounting system that provided a model for the great industries to follow. Unlike the so-called robber barons, he did not amass a great fortune at the expense of ruined competitors. A summary of his career a century after his death concluded with the statement that "no scandal touched this man."

Thomson began the crossing of the continent. Two other figures played major roles in completing it. The first one, starting without railroads in mind was Samuel Morse, America's first great art entrepreneur. A gifted painter, Morse turned, in the 1830s, from painting to engineering to develop and promote the telegraph whose guiding idea was "intelligence at a distance." Although actually invented in 1831 by America's first great 19th century physicist, Joseph Henry (1799-1878), it was Morse's skill as an entrepreneur that brought it into practical use by 1844 when Ezra Cornell (1807-1874) built a line for Morse between Baltimore and Washington. In the early 1850s railroad engineers recognized in the telegraph a solution to the worst problem of single line railroads: head on collisions. By the Civil War electrical signaling had become widespread, moving out over the great midwestern plains.

Then following the Civil War the railroad swiftly spun lines to the Rockies from the east and over the Sierras from the west, meeting in 1869 at Promontory Point where a golden spike connected the continent. The man who rode east from California to wield the sledgehammer (he missed!) was Leland Stanford (1824-1893), principal owner of the Central Pacific Railroad and later governor of his state.

It is no accident that Cornell and Stanford would take their technologically formed fortunes to found two of our greatest universities, both with powerful engineering schools at their center. But the railroad had consequences other than in education; it changed the artistic vision of the nation. As the leading American scholar of such ideas, Leo Marx has put it: "There is nothing in the visible landscape - no tradition, no standard, no institution - capable of standing up to the forces of which the railroad is a symbol." Marx had in mind both the literary and the painting tradition in 19th and early 20th century America, from writers Emerson and Hawthorne to the painters George Inness and Edward Hopper.

The consequences, driven by locomotives, included politics with the formation of the Interstate Commerce Commission in 1887, and business with the founding of the steel industry after the Civil War. Once again Americans went to Britain for the ideas, and once again the burgeoning republic quickly surpassed the Victorian superpower that had produced Henry Bessemer, inventor of the converter which began the modern steel industry.

Another figure lost to general history, Alexander Lyman Holley (1832-1882), literally brought the Bessemer process to the United States in the 1865 and designed the first major steel mills in this country. Overshadowed by

Fig. 14 - Steam locomotives by Currier and Ives

Fig. 15 - Continent was connected by rail in 1869 at Promontory Point, Utah

the pyrotechnic Andrew Carnegie (1835-1919), Holley designed the Scotsman's first and largest plant near Pittsburgh named the J. Edgar Thomson Works. The name ties Carnegie securely to the Pennsylvania Railroad, where he rose to prominence between 1852 and 1865. When Thomson offered him the general superintendent job in 1865, Carnegie decided rather to go out on his own building bridges and selling American bonds in Europe. By 1872, already a wealthy man, Carnegie entered the steel business dominated by steel rails. When he sold the business to J. P. Morgan in 1901, the great American industries, pioneered by railroads and steel mills, had become the major political issue of the nation.

The Rise of the Great American Industries

When J. P. Morgan formed U.S. Steel by joining Carnegie's vast enterprise to many smaller companies, the trend towards giant, nearly monopolistic, corporations was beginning to revolutionize American business, government, and the lives of all citizens. Along with Carnegie, three other people, fascinating to us still, overshadowed other leaders of technology. Think of Manhattan, the focus of our largest metropolis, still lit by Consolidated Edison, whose center is called Rockefel1er, and where one of the greatest dispenser of private largess continues to be the Ford Foundation. These three institutions combined with the venerable Carnegie Hall, stand for the rapid ascent of engineering-based industries between the Civil War and World War I: electricity, oil, and automobiles along with steel.

The first transportation challenge taken up by the railroads was to get across the Alleghenies, and its success can be judged by the fact that all three of these people - Thomas Edison (1847-1931), John D. Rockefeller (1839-1937), Henry Ford (1863-1947) and Carnegie - came from the other side of that barrier. The middle west had begun to show its own power, beginning with the most heralded telegraph operator of the 1860s, Thomas A. Edison of Ohio. From telegraph to stock tickers, phonographs. and finally to the famous light bulb, Edison created the base for both the electrical industry and the power network. His light bulb was not an isolated invention but from the start was conceived to be part of an integrated system of power generation, distribution lines, and appliances.

Building on the work of Henry and Morse, Edison created an industry led by his company, Edison General Electric. One direct result of Edison's innovation shines out from the series of five paintings by Joseph Stella, New York Interpreted. Two of them called the Great White Way are impossible to imagine without the dazzling lights of Manhattan. Those lights did more than inspire modern painters, they also changed great industries, among them the oil empire of John D. Rockefeller.

Entering the oil refining business in Cleveland in 1865, Rockefeller learned its technology and its markets. In 1870 he formed Standard Oil Company of Ohio and by 1880 his

Fig. 16- Electrical lighting was Edison's plan to compete with gas lights.

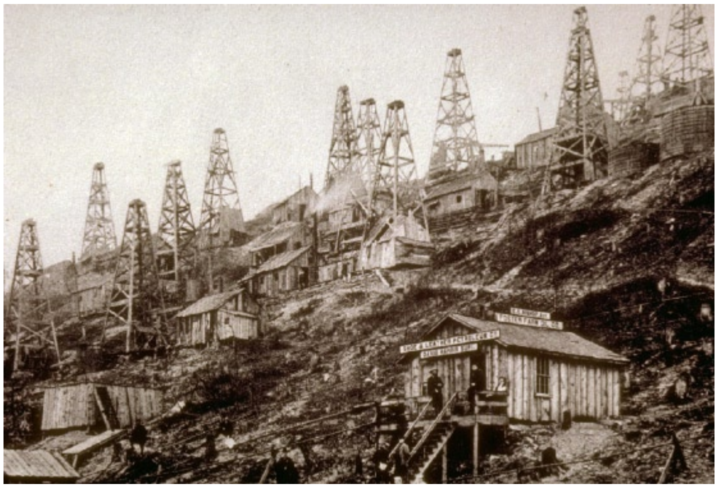


Fig.17 - Oil wells in western Pennsylvania in the 1860s.

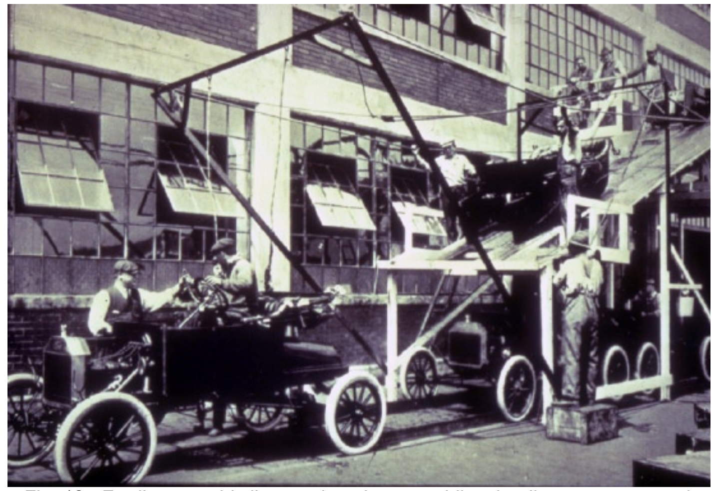


Fig. 18 - Ford's assembly line produced cars rapidly ...leading to more paved roads and longer span bridges.

firm controlled ninety percent of the refining capacity in the United States. By far the largest volume produced was kerosene sold for lighting. As the 19th century drew to a close this lucrative market began to shrink due to Edison's new electrical system. Rockefeller had to shift to a new product and here entered the third character, Henry Ford, with his novel idea of a mass-produced affordable car.

In 1908 when Ford introduced his Model T, Rockefeller opened his new Bayway refinery in New Jersey a few miles from Edison's first labroatory in Menlo Park. Bayway characterized the shift from kerosene to gasoline that fed Ford's insatiable internal combustion machines.

Electric lines went up all over the country just as rail lines had done a half century earlier. Oil pipe lines formed an underground network running from the midwestern oil fields to the east coast and gradually spread south and west to link up with the huge new fields in Oklahoma, Texas, and California discovered in the early 20th century.

Simultaneously Ford's cars demanded another network, paved highways, so that private owners in their own powered vehicles could begin to move rapidly and on their own schedules. The futurist artists in Italy caught the spirit of this movement in paintings depicting speed, while novels like *The Great Gatsby* canonized the automobile, making it the central connecting theme throughout the story.

The government entered this new entrepreneurial world to exercise its role in the public welfare, begun in response to the steamboat and railroad. This time they focused on Rockefeller, and in 1911 the Supreme Court ruled that Standard Oil had to be broken up. At the same time, the federal government realized that it had to do something about public roads. In Acts of 1916 and 1921, the government decisively entered the highway business cooperatively with the states and asphalt paving, using another by product of oil refining, began seriously.

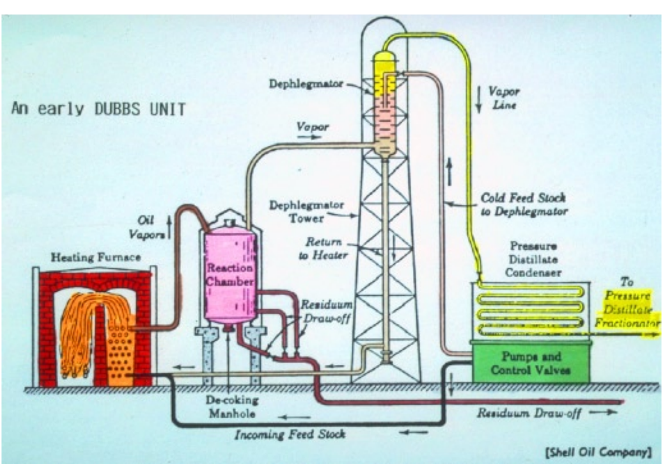


Fig. 19 - Dubb's refinery layout for producing gasoline.

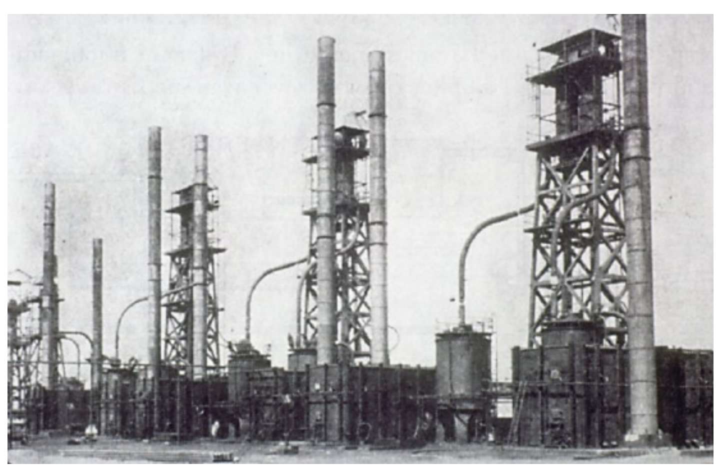


Fig. 20 - Shell Oil company refinery at Wood River, Illinois based on Dubb's design.

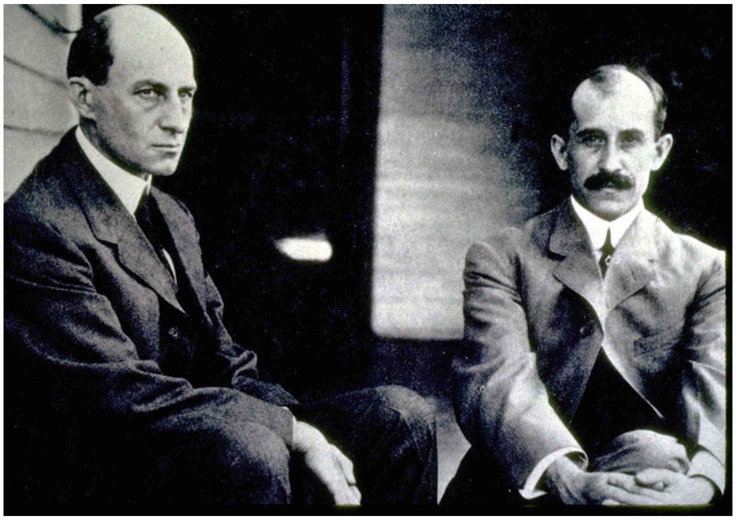


Fig. 21 - Wilbur and Orville Wright

Fig. 22 - Douglas DC-3 at the National Air and Space Museum

The aerospace story begins with two more Ohio engineers, Wilbur Wright (1867-1912) and his brother Orville Wright (1871-1948). Orville was the first to fly a powered airplane in December 1903 and Wilbur gained recorgnition in 1908 by winning a world competiton in France, the same year of the Bayway Refinery and the Model T. But the story, like that of the Hoover Dam, moved west to Santa Monica where in 1933, Donald Douglas designed and built the DC-1 and soon thereafter the DC-3, the first commercially successful streamlined planes. This led to the competition between Douglas and Boeing which in the 1960s produced the jet liner and most prominently the 747.

Regional Restructuring

As private industries grew and public utilities began to spread, a new political problem arose, unanticipated by the founders of the country. Large regions of the nation, integrated by commerce or geography, did not follow state lines. Unlike highways which can reasonably be treated state by state, rivers do not abide by the rules of engineers and their plans for traffic. Three regional issues brought about by new engineering faced the United States in the early 20th century: congested regions, depressed regions, and undeveloped regions. In each case, modern engineering of cars, electricity, and water control forced political leaders to imagine new instruments for policy, planning, and building to restructure parts of the country that transcended state barriers. Three such major examples are the Port of New York Authority of 1921, the Colorado River Compact of 1922 and the Tennessee Valley Authority of 1933. In each case politicians and engineers collaborated on designing and implementing immense long range plans for a radical reordering of the natural environment: the New York metropolitan area, the Colorado Valley and gigantic sections of Arizona and California and the seven state region containing the Tennessee River and its tributaries.

The Port Authority of New York and New Jersey as it is now called began with a commission to solve the railroad congestion problem along the Hudson River by connecting New Jersey rail terminals to Manhattan by bridges and tunnels. Having failed after several years, the agency switched from rails to rubber tired vehicles, anticipating the changes brought on by Ford and General Motors. Symbolic of this change was the authority's acceptance of a new bridge design by an unknown immigrant engineer, Othmar Ammann (1879-1965), whom they hired in 1924 to build the George Washington Bridge, completed in 1931, almost double the span of the previous longest span bridge. Ammann proceeded to design all the major bridges of New York Harbor from then until completion of his Verrazano Bridge in 1964. The Port Authority meanwhile assumed greater responsibilities for the region including the Holland and Lincoln Tunnels, mammoth container piers, and the three main airports for the region.

In part modeled after the Port Authority, the Tennessee Valley Authority focused at first on river navigation, soil erosion, and the control of water by dams. Under the initial direction of Arthur Morgan, a civil engineer, the authority was to raise the economic level of this depressed region and build experiments in town planning. Quickly electric power took precedence over the other goals. After hydroelectric potential was exhausted, the authority turned to coal-fired power plants to satisfy a growing demand for electricity within and beyond the region. David Lilienthal battled Morgan, who opposed these changes in direction

Fig. 23 - Hoover Dam completed in 1936

and in 1938 President Roosevelt fired Morgan; Lilienthal effectively directed the authority after that until 1946 when he left to head the newly-formed Atomic Energy Commission.

The third region was in the far west, where the Colorado River tore through a desolate, spectacular landscape with almost no rainfall. Here in 1922 one of Leland Stanford's first students, appropriately an engineer, Herbert Hoover (1874-1964), negotiated a compact between the seven states in the Colorado basin. Hoover was then Secretary of Commerce and the Federal Agency most concerned with that river is the Bureau of Reclamation, founded in 1902 as part of the Department of the Interior. The principal result of the compact was the Hoover Dam, begun while Hoover was President, and completed in 1936 under a different President and with a different name, Boulder Dam. It was returned to its original name in 1947. The dam had three objectives: to prevent floods in the lower Colorado, to provide water for irrigation and to create electric power. It stands as a characteristic engineering symbol of the agricultural productivity of California, especially Imperial Valley, as well as of the viability of our now second largest metropolis, Los Angeles, a city that has almost no water within its own locale. With the principal figures of Stanford and Hoover along with Frank Crowe, the engineer who built that dam and many others in the region, the story of the country moves to the far west.

Information and Infrastructure

Finally, with these regional projects all well underway, the nation following World War II came into an era of rapidly perfected high technology so called for its electronic speed and unprecedented communications power. Simultaneously all those earlier engineering institutions from textiles, railroads, steel mills to roads, bridges, and systems of water supply and electricity, all of these began to deteriorate with disturbing results. The term innovation became fashionable and the continuing American excitement over new technologies obscured the need to maintain the public works and utilities upon which our society fundamentally depends.

It is not surprising that many of the brightest young students took to electronics, aerospace, and the computer; moreover, their stories are fully as intriguing as those of Edison, Rockefeller and Ford, even if the key individuals are not as well known in the public mind.

Electrical engineering research became a major hallmark of Stanford University because of the need to distribute electricity over exceptionally long lines, since the hydroelectric plants were so far from the centers of population. Growing out of high voltage research, Frederick Terman (1900-1982) had the foresight to create around his university an industrial park, now called Silicon Valley, and to entice two undergraduates William Hewlitt and David

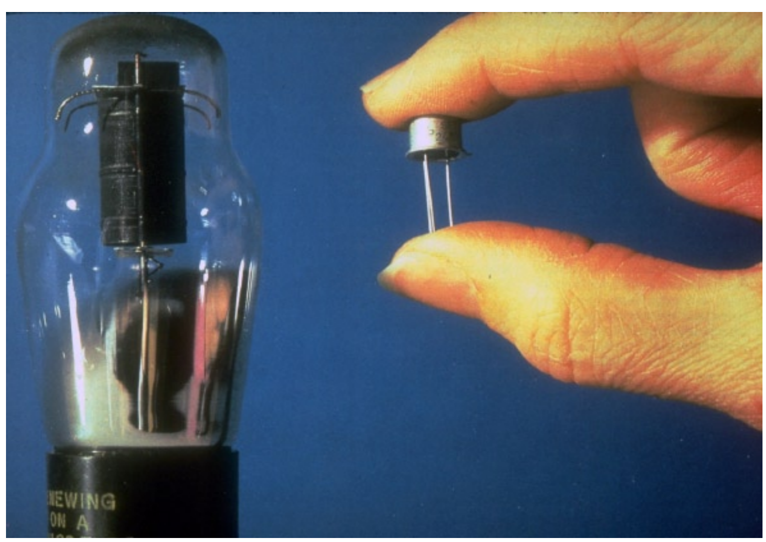
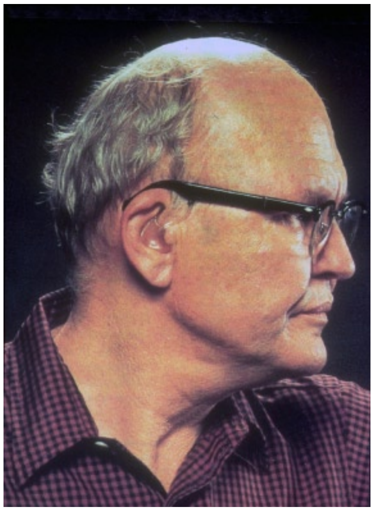


Fig. 24 - The transistor replaced the much larger vacuum tube.



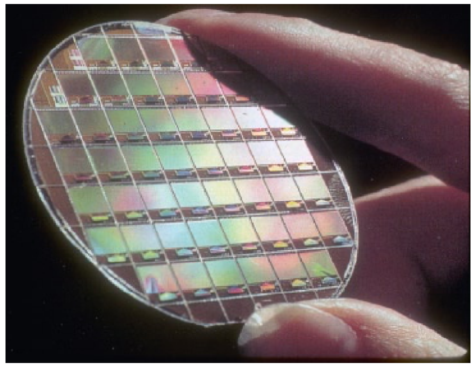


Fig.25 - Jack Kilby and an early disk with over forty silicon chips.

Packard to do advanced work in his lab. Terman helped them set up a new business in 1937.

Meanwhile at DuPont several years later, C. Marcus Olson, a chemist, devised a way to produce pure silicon which engineers at MIT immediately seized upon, as wartime development sped up, for diodes in radar. Then at war's end the director of research at Bell Labs in New Jersey got a group of physicists together and asked them to develop an electronic means for fast telephone switching to replace cumbersome mechanical systems then in use. The result was the Germanium transistor of 1947. At Texas Instruments in Dallas, researchers found by 1954 a way to produce transistors out of pure silicon and the transistor entered hearing aids, radios, and by 1955 computers. There was only one problem. Transistors were tiny and powerful and, in concept, permitted huge numbers to be put into miniature computers; but how to connect them together appeared to be an insuperable problem.

This tyranny of numbers was destroyed in 1958-59 almost simultaneously by two men, Jack St. Clair Kilby (b. 1923) at Texas Instruments and Robert Noyce (1927-1990) at Fairchild Semiconductors in Silicon Valley.

The central idea was to abandon the isolated transistor and to make all components on a single piece of silicon. No connections were needed. The microcomputer followed. Kilby went on to invent the pocket calculator and in 1999 won the Nobel prize in physics. Noyce founded Intel Corporation which by 1993 was the most profitable semiconductor company in the world.

Conclusion

When Noyce founded Intel in 1968 other things were on the front pages of the newspapers: assassinations of national figures and riots in cities. When the fires burned down, the country knew it had problems with its urban infrastructure. In older cities like Newark, N.J. and New York City these problems show up dramatically in bridges, corroded unsafe structures that endanger their users. To the amazement of most people, these public works have not been maintained. Who will come forward to save these artifacts vital to the collective life of an urbanized, industrialized society? It is those trained as engineers combined with all others who will become civic leaders, and the education that both groups need is a liberal education: one which faces contemporary problems but in the perspective of an historical context.

Appendix:

Course Materials

(1) Billington, D.P. , *The Innovators: The Engineering Pioneers Who Made America Modern,* John Wiley and Sons, New York, 1996.

(2) *Instruction Manual for the Innovators,* Department of Civil and Environmental Engineering, Princeton University, Princeton NJ, 1996.

(3) Billington, D.P. and D.P. Billington , Jr , *The Innovators II: Engineers and Entrepreneurs,* manuscipt, Princeton University Press, February 2005.

(4) *Laboratory Procedures,* Department of Civil and Environmental Engineering, Princeton University, Princeton NJ, 2004.

(5) *The Entrepreneurs,* CD -ROM, 1998.

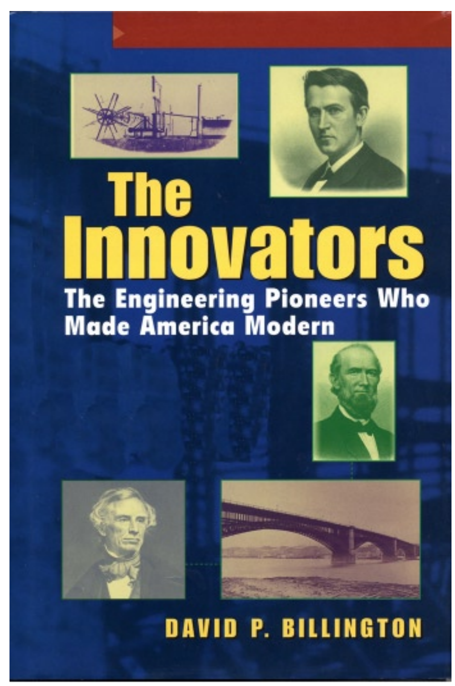


Fig.26 - Book cover of *The Innovators*

Workshop

August 10-13, 2004

Structural Art - Overview

Professor Maria Garlock
Princeton Universtiy
Reported by Shawn Woodruff - Graduate Student, Civil and Environmental Engineering at Princeton University

Professor Garlock first described structural art, the major motivation for CEE 262, "Structurees and the Urban Environment". She defined and described structural art, and included its three dimensions: scientific, social, and symbolic. The measures of these three components, efficiency, economy, and elegance, respectively, were then discussed in terms of minimum materials and cost and maximum personal expression. Garlock then went on to describe the fundamental difference between scientists and engineers. Both follow the laws of nature, but engineers invent forms while scientists invent formulas.

The main ideas behind each of the three dimensions of structural art were then explained. With the scientific component, the idea of a structure's form controlling the forces was presented. Garlock used Heinz Isler's Sicli building and his ice sculptures to demonstrate how his "hanging cloth method" was used to create forms that controlled forces to act in complete compression. She also added how Isler, like many other structural artists, did not rely on mathematical theory to develop his forms, but rather on experimentation and experience.

With the social component, the need for public support and the advantage of design competitions was discussed briefly. Garlock spoke about the Woodrow Wilson Design Competition in the United States, but she also described Swiss design competitions. While describing the Swiss, three different Swiss bridge designers and artists were discussed. Garlock showed how Robert Maillart transformed concrete into forms that were visually stimulating. She also explained his career progression and how his criticism of his own designs led to better and more efficient forms. This is a common trait of structural artists. Garlock also mentioned how telling stories about an engineer's life make the engineers and the material easier to relate to for students. Another Swiss artist (Othmar Ammann) and his famous New York City bridges were then described. The last Swiss engineer presented was Christian Menn, a major bridge engineer still today. The influence of Maillart on Menn was briefly presented along with a short analysis of Menn's Felsenau Bridge.

With the symbolic dimension, Garlock showed several structures (including the Golden Gate Bridge and the Brooklyn Bridge) which inspire national and local pride. Some structures such as the Verrazano Narrows Bridge and the George Washington Bridge have even appeared on stamps. She also spoke of how some structures are featured on currency.

After describing the three components of structural art, Garlock then spoke of the importance of teachers to structural art. Here she focused on Wilhelm Ritter and Pierre Lardy, both teachers at the Swiss Federal Institute of Technology (ETH). Ritter educated future engineers (including Maillart and Ammann) on how to be sensitive to aesthetics. Lardy also emphasized aesthetics in his teaching of two more future prominent engineers, Isler and Menn. Garlock then emphasized how teachers in the U.S. can attempt to act in the same manner to motivate their students. Then she went into more detail about the Princeton CEE 262 course, including content and format.

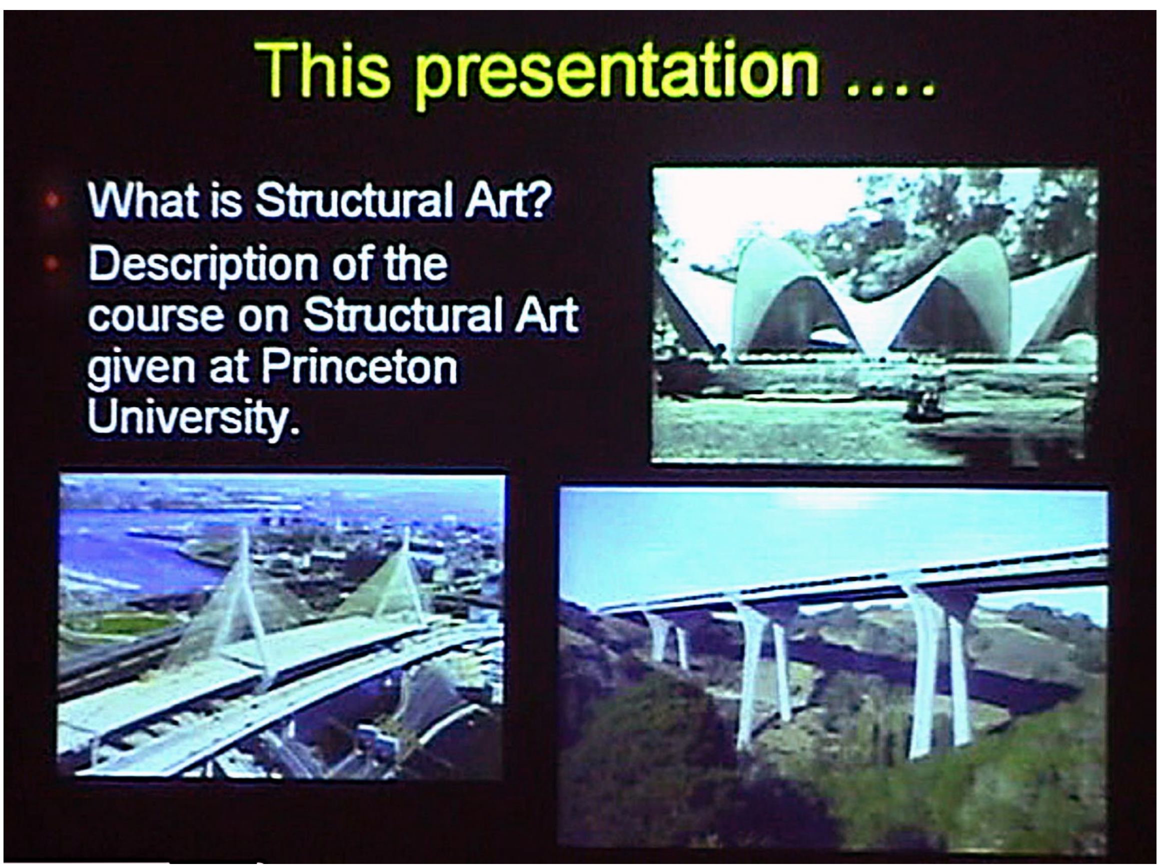
CEE 262 is a history of selected structural artists, and it includes some of the best structural works in the last 200 years. These artists' technical and creative sides are explored and explained. Several different types of forms developed and used by these artists are presented. These forms include the column, cantilever, cable, arch, beam, and truss. Students are supposed to be able to recognize these forms and their differences. Garlock also showed all of the different building materials used by the artists that are presented in the course, ranging from cast iron to prestressed concrete. She explained that one of the fundamental ideas of the course is to be able to view structures as art. "Structural art is parallel to and independent of architecture." Garlock stated that another goal of the course at Princeton is to get students to critically compare two different structures using the three dimensions of structural art. She then presented an example with a comparison of Abraham Darby's Iron Bridge to Thomas Telford's Craigellachie Bridge.

Lastly, Garlock discussed the format of the CEE 262 course at Princeton. The course is offered for both engineers and non-engineers: 200 students enroll in the course, while 150 of those are non-engineers. The same material is presented for both groups; however, the non-engineering students have a lab every other week. Both types of students have precepts; however, the engineers have precept every week, rather than every other week.

Garlock concluded her speech by discussing how an engineer can also be a creative artist. She ended with a quote from Professor Billington explaining the existence and position of the discipline. "As photography is to painting, so is structural art to architecture."

After Garlock's presentation concluded, a brief discussion developed among symposium attendees. Several topics were addressed, and a few major ones emerged. A question regarding how different students respond to the course material was first posed. Many people responded that it is typically more difficult to teach the calculation side of the course to liberal arts students. However, most people also found that liberal arts students are more receptive to the idea of engineering as art than engineering students. Another major discussion point revolved around the time in one's collegiate career a typical student should take CEE 262.

Many graduate students expressed the view that the course would be more beneficial to take later in one's career; students would then have a better understanding of the engineering and the class would have more meaning to them. There were two major arguments against this viewpoint. The first was that this course in a way serves to advertise the profession of engineering, and sometimes liberal arts students switch majors to engineering after taking this course. So, it would be more beneficial for them to take it earlier. Also, other teachers said that they teach the course before introductory statics or dynamics to teach students to be proud of what they do. This will allow their work to have more meaning later.



Structural Art: Visual Analysis

Professor David Billington
Princeton University
Reported by Shawn Woodruff - Graduate Student, Civil and Environmental Engineering at Princeton University

David P. Billington

Professor Billington, giving the second talk of the day, focused on a more detailed look at the humanistic side of engineering. He first began with a comparison of two three-hinged arch bridges, continued with a discussion of Fazlur Khan, and finished with a detailed look into a couple of design competitions. At the very beginning of the talk, Billington emphasized how engineering can be art and how bridges can find their niche in the general culture of society by comparing Maillart's Vessy Bridge to the Leipheim Bridge in Germany.

The Vessy Bridge was designed by Robert Maillart toward the end of his career in 1936. The structure is a three-hinged arch with approach supports in an "X-type" of pattern. Many critics of the bridge call the atypical supports "decorative," however, Maillart's calculations prove otherwise. Billington showed (through Maillart's own calculations) that the shape of the piers is the same as the bending moment diagram of the motion of the deck under temperature. The shape of the piers has a rational basis, and function follows form.

The Leipheim Bridge was designed in 1938 and featured in an article in the German technical journal Die Bautechnik in September of that year. Here the designers claimed that they copied a Maillart type bridge. Maillart responded by showing the difference between his Vessy Bridge and the Leipheim Bridge. Both structures are three-hinged hollow boxes with approximately the same span. However, the cross section of the Leipheim bridge is much heavier (and therefore probably more expensive) than the Vessy bridge. No data has been found on the cost of the Leipheim Bridge. The expression of the middle hinge is non-existent in the Leipheim crossing, where, in contrast, it cannot be missed in the Vessy structure. Also, the type of middle hinge used in the Vessy is much lighter than (and just as effective as) the heavier, expensive middle hinge used for Leipheim. Lastly, the quarter-span depths (the most critical points of live loading) are not expressed in Leipheim where in Maillart's Vessy Bridge and almost all of his other designs they are.

Clearly, the designers of the Leipheim Bridge did not really understand the innovations in Maillart's designs that Maillart had continually improved upon throughout his career.

Billington then went into how another structural artist, Fazlur Khan, continuously improved his designs throughout his career. Billington focused on how Khan approached the common skyscraper problem of opening up a building at its base. Khan's different approaches with his Brunswick, Dewitt, Walker, and Marine Midland Bank Buildings were highlighted in the speech. The Brunswick building solves the problem with an extremely large, heavy horizontal transfer girder. Khan did not like this visually, so he used a combination of a smaller horizontal band and fewer columns with his later design for the Dewitt building. The Marine Midland Bank and the Walker Building visually expressed the force transfer the best of these four designs. The Marine Midland bank has an undulating exterior with a gradual decrease in the number of columns close to the base. When viewed from a distance, one can actually see the forces being funneled into the bottom columns. The Walker building, in contrast, has no exterior undulations. However, it solves the problem by using thicker columns to take most of the load with thinner columns transferring smaller amounts of load. The result is a tree-type effect in which one can visually see where most of the load is being taken.

After discussing Khan, Billington moved into bridge competitions and their effects on the engineering design process. He first discussed Christian Menn's first prestressed concrete cantilever structure, the Felsenau Bridge. Unlike several other designs submitted in the competition, Menn designed for symmetry around the valley, rather than symmetry around the small river in the valley. Billington also spoke of another competition Menn won for the San Pellegrino Viaduct.

Most of Billington's discussion, however, rested on a Maryland bridge design competition with which he was directly involved. In the U.S., bridge competitions are rare, so many of the best engineering firms in the country were not used to the procedure. Still several firms (with the help of architects) submitted designs. Although most of the designs were inappropriate for the crossing, a winning design was adapted and a satisfactory result was obtained. Billington said the result was not a dramatic bridge, but a much better bridge than the state of Maryland would have gotten without a formal competition.

Professor Billington concluded his talk by showing how there are always multiple, equally good solutions for a given problem. He then emphasized the importance of academics being close to the profession and being aware of what is being done in the field. Even if one is not a practitioner, one should still be able to teach what practitioner's are doing. He concluded with the following quote: "You don't have to be a great poet to teach poetry."

Several questions again emerged from the symposium attendees after Billington's talk.

One interesting question was posed. It asked why expression of form is a requirement of structural art. Billington responded by talking about the difference in works of architecture and works of engineering. He used Frank Lloyd Wright's Falling Water as an example. Falling Water is not a good structure, but it is good architecture. Billington said that one needs to start with the discipline, and then go into the critique. Expression of form implies minimal materials and minimum cost in engineering. Billington then went on to describe the elegance component of structural art. "Beauty is in the eye of the beholder" is the wrong idea, as it is possible to refine one's taste. The goal of the course is to explain what types of problems occur in this art form and how artists face and overcome them. Billington ended his response by stating that the art world (people trained in aesthetics) saw Maillart's works as art, even though not many engineers saw them that way. Maillart was greatly influenced by his teacher at the Federal Institute in Zurich (Fig. 1)

Fig. 1 - Professor Billington discusses Robert Maillart in slide at left and his principal teacher Wilhelm Ritter in slide on the right.

Rivers and the Regional Environment

Professor James Smith

Princeton University

Reported by Sinéad C. Mac Namara - Graduate Student, Civil and Environmental Engineering at Princeton University

CEE 263 "Rivers and the Regional Environment" attracts students from both CEE and the liberal arts. It fulfills a math requirement for liberal arts students and for the departmental majors it serves to unite both the structures and water resources/environmental programs.

In the course we talk about the river basins in the U.S. and their redevelopment. The course looks at the scientific element, the ecological questions and the political and social aspects of river basin restructuring. The historical perspective that drives the course is that of the era of big dam building. Thus we look mostly at the 20th century with a glance at the heritage of the 18th and 19th centuries. Dams both affect and are affected by their environment. The purposes of a dam, flood control, power production, navigation etc. are very much a function of environment.

James Smith

We begin with the Johnstown, Pennsylvania Flood of 1889, which claimed over 3000 lives after the failure of the Southfork Dam. The students in the course look at how dams work and in this way see how the dam failed. The Southfork Dam had all the features of the dams we see throughout the course, a spillway, an embankment to impound the water etc. The river basin, on the order of only 100's of square miles, also played a role in the failure, as did the rainfall, deforestation, the design of the dam and its maintenance. In the final analysis you cannot point to once reason for the failure. One of the important things about this example is that there is a lot of data available, the students can calculate spillway capacity, rainfall, and discharge patterns.

The Miami Conservancy, a political construct formed to protect Hamilton and Dayton, Ohio from flooding (stimulated by the flood of 1913) becomes the model for the development of river basins all over the U.S. especially in the U.S. Army Corps of Engineers and the TVA. Arthur Morgan head of the Miami Conservancy goes on to become the first chairman of the TVA. A remarkable engineer, he developed many techniques of flood control design still used today. He placed huge importance on the collection of as much data about the river basin and weather as possible, and the use of such data to frame the problem in a risk assessment context. To design flood control structures it was important first to know what the 1913 flood represented (the 100 year flood, the 1000 year flood, the 10,000 year flood?) and then to decide what level of protection you want to provide.

In the Miami Conservancy an issue of equity emerges when dams are built (and land is flooded) in agricultural areas to provide urban flood control. Uses of dams for power production, flood control and navigation can also conflict with each other. In the Missouri River Basin we look at construction on a grand scale when we look at Fort Peck Dam. The dam was featured on the front cover of the first issue of Life magazine (in photographs by Margaret Bourke White) such was its importance to the development of the U.S. during the depression.

The impact of dam building on the environment can be seen when the sediment load in the lower Mississippi River is compared from 1700 to the present day. The many dams on the Missouri have all but shut off the sediment transport from that branch, while in the Ohio Basin deforestation has increased erosion and increased sediment flow from that branch. The overall sediment flow is greatly reduced and this has a huge impact on the environment.

Hoover Dam is an icon for technological development in the U.S. as well as being an important structure for power, water supply, irrigation, and flood control. It has the same basic components that we saw at the Southfork and Fort Peck Dams. The students do calculations to see how conservative the design was and we ask why it was designed this way. Another important dam on the

Colorado is Glen Canyon Dam. With this dam we look at the push to remove dams, a controversial subject with which it is easy to engage the students. A broader issue in the course is the question of what to do with dams that have reached the end of their life cycle, how and if these dams should be decommissioned.

Another broader theme in the course is that of how to treat the scarce commodity of water in the west. John Wesley Powell, a key figure in the early part of our story, the first European-American to navigate the length of the Colorado and later a director of the U.S. Geological Survey, had strong views on the subject. He believed that it should the exploited as fully as possible for the benefit of mankind. This idea of the scientific management of resources drove much of the research into how rivers worked.

The Columbia River Basin has been dramatically restructured, principally for hydropower production. The Columbia has huge flow and a large drop in elevation, making it perfect for hydropower production. An interesting geological feature in this region is Dry Falls. The falls are three times as high as Niagara Falls and five times as wide. An assertion made by J. Harlon Bretts early in the 20th century that these falls were formed by a great flood led to him being blackballed from the scientific community as his theory fit (too) neatly with religious claims that geological features were the work of God. The irony of the story is that he was right, 15,000 years ago an ice dam failed spectacularly and the Columbia Basin was dramatically reshaped by the Missoula Floods.

The Potomac River Basin is the final stop on our tour of US river basins. Largely unregulated, the Potomac has only one big dam and provides Distrrict of Columbia with all its water supply. Thus, its huge variations in flow were naturally a problem. The Jennings-Randolph Dam, the last of the major federal dams, was built in the 1980s to address this problem. The dam, built to minimize environmental impacts, was quite successful, a positive note at the end of our story.

Engineering in American History

Professor Donald Jackson

Lafayette College

Reported by Sinéad C. Mac Namara - Graduate Student, Civil and Environmental Engineering at Princeton University

Donald Jackson

[Introduction by David P. Billington] Donald Jackson is a Professor of History at Lafayette College and has been the principal consultant for a new course here at Princeton, CEE 263 Rivers and the Regional Environment. DC is a Civil Engineering Graduate of Swarthmore; he received his PhD in the History of Technology from University of Pennsylvania after working for some years for the Federal Government. Prof. Jackson teaches mostly history students with no engineering experience. His classes focus less on the mathematics and more on the influences on the systems and technologies that we have today, and on what they look like and how they work.

The law can have a huge impact on the structure of many things. Water laws are mostly state laws, but rivers do not respect state boundaries. There is no one formula for how the courts resolve the inevitable disputes that arise. Another, more recent, influence on the engineering of rivers is the Fish vs. Power debate. The fish have always been there but only quite recently do we see fish used as an argument for dam removal, it's very much a question of what we as a society value. In a similar vein we see conflict between public and private interests in the use of rivers, the inevitable calls for government regulation in the wake of something like the Johnstown Dam collapse in conflict with the push against "big government" and the desire for a free market. By far the biggest influence on the big dam era is that of electricity. While mechanical hydropower had been hugely important for the textile and other industries in the late 19th century it was geographically limited. With the coming of electrical hydropower the potential to develop remote power sites was huge.

In the 1880's the development of electricity for light rather than power was at the fore. Edison conceived of his universal light system as a business idea in competition with gas light. Edison was driven by very real economical factors to develop the high resistance light bulb. And, it is no coincidence that the first system was used to light Wall Street. Edison went on to successfully sell franchises all over the country, trading his patents and knowledge for half the stock or equity, while the funds came from local investors. The direct current system was limited because of power losses at a distance, alternating current was around as an option very early, but Edison was bitterly opposed to it.

Niagara Falls is often thought of as the forerunner of the AC power generation that came to dominate in the 1890s, but California was actually the leader in this area. The first AC three-phase generation was online there in 1893 transmitting three miles, and by 1901 (when Niagara Falls began transmission to Buffalo 28 miles away) San Francisco was receiving power from 200 miles away.

Regional development was initially very much a private movement, but with the emergence of the anti-trust movement in the 1890s there was a growing sense that the government would be involved as a regulator especially where power generation on public land (as much of the west still was) was concerned. In 1902 when the Bureau of Reclamation was formed, it was intended to build dams for irrigation purposes only; it was not immediately obvious that the Federal Government would become involved in hydropower, especially considering that, despite the overriding Federal interest and the interstate commerce clause ensuring federal jurisdiction over navigable rivers, water law was mostly a state issue. It was not until the 1920s that interest in large inter-regional systems prompted the Federal government to become directly involved in hydropower production.

Construction of a large hydropower dam at Muscle Shoals, Alabama, built to provide power for nitrogen fixing for the explosives industry, was begun by the government for World War I but not actually completed until after the war. Initially there was no consensus as to what to do with Wilson Dam, it later became the core of the Tennessee Valley Authority. The second major Federal involvement in hydropower production was Hoover Dam.

The Imperial Valley in Southern California, a desert and an old channel of the Colorado River, became an incredibly fertile farming area when irrigated by a small private canal diverting water from the Colorado. A 1906 flood caused the Colorado to change course into its old channel, inundating the Imperial Valley and creating the Salton Sea, leading to calls for flood control on the Colorado River. Growing Los Angeles was anxious for more water supply and hydropower could be used to pump water over the mountains from the Colorado. Southern California Edison and other private power interests were vehemently opposed to public power.

In the Depression era, dams become symbols of progress, of employment, of rising up. Hoover, though planned earlier, became a symbol of FDR and the New Deal Big Dams era. It's never really questioned again that the Fed has a role to play. During World War II many of the big hydropower projects were coming online just as they were needed, in the Pacific Northwest for the aluminum industry and in the Tennessee Valley at Oak Ridge for the separation of uranium, and once that happened no one ever looked back. The model was in place and it became a matter of filling in the stair steps with more dams along these rivers until we got to the point where Lewiston, Idaho was a port.

By the 1960s the big dam era was almost over, most of the good sites had been developed and environmental objections were emerging. Today, two factors are fuelling the calls for dam removal. With increasing numbers of dams and longer stretches of slack water, fish find it harder and harder to swim upstream to spawn and go back out to sea again. In addition, hydropower is no longer the significant portion of total power that it was (Glen Canyon Dam for example produces 1/700th of the power of a large steam plant).

Fig. 1 - Most of the power generated at Hoover Dam goes to southern California

Engineering and Natural Science

Professor Michael Littman
Princeton University
Reported by Kristi Miro - Graduate Student, Civil and Environmental Engineering

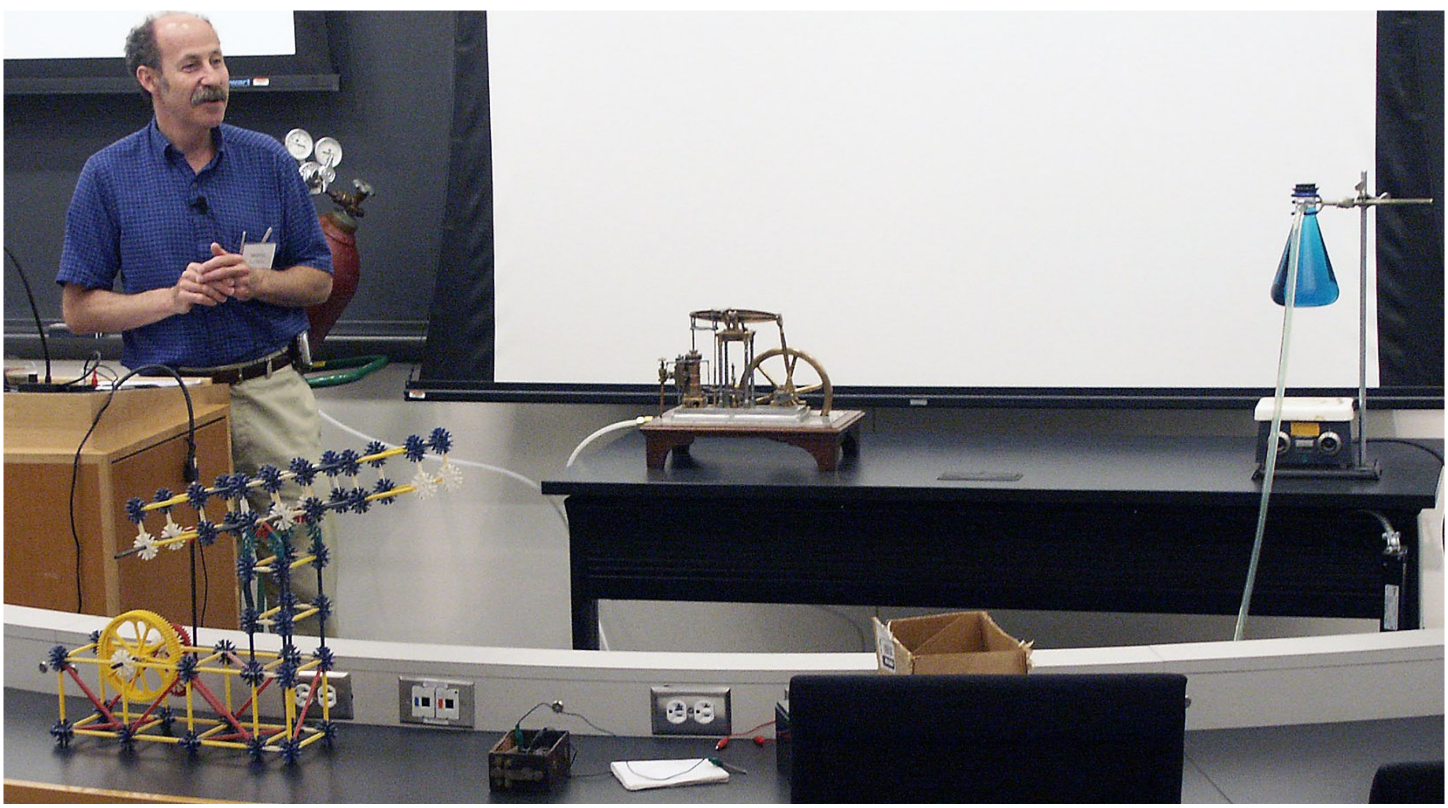
In his lecture for the theme of Engineering and Natural Science, Professor Michael G. Littman began by presenting the three theories of innovation discussed in the CEE 102 course. These theories are engineering as a response to applied science, engineering as a result of social progress, and engineering as a product of individual genius. In keeping with the theme of the day, Littman focused his lecture on the idea of engineering as a response to applied science and showed that although engineering follows scientific theory in some cases, in others the opposite is true.

He began with the idea of transformations through the use of the steam engine. In the scientific aspect, the transformation was from heat to work. In the social aspect, the transformation was from animal to machine. In the symbolic aspect, the transformation was from a reciprocating engine to a rotary engine. The next image on the screen was a painting of a steam winding engine which extracts coal from mines. Along side the engine were horses and mules. This image of animals and machines symbolizes the social transformation brought on by the steam engine.

Littman then discussed the idea of "lifting water by fire", the principles of the steam engine. First a boiler transformed heat to steam, then a condenser transformed the steam into a vacuum, and finally a motor transformed the vacuum to work. The next image showed three different engines in order to highlight the progression of the steam engine. The first engine, designed by Papin in the late 1600's, had the boiler, condenser and motor all together. The next engine, the Newcomen engine of 1712, had a separate boiler. The final engine, the Watt engine, patented in 1775, had a separate boiler and a separate condenser. The separate condenser made the engine more efficient because there was no energy wasted on cooling the cylinder.

Littman then moved on to a demonstration where he had a flask filled with steam. A side spout in the flask

Fig. 1 - Michael G. Littman with demonstration models



connected to a tube which then connected to a beaker of colored water. As the steam in the flask cooled, the pressure in the flask dropped and the water began to climb the tube by vacuum. The water continued to climb and eventually filled the flask to the top. This demonstration showed that condensing steam creates a vacuum which can then do work. The idea of using a vacuum to do work is summarized in a formula, known in CEE 102 as the "PLAN" formula. It states that in an engine cylinder the amount of work (in horsepower) is directly equal to the product of the pressure, P; the stroke length of the piston, L; the cross sectional area of the piston head, A; and the frequency of strokes, N; all divided by the Watt factor of 33,000.

Littman then moved on to give a short background on James Watt, inventor, who patented his separate condenser in 1769; and Matthew Boulton, investor and entrepreneur, who became partner with Watt in 1774 and convinced him to obtain a 25 year patent extension on his separate condenser. Boulton also set up the first research and development lab in which Watt could work on his inventions.

Next Littman explained that Boulton convinced Watt to work on a mechanism for converting reciprocating motion into rotary motion because of the large market for rotary engines. In his second demonstration, Littman showed with a K'nex model how a set of interlocking gears can convert reciprocating motion to rotary motion.

Littman then described efficiency and economy of machines compared to the efficiency and economy of structures, another aspect of the CEE 102 course. With Thomas Telford, an early structural engineer, efficiency meant the use of minimal materials and economy meant low construction costs. With James Watt and the steam engine, efficiency meant the minimal use of fuel, and economy meant low operational costs.

Arriving at what he called the "punch line", Littman explained how the French scientist Navier studied the bridges of Thomas Telford and from that study developed the science of structural mechanics. Similarly, Littman noted that the French physicist Carnot studied Watt's steam engine in Britain and developed the science of thermodynamics. These two cases do not show engineering as applied science but rather science stimulated by engineering works.

In conclusion to the lecture, an opposite case presented by Littman was that of Marconi and the radio. Maxwell discovered the science of electromagnetic theory and out of this formalism came Marconi's engineering application. Although Hertz was the first to verify the existence of electromagnetic waves in 1887, it was Marconi who secured a patent for the wireless in 1897 and sent the first transatlantic signals in 1901. This case is a clear example of engineering applying science.

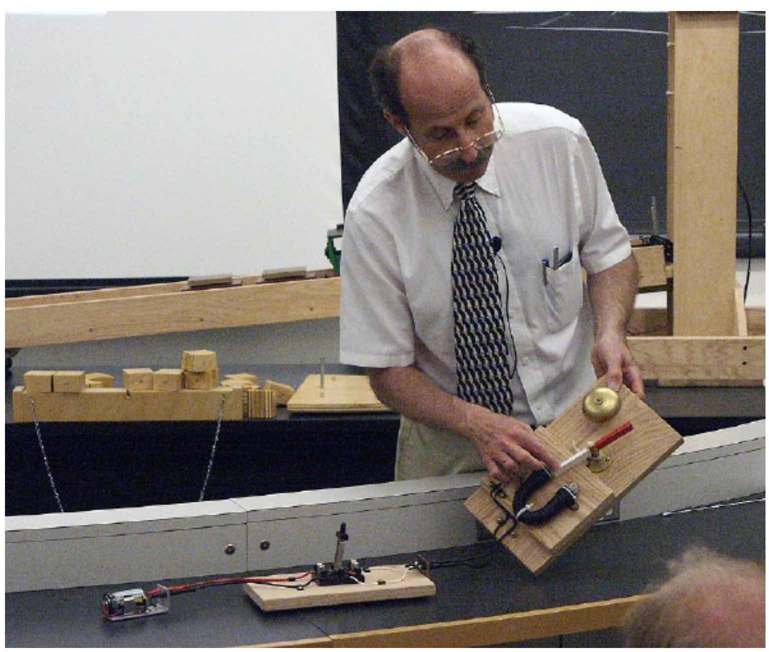


Fig. 2 - Demonstration of telegraph key

Innovation, Design and Applied Science

Professor David BillingtonAs AC power generation comes to dominate in the 1890s,
Princeton University
Reported by Kristi Miro - Graduate Student, Civil and Environmental Engineering

In continuing the day's theme of engineering and natural science, Professor David Billington began his lecture with an image of the 1876 Corliss Engine, the centerpiece of that year's World's Fair. The next image was of the 1876 Otto engine. The Corliss engine, running on steam, represented the past while the Otto engine, running on oil, represented the future.

The oil story began in 1859 when Edwin Drake first discovered oil in western Pennsylvania. The abundance of oil there attracted many prospectors, and chaos ensued. John D. Rockefeller saw this chaos and had a vision of organizing it. The components of the oil business are prospecting for resources at the oil wells, transporting oil via pipelines, and transforming oil to gasoline in refineries. Until Rockefeller entered the industry, all three components were run separately. Rockefeller's Standard Oil Company was the first to unify the industry, controlling all three aspects, and opening his first oil refinery in Cleveland, Ohio.

The story then moves on to William Burton, (Fig. 1) an engineer who received one of the first PhD's given in chemistry in the U.S., from Johns Hopkins. University. Burton began with Standard Oil and eventually became lead engineer and president of Standard Oil of Indiana. Billington then briefly explained how distilling (basically boiling) crude oil yields gasoline, kerosene, fuel oil, and asphalt. After 1865 kerosene replaced whale oil for use in lighting, while gasoline was considered a waste product. By 1882, electricity began to replace the need for kerosene as an illuminant, but in 1908, Ford introduced the Model T and suddenly gasoline was in demand.

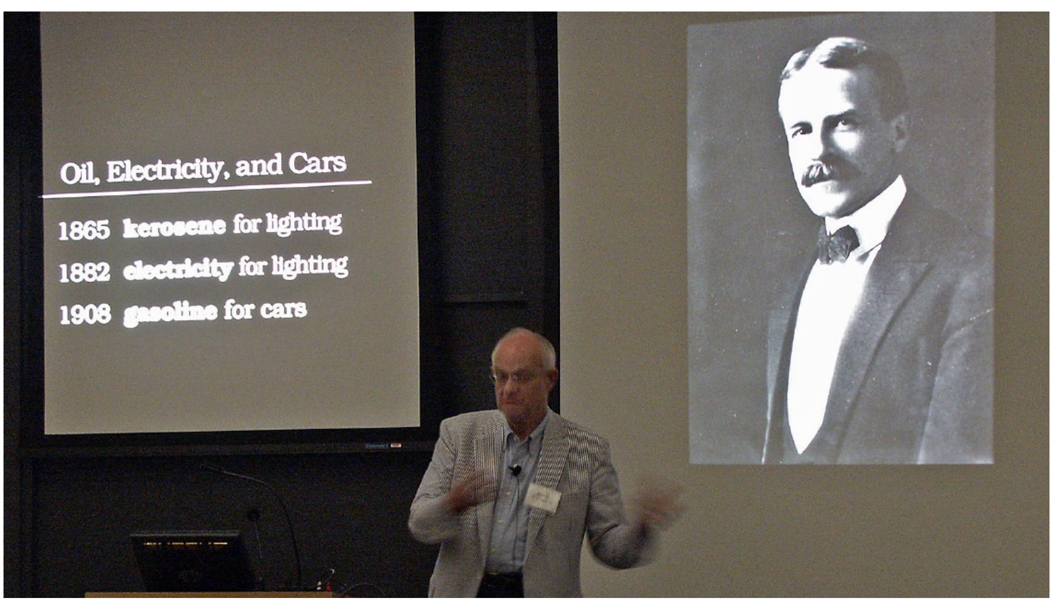


Fig. 1 - Slide on right shows William Burton

Burton saw the growing need for gasoline, and to meet this demand refiners had to obtain more gasoline per barrel of crude oil. Burton argued to the heads of Standard Oil that if he introduced high pressure as well as heat in the distillation process, crude oil would yield more gasoline. The heads of Standard Oil, all too familiar with the boiler explosions on steamboats, rejected Burton's idea of pressurization. Here was a clear example of a company which was successful, but which was not looking to the future, and not listening to the advice of the engineer.

Next Billington demonstrated how politics played a role in engineering, a major theme in CEE 102. The Sherman Anti-Trust Act of 1890 led to the 1911 dissolution of Standard Oil. With Standard Oil now broken into several companies, competition grew. Burton, in the Indiana region finally was able to use his high pressure method of cracking to produce more gasoline per barrel of crude oil in order to meet the demand for gasoline that followed the Model T.

Here Billington showed the integration of industries. The oil industry depends on the automobile industry which depends on roadways and bridges. In the CEE 102 course, the different industries are separated because each has a different specific idea behind it, but the way they interact is stressed as well.

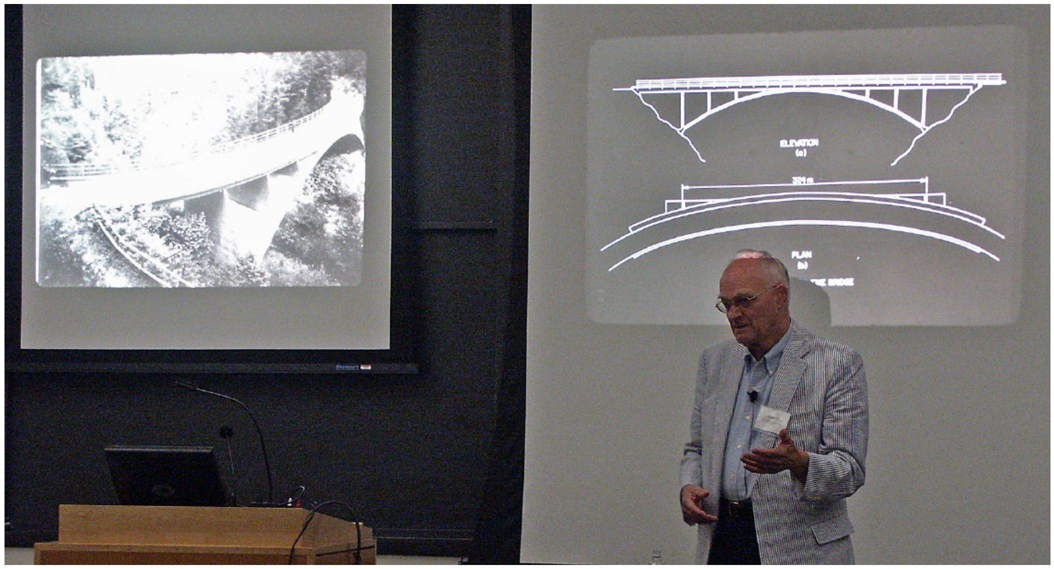


Fig. 2 - Photo of Schwandbach at left, profile and plan at right

Next Billington turned from private industry to public works with an image of the 1912 Aarburg bridge designed by the structural artist Robert Maillart.

An arch is exceptionally stiff when under a uniformly distributed load, but when it is asymmetrically loaded, the loaded side deflects downward and the other side deflects upward. The deck girders of the Aarburg bridge sustained substantial cracks because the deck was deflecting with the arch under these side loads. The girders were not reinforced for that type of deflection because Maillart assumed the live load would be taken by the arch via the supporting columns. Seeing these cracks, Maillart knew he had made a mistake.

This realization led Maillart to the idea of the deck-stiffened arch. Billington then showed an image of Maillart's notes from one the lectures of his professor, Wilhelm Ritter, who taught that one can design a very thin arch as long as the deck reinforces it. Maillart realized he could use a thin arch and stiffen it with a parapet which, until then, had never served a structural purpose.

The first deck-stiffened concrete arch, the Flienglibach was designed by Maillart in 1923. To make calculations for this bridge, Maillart employed the graphic statics used by Ritter to understand bridge design in a direct way instead of using the algebraic methods more commonly in use. This approach soon led Maillart to develop even simpler calcuations of his own, still guided by Ritter's teaching. So, in the design of his next deck-stiffened arch, the Valtschielbach Bridge, all calculations for a side load on the arch were done in less than half a page. Maillart did this, Billington explained, because he clearly understood that when a stiff deck and a thin arch bend together, nearly all of the bending goes to the stiffest point.

Maillart used minimal calculations because he wanted to concentrate on aesthetics. His Valtschielbach bridge was a technical masterpiece, not an aesthetic one. The approaches are Romanesque and there are kinks between the roads and the connecting bridge. In his Schwandbach bridge, Fig. 2, he improved upon the Valtschielbach form. Instead of purely decorative Romanesque approaches, Maillart integrated the approaches with the span, making use of them structurally. He also used a polygonal arch as opposed to a smoothly curved arch because loads are transferred to the arch via columns that connect at discrete points. The arch was also wider at the base than at the crown, so it was stiffer and more visually interesting. Finally, the span was now horizontally curved, removing the unsightly kinks between the roadway and the bridge. Billington pointed out how Maillart solved structural problems while also obtaining an aesthetic new form.

Billington highlighted the idea that good engineering comes not only from what is learned from a teacher, but also by what is seen in the field. As Maillart demonstrated, the field is a civil engineering laboratory, where engineers can view structures and find ways to improve them.

Assessment as a Tool for Learning: Aligning Teaching Goals and Student Learning

Linda Hodges

Director, McGraw Center for Teaching and Learning, Princeton University

As you from Schools other than Princeton plan to implement and improve your teaching of new courses, assessment can be an asset for you in at least two ways: both in thinking through what you really want students to get from this experience and how you'll know if they have, and in providing documentation for the effectiveness of the course to your institutional administrators and potential funding agencies.

Linda Hodges

Although sometimes we may think of assessment as a four-letter word, it's really a tool for us to use to move beyond anecdotal impressions to meaningful information about what works and what doesn't in our courses and our teaching. Specifically, practical roles of assessment include:

- Finding out what your students know
- Helping your students learn
- Researching teaching outcomes
- Documenting course effectiveness

Educational assessment can be challenging. Although collecting this kind of information is akin to collecting scientific data, the field of learning doesn't always lend itself to study in the same way. We can't control variables as we may be able to in scientific and engineering studies, and our classrooms tend to be rather messy arenas for collecting data. Thus, gathering information in a number of different ways and from a number of different perspectives, a process called "triangulation," is important for coming to significant conclusions. In assessing these courses, there are at least three kinds of outcomes that are worth examining: student perceptions, student performance, and student learning.

In assessing perceptions we ask questions related to how students rate their own learning in these courses. Although our standard course evaluations may be used in this regard, one must look carefully at them because many of these instruments ask questions related more to faculty performance or how students liked the course and are less focused on actual learning issues. Or faculty may construct their own student evaluation of learning using a convenient on-line tool called the Student Assessment of Learning Gains (SALG) found at http://www.wcer.wisc.edu/salgains/instructor/. Assessment of student performance may include keeping track of how well students do in these courses, but perhaps more illuminating is asking what students benefit most from these courses in terms of achievement and persistence to degree. And finally, a key area of assessment is finding out what student learning outcomes are promoted by these courses. Often we may approach the idea of learning outcomes as finding out what students know in the content area. Another way to think about student learning that offers us a fresh perspective is to ask: upon completion of this class, what do you want your students to be able to **do**? How will you determine whether your students have met these goals? And, how will you help students to reach these goals?

Begin with the end in mind: upon completion of this class, what do you want your students to be able to do? Some ideas offered by participants included: define engineering, represent concepts graphically, solve numerical problems related to course content, recognize or appreciate structural art. Once you as instructor have clearly articulated what your goals for your students are in the course, then the questions become: how do you know if your students have attained these goals, and how do you facilitate your students' attainment of these goals? Lectures, discussions, writing assignments, group projects, all play a role in helping students develop these abilities or sensibilities. Certain assignments may be designed in such a way that they allow students opportunities to practice (and perhaps to fail) without dire penalties. Providing feedback and additional opportunities for students to try again are key steps to students' developing the abilities and long-term habits of mind that you want them to have. Likewise some of these assignments may be designed by you as a way to evaluate at the end how successful your and your students' efforts have been in achieving these aims.

As participants pointed out, a key element to remember is that developing these student abilities and sensibilities takes practice and may take more time than is available in your one-semester course with them. Which of your goals are ones that you especially want students to achieve during the timeframe of the course? What are ones that may develop more incrementally and that you assess through alumni surveys perhaps? How do these goals manifest differently if your course is one for the general student population? For introductory engineering students? For more senior engineering majors?

Finally, as you think through your goals for your students in these courses, it may help you to keep in mind what cognitive science is now saying are the critical factors that affect student learning:

- Prior knowledge
- Practice at retrieval
- Varied learning conditions
- Re-representation of information
- Interpretative work

Integrating these ideas in class may mean: designing assignments that help uncover and exploit students' prior knowledge and experience, varying the learning conditions between lecture, group work, and discussions, giving students practice at retrieval of key ideas, re-representing work in verbal, written, and graphical forms, and interpreting for themselves ideas that they hear in class. These strategies are all ways that can help you as you endeavor to implement or improve your teaching of these established courses.

Bridges and Culture in Modern Japan

Professor David P. Billington

Princeton University

Reported by Powell Draper - Graduate student, Civil and Environmental Engineering. Princeton University

Background: In the summer of 1989, Professor Billington was invited by the bridge establishment in Japan to look at their big bridges and present a critical report on their aesthetics. Professor Billington also wished to develop a lecture for the CEE 262 course from the experience. Professor Billington asked a colleague, Princeton University's expert in Japanese history, Professor Marius Jansen, to review and comment on the course once it was developed.

Japan had built, or was building, three bridges to connect the islands of Honshu, the main island, and Shikoku. The trip began in Tokyo and progressed south and led to the theme of the lecture: "Democratic and Entrepreneurial Island Cultures Produce Record Bridge Spans." Specifically, these cultures were Great Britain, the United States (in particular, New York City), and Japan. Great Britain built the big bridges of the nineteenth century. In the United States, the island culture is represented by New York City, a collection of islands. Beginning with the Brooklyn Bridge and leading up to the Verrazano-Narrows Bridge, the U.S. led in long-span bridge design. The connection then extends to Japan, the most modern of the stories.

We begin by looking at long span bridges in Japan from our typical perspectives: the scientific, social, and symbolic:

Scientific: Technical challenges of the world's longest spans.

Social: Industrial strengths of modern Japan.

Symbolic: Modern forms designed to reflect traditional Japanese icons.

The trip began in Tokyo, at the Meiji Shrine, a nineteenth century physical manifestation of the opening up of Japan and the beginning of their modernization. The exterior of the Olympic swimming pool stadium resembles the shrine and shows the Japanese attempt to relate modern forms to the past. Inside the stadium, the power of the modern Japanese steel industry could be seen in the cables.

To get a sense of scale, we can compare the region encompassed by Tokyo, Kyoto, and Osaka to a superimposed map of the state of Pennsylvania. The distance between Tokyo and Osaka is roughly the same as the distance between Philadelphia and Pittsburgh, although traversed a bit quicker due to the high-speed trains.

Fig. 1 - Konohana Bridge - Osaka, Japan - 1990. Monocable suspension span - self anchored cables - box deck.

Fig. 2 - Kita Bisan-seto/ Minami Bisan-seto 1987. Double suspension spans 990 m and 1100 m.

Japanese Bridges

I. Harbor Highways: Osaka-Kobe, Tokyo-Yokohama

II. Island Connectors: Honshu-Shikoku

III. Wilderness Works: Kyushu, Kuma River

High population density along the coast of Japan, due in part to the mountainous inland terrain, has resulted in the building of artificial islands. These in turn must be connected by roadways, or harbor highways. As seen in other parts of the course (e.g., Eiffel and Maillart), a great deal of interesting work occurs in the wilderness, where the high-art world cannot put a damper on structural art.

The first bridge encountered was a cable-stayed bridge. Of interest are the towers. The deck is quite slender. The towers have a kind of truss work below the deck, which is unnecessary and the intent of which was unclear. The way to approach the critique is to contrast it with other bridges:

Delta Tower, Cable-Stayed Bridges

East Huntington, Ohio River, 1985
Straight top
Solid pylon below deck
Tempozan, Osaka, 1989
Cable-less top
Truss pylon below deck

The solid pier below the deck of the East Huntington Bridge is also unnecessary. It had apparently already been built as a part of a required material comparison with steel.

The next bridge, the Konohana (Fig. 1), was completely different, a single- or monocable suspension bridge, which is very unusual. This demonstrates that the Japanese were clearly exploring forms, a commendable idea. The bridge is also a self-anchored suspension bridge. This bridge form has been built in a series of bridges in Pittsburgh. It is a sound technical idea, but difficult to construct.

Konohana Bridge, Osaka (1990)
Monocable suspension bridge
Self-anchored cables
Box deck

Rounding the harbor, one then approached the Minato Bridge, a cantilever bridge. It is one of the three longest-spanning cantilever bridges in the world:

Cantilever Bridges

1890—Firth of Forth—Scotland
1710 foot spans (two)

1917—Quebec Bridge—Canada
1800 foot span

1974—Minato Bridge—Japan
1671 foot span

The Minato Bridge looked different from the other two. The Minato does not have peaks at the supports. The Japanese explained that they used very high strength steel in these regions, allowing them to employ a lower cantilever edge. The Quebec Bridge lacks the grace of the Firth of Forth, and also had many well known difficulties during construction. The Minato Bridge does not express that it is a cantilever bridge.

Another problem the Japanese faced with their dearth of land is the lack of room for long approaches to high bridges. One solution is a circular approach. An example of their clever land use is a baseball diamond beneath one of these bridge approaches.

For the island of Shikoku, a sense of scale is provided by a comparison with the similarly sized New Jersey. The Japanese were going to connect this island with three major crossings.

Record-Setting Island Connectors:

Honshu-Shikoku Bridges

Kojima-Sakaide Route, (1988):
Longest railway viaduct over open sea

Kobe-Naruto Route (1998):
Longest suspension bridge—Akashi Straits

Onomichi-Imabari Route (1999):
Longest cable-stayed bridge—Tatara

The first completed, the Kojima-Sakaide Route, lies between the others and is important because it has a high speed rail line (Fig. 3). It is composed of suspension bridges and cable-stayed bridges. No one had ever been able to build a suspension bridge for railroads that stood save for Roebling's Niagara Falls Bridge, which had to be replaced because of the tremendous dynamic loading of the rails and Roebling's limited budget. This still poses problems for the Japanese bridge, which requires the high speed rail line to slow down as it crosses. The route completed at the time of the trip was the Kojima-Sakaide Route:

Kojima-Sakaide Bridges

Shimotsui Seto (1988):
Suspension, 940-meter span

Hitsuishijima/Iwakurojima (1988):
Double cable-stayed, 420-meter main spans

Kita Bisan-seto/Minami Bisan-seto, (1987):
Double suspension bridge, 990 m/1,100 m

The three bridges are of the same scale as the George Washington Bridge or the Verrazano Narrows Bridge.

The first items of note for the Shimotsui Seto Bridge are the towers, which seem a bit odd. Otherwise it is a fairly straightforward suspension bridge. Comparison with other suspension bridges of similar scale shows that there is no optimum design for the towers.

A Japanese article explained the origins of some of the designs for the Japanese bridges. Starting with a traditional Japanese temple, with large buildings connected by "spans," we see the similarity to a cantilever bridge. From there we can see the progression to the cable-stayed bridges, which they employed. We can then start to see how they progressed from traditional ideas to new forms. Another example of this is seen in the progression from the forms of traditional garb or shrines to bridge tower designs. These were conscious arguments made by the designers.

The Kita Bisan-seto/Minami Bisan-seto spans include awkward anchorages and a massive center anchor block (Fig. 2). In looking at structures from an aesthetic point of view, there are many different approaches that from a technical point of view can be justified, but from an aesthetic point of view they may be thought inferior.

Returning to the varying ways in which towers have been designed for suspension bridges of similar span also shows how students could approach this idea for a term paper: how do they differ technically, aesthetically, and/or economically?

The trip then progressed to Kyushu, or the wilderness island. The island also is of a similar size to New Jersey. The island is home to the longest concrete bridge in Asia. The bridge was made of concrete instead of the usual steel because of the steam emitted from the hot springs on the island. There are many other deck-stiffened arches in Kyushu, as well. They have also painted some of the bridges in different colors. This fits with the idea in structural art to stand out against the environment.

Another interesting design seen was for the deck of a bridge to be connected to the towers by way of hinges, which would aid the bridge in absorbing the energy from an earthquake, rather than rip it apart. There was also an interesting curved, cable-stayed bridge.

Upon departing, the airport had a mural, in the middle of which was a bridge. Long ago, the bridge represented in the mural was the reference point for all distances in Japan. This was an apt coda for the trip, in which a bridge stood at the center of their island culture.

Discussion: Michael Hein (Auburn University) commented on the seeming repetitiveness of the bridges, an issue that had not occurred to Professor Billington. Sanjay Arwade (Johns Hopkins University) noticed that Professor Billington did not identify any of the bridges' designers. Professor Billington responded that the information was generally not available, that they are almost always large joint ventures with no individuals or even individual companies specified. Professor Billington believes it may be due to cultural differences. Were the information available, Professor Billington would certainly include it.

Dennis Horn (Gonzaga University) asked how Professor Billington's critique was received in Japan. Professor Billington responded that it ranged from "graciously" (primarily) to "quite hostile" (in some cases, particularly among designers of whose bridges he was critical).

Paul Gauvreau (University of Toronto) asked about seismic factors influencing the form of the bridges. There are cases, according to Professor Billington, of some that have worked and others that have not. Professor Billington also related the story of the Akashi Straits Bridge, which was still under construction when the Kobe earthquake occurred (the epicenter of which was right under the bridge). After the earthquake, the span length was one meter longer. Also, the most dramatic failure as a result of the earthquake was a very heavy concrete overpass.

Drew Guswa (Smith College) pondered the inclusion of cables on the back span of a suspension bridge should the deck truss be sufficient to support it alone. Professor Billington noted that those cases are generally rare (although it did occur with the Williamsburg Bridge).

Fig. 3 - Kojima-Sakaide Route - 1988. Longest railway viaduct over open sea.

Ford, General Motors and Mass Production

Professor Michael G. Littman
Princeton University
Reported by Powell Draper - Graduate student, Civil and Environmental Engineering, Princeton University

Michael G. Littman

The Automobile

This lecture largely dealt with Ford Motor Company and General Motors. The scientific side had to do with a new kind of power, the internal combustion engine. On the social side was a new method of assembly, the assembly line, introduced into the automotive industry by Henry Ford. With his Model T, Henry Ford played an enormous role in the creation of a middle class. The symbolic side was represented by a new mobility for society.

The Rise of the Great American Industries: 1876-1939

Speed

Ford and the Model T
Sloan and General Motors
The Wright brothers,
Douglas and the DC-3

Fairs and Exhibitions

1876—Centennial Exhibition, Philadelphia
Steam Power – Telephone – I.C. Engine
1893—Columbian Exhibition, Chicago
Electricity – Light
1939—World's Fair, New York and San Francisco
Automobile – Airplane – Television

The 1876 Centennial Exhibition was the last gasp of the steam engine. It was also where Alexander Graham Bell demonstrated his newly patented telephone and Nicholas Otto demonstrated his internal combustion engine. The Columbian Exhibition in 1893 was a celebration of electricity and light. The foci of the 1939 fairs were the maturity of the automobile, the airplane connecting the two coasts, and the introduction of the new technology of the television.

A New Type of Power

STEAM
"heat to steam" then "steam to work"

INTERNAL COMBUSTION
"heat directly to work"

Nicholas Otto, a German salesman and hobbyist, came up with a really innovative device, the four-stroke internal combustion engine.

Automobile Industry

Nicholas Otto (1832-1891)

Henry Ford (1863-1947)

Alfred P. Sloan Jr. (1875-1966)

On a diagram, one can see the roles of the crankshaft, piston, valves, and spark plug on the intake and ignition strokes and the power and exhaust strokes.

Demonstration:
K'NEX model of a four-stroke internal combustion engine

Demonstration:
Ping-pong ball rocket

Electrolysis of Water

$$2H_2O = 2H_2 + O_2$$

What drives the ping-pong ball into the air is what drives the piston in the Otto engine.

Henry Ford 1863-1947

Watches and machines	1879
Edison Illumination Co.	1891
Car building and racing	1899
Ford Motor Co.	1903

In 1876, Henry Ford was thirteen years old. While his father, a farmer from Michigan, went to the Centennial Exhibition, Henry did not. We do not know if he came back and reported Otto's internal combustion engine, but Henry Ford was mechanically inclined and did not care much for farm work. In 1891, he became the engine operator for the Edison Illumination Company in Detroit. In 1896, he built his first automobile, the quadricycle, although he was not the first in the U.S. to build a gasoline car. He met Thomas Edison, who was working on an electric car. Edison gave Ford encouragement, which was the beginning of a close association. Ford used the proceeds from racing to fund his company.

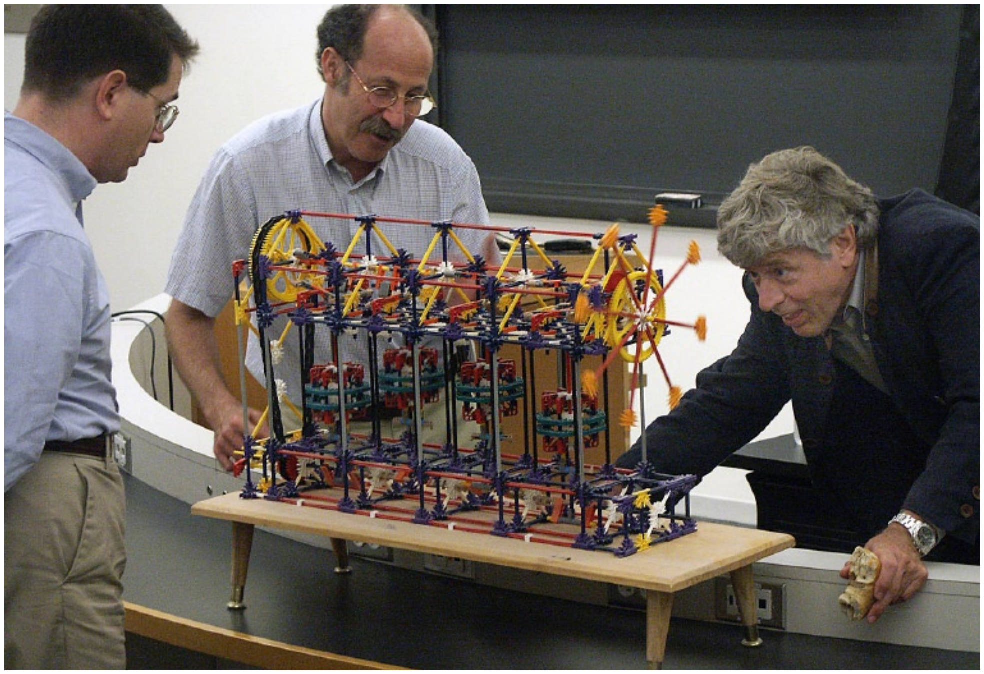


Fig. 1 - Demonstration: K'NEX model of a four-stroke internal combustion engine

Races and Competitions

Fulton	- Monopoly	- 1807
Stephenson	- Sales	- 1829
Ford	- Capital	- 1899
Wright Bros.	- Recognition	- 1908

Races and competitions are familiar themes in the course. Robert Fulton's race of steamboats up the Hudson River gave him a monopoly with his partner, Robert Livingston. The Rainhill Trials in Manchester gave George and Robert Stephenson sales for their locomotives. Ford used his winnings in several car races as capital to start companies. And the Wright Brothers' win in an important race gave them recognition for their airplane.

Demonstration:

Curving wheels forward is a distortion in a sketch for portraying speed. This distortion is evident in early photographs of automobile races.

Focal plane shutter view camera (Graflex) explains distortion in Lartigue's famous 1912 photograph of a racing car at LeMans

Ford Motor Company

Model N	1906
Model T	1908-27
Model A	1928

The Ford Motor Company started in 1903. One of Ford's earlier companies morphed, under Henry Leland, into the Cadillac Company. Ford's partners wanted to make an expensive car. Ford, a farm boy, wanted to make a car for the masses. The Model T, with a high wheelbase, was very good for the poor roads.

Ford also had to deal with George Selden who patented an automobile in 1895. Selden was a Rochester attorney whose association charged all automobile manufacturers a fee. Ford initially lost in court, but eventually convinced an appeals court to narrowly construe the patent and free Ford from the license fees.

Manufacturing 1903-1929

Dodge Brothers – Mack Avenue	1903
Assembly Line – Highland Park	1913
Integrated Complex – River Rouge	1927

Ford initially had different manufacturers make the various parts for his cars. He then turned to the idea of the assembly line, which he got from the meat packing industry. Ford also wanted to own every step of the assembly process, from the iron ore to the railroads to the factory to the finished car. Ford cut the assembly time for a vehicle from twelve hours to one and a half hours. He produced a vehicle every minute.

There was a great deal of turnover, though; the workers were tired and bored by the repetitive work. Ford, although his motives are unclear, doubles the pay of his workers and announced the idea of the five-dollar day.

Manufacturing went on for twenty-four hours a day in shifts. He hired many of those not able to be employed by the rest of society and drove the cost of the vehicle down.

The Ubiquitous Model T

Types and Prices 1916

touring	$360
runabout	$345
town	$595
sedan	$640
coupélet	$505

Ford soon dominated the market. 1924 saw the production of his ten millionth car. The fifteen millionth car found him not so happy, though, as the Model T was not able to keep up with the competition.

General Motors grew from Cadillac, Ransom Olds's Oldsmobile, and Will Durant's Buick. In 1908, Will Durant formed the General Motors Company. Durant later teamed up with Louis Chevrolet, an automobile racer.

Durant hired Alfred Sloan in 1915. Sloan was a graduate of MIT who made roller bearings for vehicles. One of Sloan's partners was Pierre DuPont, who eventually became Chairman of the Board of General Motors. He in turn appointed Sloan as head of the company.

Alfred Sloan 1875-1966

1918	GM Vice President
1920	Pierre duPont takes over
1923-37	GM President
1937-57	GM Chairman of Board

Sloan differed from Ford in many ways. Sloan introduced the idea of a closed body. Also, influenced by Paris fashion, he changes the models annually. General Motors also introduces financing. From 1927 on, General Motors becomes the dominant automobile company, displacing Ford , who clung rigidly to the Model T for too long.

Transforming Ideas

Images: Machines -new leisure and mobility

Transforming Society

History: Machines - the economics of private enterprise

1999 Fortune Global 500

1. General Motors	$161.3B
2. DaimlerChrysler	$154.6B
3. Ford Motor Co.	$144.4B

The economic impact of automobiles shows the enormous effect they have had on our society. The top of the Fortune 500 to this day consists of automobile companies. Even Wal-Mart may be thought of as resulting from the automobile.

Symbolic

Toulouse – Lautrec	1896
The Great Gatsby	1925
Worlds Fair	1939

Toulouse-Lautrec's painting of a motorist showed the sense of freedom that came with the automobile. Fitzgerald put it elegantly in describing a 1920s car:

> "I'd seen it. Everybody had seen it. It was a rich cream color, bright with nickel, swollen here and there in its monstrous length with triumphant hat-boxes, and supper-boxes and tool-boxes, and terraced with a labyrinth of wind-shields that mirrored a dozen suns. Sitting down behind many layers of glass in a sort of green leather conservatory, we started to town."

The World's Fair of 1939 showed a vision of the future that consisted of cities marked by great highways.

Philanthropy

Ford Foundation (Int'l Affairs, Public-Service TV)
Sloan Foundation (Health, Education, Management)
Memorial Sloan-Kettering Cancer Institute
Sloan School of Management – MIT
Firestone Library – Princeton

The automobile created a great deal of wealth that in turn partly supports culture, a theme of the course.

Demonstration:

Auto-cycle engine - The internal combustion engine is a very quiet, compact, useful engine that got the automobile going.

Discussion:

Michael Hein (Auburn University) asked about the number of demonstrations for each lecture. Professor Littman replied that it is usually two or three per lecture, but some lectures may not include a demonstration.

Appendices

A - Laboratories

B - Schedule of Events

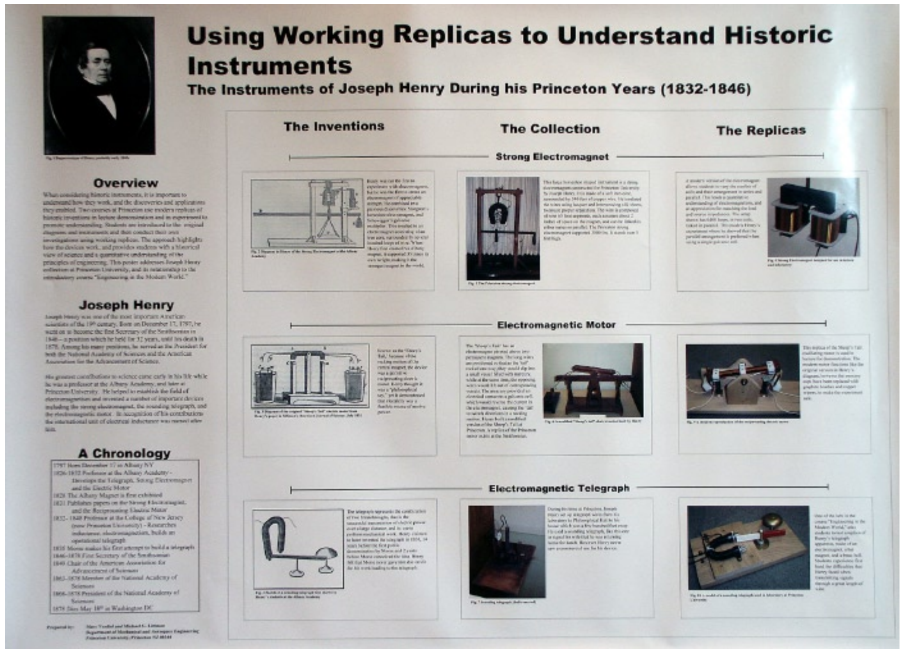
C - Participants

D - Evaluations and Correspondence from Participants

Laboratories

Laboratory Work is Based on Historic Experiments and Measured with Modern Instruments

Joe Vocaturo - Laboratory Manager



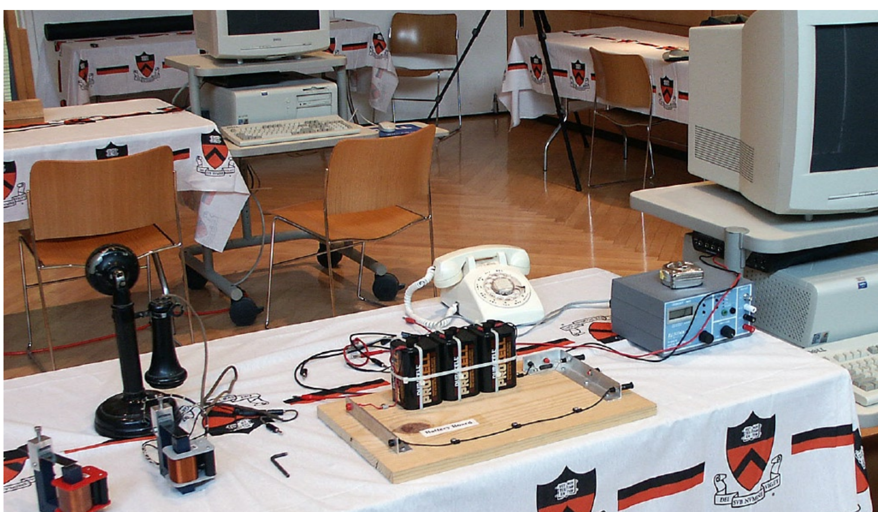


Fig. 1 - Telephone system components

Fig. 2 - Experimental model of Edison's 1882 Pearl Street to Wall Street Lighting System.

Fig. 3 - K'Nex model of the Eiffel Tower -- Used by students to understand free body diagrams and wind loading.

Fig. 4 - Experiment modeled after Gaspard de Prony brake dynamometer of 1821. Students measure the power of an electric motor and a model steam engine.

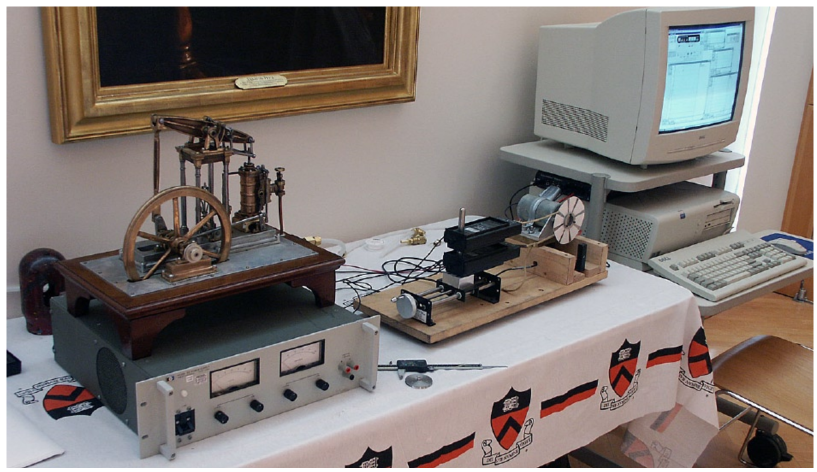


Fig. 5 - K'Nex model of Telford's 1826 Menai Straits Bridge. Students load the deck of the bridge and measure vertical and horizontal reaction forces.

Schedule of Events

Summer Symposium and Workshop for Teaching and Scholarship in the
Grand Tradition of Modern Engineering

August 8-13, 2004
Princeton University

Sunday, August 8 at Prospect House

3:30-5:00 p.m.	Registration at Scully Hall
5:30 p.m.	Reception
6:30 p.m.	Dinner, Presidents Room
7:30 p.m.	Opening Remarks

Monday, August 9 at the Friend Center - Symposium on Engineering Courses

9:00 a.m.	Continental Breakfast in the Lobby
9:30 a.m.	Talks by visiting faculty on their teaching of the Structures and the Urban Environment course, Rm. 004
	Andrew Guswa, Smith College
	Harry West, Pennsylvania State University
	Ben Schafer & Sanjay Arwade, Johns Hopkins University
10:45-11:00	Break
	Sarah Billington, Stanford University
	William Case, Grinnell College
	Michael Botwin, California Polytechnic Institute, San Luis Obispo
12:15-1:30 p.m.	Lunch, Convocation Room
1:30	Talks by Princeton Staff on the Engineering in the Modern World Course, Rm. 004
	David P. Billington: Engineering and American History
	Remarks by Tom Roddenbery and David P. Billington, Jr.
2:30-3:00	Discussion and Break
3:00	Michael G. Littman: Lectures, Demonstrations and Laboratories
	Remarks by Roland Heck and Maria M. Garlock
4:00-4:30	Discussion
6:30-8:30 p.m.	Reception, Dinner, Convocation Room
	Presentation by Shawn Woodruff on Norwegian Bridges Rm. 004

Tuesday, August 10 - First WorkshopTheme: Engineering and the Humanities

9:00 a.m.	Continental Breakfast, Lobby
9:30 a.m.	Lectures on Engineering and the Humanities, Rm. 004
	Maria M. Garlock: Structural Art: Overview
10:20-10:40 am.	General discussion and break
10:40 a.m.	David P. Billington: Structural Art - Visual Analysis
11:30 a.m.	General Discussion
11:45 a.m.	Lunch, Convocation Room
12:45-1:45 p.m.	Preparation for Small Group Meetings (Readings #1)
2:00-5:00 p.m.	Small Group Labs & Meetings, Convocation Room, 110, 111, 112
6:30-8:30	Reception, Dinner, Convocation Room
	Presentation by Gregory Hasbrouck on Swiss and Spanish Bridges Rm. 004

Wednesday, August 11 - Second Workshop Theme: Engineering and Social Science

9:00 a.m.	Continental Breakfast, Lobby
9:30 a.m.	Lectures on Engineering and the Social Sciences, Rm. 004
	James A. Smith: Rivers and the Regional Environment
10:20-10:40 a.m.	General Discussion and Break
10:40-11:30 a.m.	Donald C. Jackson: Engineering in American History
11:30 a.m.	General Discussion
11:45 a.m.	Lunch, Convocation Room
12:45-1:45 p.m.	Preparation for Small Group Meetings (Readings #2)
2:00-5:00 p.m.	Small Group Labs & Meetings
6:30-8:30 p.m.	Reception, Dinner, Convocation Room
	The Columbia Gorge Film Rm. 004

Thursday, August 12 - Third Workshop Theme: Engineering and Natural Science

9:00 a.m.	Continental Breakfast, Lobby
9:30 a.m.	Lecture on Engineering and Natural Science, Rm. 004
	Michael G. Littman
10:20-10:40 a.m.	General Discussion and Break
10:40 a.m.	Lecture on Innovation, Design & Applied Science, Rm. 004
	David P. Billington
11:30 a.m.	General Discussion
11:45-12:45	Lunch, Convocation Room
12:45-1:45	Preparation for Small Group Meetings (Readings #3)
2:00-5:00	Small Group Labs & Meetings
6:30-8:30 p.m.	Reception, Dinner, Convocation Room
	Linda Hodges: Discussion on Modes of Teaching
	Director of the McGraw Center for Teaching and Learning Rm. 004

Friday, August 13 – Fourth Workshop Theme: Contemporary Engineering

9:00 a.m.	Continental Breakfast, Lobby
9:30 a.m.	Course Lectures in Room 004
	David P. Billington: Bridges and Culture in Modern Japan
10:20-10:40 a.m.	General Discussion and Break
10:40 a.m.	Michael G. Littman: Ford, General motors and Mass Production
11:30 a.m.	General Discussion
11:45 a.m.	Luncheon, Convocation Room
1:00-3:00 p.m.	General Discussion and Evaluation of the Workshop, Rm. 004
3:00 p.m.	Workshop Ends Promptly

Participants

Princeton University

David P. Billington	Professor CEE*
Michael Littman	Professor MAE*
Maria Garlock	Assistant Professor CEE
James A. Smith	Professor CEE
Tom Roddenbery	Staff SEAS*
Roland Heck	Associate Dean SEAS
Joe Vocaturo	Laboratory Director CEE
David Billington , Jr.	Historical Consultant

Graduate Students CEE

Powell Draper
Greg Hasbrouck
Sinéad C. Mac Namara
Kristi Miro
Shawn Woodruff

Undergraduate Students CEE

Jiffy Bennett
Lizzie Blaisdell
Greg Glass

Visiting Faculty

Sanjay Arwade	Johns Hopkins University
Mike Botwin	Cal Poly/San Luis Obispo
Stephen Buonopane	Bucknell University
Paul Butler	Ocean County College
William Case	Grinnell College
Larry G. Crowley	Auburn University
Paul Gauvreau	University of Toronto
Andrew Guswa	Smith College
Michael Hein	Auburn University
Katherine Hill	Rensselaer Polytechnic Institute
Dennis Horn	Gonzaga University
Paul Hutta	Pennsylvania State University, Abington
Jeffrey Kantor	University of Notre Dame
Suzanne Keilson	Loyola College
Franklin Moon	Drexel University
Ben Schafer	Johns Hopkins University
William Schonberg	University of Missouri-Rolla
Ron Wakefield	Virginia Tech
Ronald Welch	United States Military Academy
Harry West	Pennsylvania State University
Carole Womeldorf	Johns Hopkins University

* CEE- Civil and Environmental Engineering, MAE - Mechanical and Aerospace Engineering, SEAS - School of Engineering and Applied Science

Evaluations and Correspondence from Participants

Of the twenty people who attended at least four days of the workshop, eight had to leave before the final hour when we had participants write their evaluations. Three of the eight wrote unsolicited letters which are included here. Specifically, the participants found the lectures the most valuable events with the laboratory experiences also ranked well. In general, the attendees had two major reactions. The first was highly favorable with all participants enthusiastic about the material and the presentations. What the participants wanted was to see how we teach, to study the materials, and to interact with us as they adapt courses to their specific local requirements. In general the participants look forward to another workshop and to closer contact with us at Princeton and with other participants.

The second general reaction was that the next workshop be shorter, probably about three days. To give a sense of their specific reactions we quote in full the general comments by four of the participants (written anonymously).

"One of the best week-long workshops I've ever attended, perhaps because my interests are closely aligned with the subject material. The lectures were excellent, not only for the subjects, but for the innovative ways in which the topics were presented and bolstered with images/demonstrations.I feel inspired to try to reproduce the flavor and approach I've seen here in my efforts to develop the introductory course at my own institution.

Kudos to the faculty, staff and students for their involvement, enthusiasm and willingness to share"

"Lectures: ..awesome – showed the possibility of how best to present the content of these two courses. Inspired me to push for 102 and use 262 throughout my curriculum.

Small Group Discussions: Probably not the real focus- but we focused on what we would need to start these courses. I think we were to totally focus on the readings- but discussions were appropriate and everyone had the opportunity to participate.

Labs: Great! Without experiencing them we would not truly know what the students experience. Hands-on is the most important learning event to see value to their learning.

Readings: Super! Showed quickly how easy the readings were for liberal arts students. Amount was just right- Caught myself reading more than required once I got the book.

Evening Events: Great way to get to know each other - breaking bread. Impressed with the quality of your students, information was just right.

Comments: thank you for setting the standard for all-sharing content of a course you have developed.. Novel idea! Maybe more info on how you were able to get 102 as a history course."

"The real joy of this symposium was the lectures. Observing them left me enthralled with the material, but also left me grappling with why they worked so well – and how I could duplicate them with my own material.

The small group discussion was interesting to see how a precept class worked, but didn't add that much to the programs.

The student involvement with the presentation and the symposium worked well in showing what is possible in a lively academic environment.

Labs would work better for me if they were confined to a single period and they were more a demonstration of the lab rather than attempting them ourselves. I would like see some discussion abut the framewrok and development of the lectures themselves. How do you progress through the process from idea to research to presentation and refinement.

Meals and group time was great. Good blend of people."

"I enjoyed the workshop very much and found it to be very informative in a number of ways.

First, it gave me an excellent introduction to the Innovators course and the Rivers course, neither of which I was familiar with.

Second, it was truly inspiring to see the labs and use them, through the exposure to get an idea of how effective they can actually be in teaching this type of course.

Finally, to meet a group of colleagues who share an interest in the social and cultural aspects of engineering was very encouraging. It was very helpful to learn of their experiences in delivering these courses and their plans to put on such courses in the future.

From a personal perspective, it is always inspiring to see and talk about great works or engineering. Thanks to David and all the Princeton people for an excellent week."

GONZAGA UNIVERSITY

SCHOOL OF ENGINEERING

August 19, 2004

Dr. David P. Billington
Department of Civil and Environmental Engineering
School of Engineering and Applied Science
Princeton University
Princeton, New Jersey 08544

Dear David:

I was unable to stay until 3:00 pm last Friday, so I am writing now to express my deep appreciation for my experiences during the Symposium and Workshop last week. After too many years buried in administration and away from the classroom, I am exhilarated by the prospects of teaching the Engineering in the Modern World course next spring at Gonzaga. The approach that you developed, with the extensive use of visual images to capture the attention and imagination of students and to clarify the sometimes dry words of any lecture, makes this venture more exciting than any course I have previously taught.

What I am particularly thankful for was the openness and willingness to share that was so evidenced by you and your colleagues. Too often in academe there is a jealous guarding of lecture materials, with far too many great courses totally dependent on a single individual. Your desire to see that all of your hard work becomes replicated and disseminated, so that it leaves a lasting impression on new generations of students throughout the country, truly epitomizes the concept of "Princeton in the Nation's Service." I have never felt more proud to be a Princeton alumnus, and will do my very best to adhere to the high standards you have set as I work on the course for Gonzaga students.

Please also convey my heartfelt thanks to Michael Littman and Maria Garlock for their involvement and assistance throughout the week. Overall, it was an experience for me that will linger in my mind for years to come.

Sincerely,

Dennis R. Horn '64
Dean of Engineering
Gonzaga University

SPOKANE, WASHINGTON 99258-0026 • (509) 323-3522 • FAX (509) 323-5871

Subject: Re: August workshop
From: Suzanne Keilson <SKeilson@loyola.edu>
Date: Fri, 03 Sep 2004 15:10:00 -0400
To: posnett@Princeton.EDU

I am sorry that I did not do this sooner, but I wanted to make sure I sent you a big THANK YOU before the craziness of the semester starts in earnest. I had a wonderful time and Princeton and would be interested in following up in some ways on the workshop.

For example, I am going to use the Engineering and the Modern World overview with our freshman program, though we have not worked out the details. I also was wondering whether a powerpoint presentation of the overviews that we saw during the week about the other two courses might be made available?

My other idea was to work with some of our senior students to provide you with some editorial feedback on the manuscript for Innovators II from a students perspective. I will be teaching "field theory" in the spring and that might be a good class of students to have read the sections on electrical innovations.

I am sure that there were things I wanted to say but that I am forgetting. I am sending all of this detail to you because I have your e-mail so readily accessible in my file. Please if you don't mind pass this information along to David and David for their feedback and response. I look forward to our future contacts.

All the best,
Suzanne

Suzanne Keilson, PhD
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Assistant Professor, Department of Engineering Science
Loyola College
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UNIVERSITY OF
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August 23, 2004

Professor David Billington
Department of Civil and Environmental Engineering
School of Engineering/Applied Science
Princeton University
Princeton, NJ 08544

Dear David,

This is a belated note of thanks for all that you did to make the Summer Symposium and Workshops for Teaching and Scholarship in the Grand Tradition of Modern Engineering a learning experience for me and the other visitors to Princeton. Being an engineer, I've long applauded your efforts to illustrate engineering as a creative endeavor. But I didn't fully appreciate the degree to which you have embedded your teaching of technology into the scholarly traditions of the humanities. I'm certainly looking forward to learning still more, and collaborating with the people you were able to draw together at the Symposium.

In confusion surrounding my travel arrangements, I did not have a chance to return the card and key to my room in Scully Hall. Please find them enclosed.

Also, I mentioned to you and Mike Littman the name of John Keegan, President and Chairman of the Charles Edison Fund. John is a Notre Dame graduate who has a long-standing interest in promoting an understanding Thomas Edison's contributions to American life. I know that John would appreciate hearing of how you have incorporated a brief technical and biographical history of Thomas Edison into the CEE102 Course "Engineering and the Modern World". John will be visiting Notre Dame in September, and I'll bring this to his attention.

With Best Regards,

Jeffrey C. Kantor
Vice President
Graduate Studies and Research