AC 2012-3072: EDUCATIONAL MATERIALS DEVELOPMENT AND ASSESSMENT FOR ENGINEERING HISTORY AND HERITAGE

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Educational Materials Development and Assessment for Engineering History and Heritage

Abstract

This paper summarizes the development and the first offering of a new course at Cleveland State University, ESC 200 Engineering History and Heritage. The student response to the first course offering was highly encouraging. Student survey results indicated that the course seemed to be effective at addressing a number of important ABET student outcomes. Rather than teaching engineering history per se, the course teaches engineering through historical case studies. The course provides an opportunity to integrate professional and ethical responsibility, impacts of engineering solutions, sustainability considerations, life-long learning, and contemporary issues with technical topics.

Introduction

University undergraduate engineering programs have technical components as well as general education and liberal arts components. Often, the various components are not integrated well, and students may not see the relationships between technology and history. On the other hand, non-engineering students very rarely take engineering courses, and thus may graduate with very limited understanding of engineering and technology and their roles in society.

At Cleveland State University, a course entitled ESC 200 Engineering History and Heritage has been developed to allow students to investigate the development of technology in civil, mechanical, chemical, and electrical engineering in the context of historical case studies. The course is a requirement of the recently revised ABET accredited Bachelor of Civil Engineering (BCE) degree program, and was first offered in the spring 2011 semester. Although the course has no prerequisites and is open to any student at the University, only civil engineering students took it during the first offering. The course is scheduled in the second semester of the second (sophomore) year of the four year BCE curriculum.

Course Description

The course was developed to meet the challenge of addressing principles that are vitally important to the professional practice of engineering, but are often difficult to incorporate in the curriculum. The course description states that the course “Examines how constraints and considerations such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability influence engineering practice. How professional and ethical responsibility affect engineering. Places the impact of engineering solutions in a global, economic, environmental, and societal context.”

The course used two books by Professor David Billington of Princeton University as texts, *The Innovators: The Engineering Pioneers Who Made America Modern*[1] and *Power, Speed, and Form: Engineers and the Making of the Twentieth Century*[2]. The course uses a case study approach.

In some respects the course title is a misnomer. Rather than teaching engineering history per se, the course teaches engineering through history.

The course also included a final group project. Students were assigned to groups of 4 or 5 by the instructor. Each group selected a historical case study topic, wrote a technical paper, and presented it on the final day of the class.

A similar course is taught by Dr. Billington course at Princeton University. The course is entitled “Engineering in the Modern World,” numbered CEE 102A (also EGR 102A, MAE 102A). The course description is “Among the works of concern to engineering are bridges, railroads, power plants, highways, airports, harbors, automobiles, aircraft, computers, and the microchip. Historical analysis provides a basis for studying urban problems by focusing on scientific, political, ethical, and aesthetic aspects in the evolution of engineering over the past two centuries. The precepts and the papers will focus historically on the social and political issues raised by these innovations and how they were shaped by society as well as how they helped shape culture.”[3]

A related course is taught by Dr. Henry Petroski of Duke University, but focused on structural engineering. The course is “EGR 120L(25L). Introduction to Structural Engineering. An introduction to engineering and the engineering method through a wide variety of historical and modern case studies, ranging from unique structures like bridges to mass produced objects like pencils.”[4]

Objectives of the Course

The requirements that civil engineering programs have to meet now, and will have to meet in the future, are contained in a number of documents. The requirements are written in terms of outcomes, which include technical knowledge as well as the ability of graduates to explain concepts and problem solving processes involving management, business, public policy, public administration, and leadership. These include the general and program specific ABET Engineering Accreditation Commission (ABET EAC) criteria[7] and the Civil Engineering Body of Knowledge (BOK)[5]. ASCE also publishes a commentary on the ABET EAC criteria[6].

The course was designed to help document that the students had achieved specific ABET Engineering Accreditation Commission[7] learning outcomes, which are:

(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
(e) an ability to identify, formulate, and solve engineering problems
(f) an understanding of professional and ethical responsibility
(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
(i) a recognition of the need for, and an ability to engage in life-long learning
(j) a knowledge of contemporary issues[7]

Some of these outcomes can be difficult to document in a course strongly focused on technical content. These include Outcome (f), understanding of professional and ethical responsibility, and Outcomes (h) and (i) which cover the direct global, economic, environmental, and societal impacts of technology, and demonstrate the need for lifelong learning by highlighting the evolutionary nature of engineering design procedures.

Historical case studies may be used to support Outcome (j), knowledge of contemporary issues. As students review the historical development of engineering, they will realize how the past affects future practice, and can discuss contemporary issue in light of that past history.

In addition, civil engineering programs have to meet program specific criteria. Civil engineering students have to be able to explain basic concepts in management, business, public policy, and leadership; and explain the importance of professional licensure. The historical case studies address these issues well.

Developing Educational Materials

The educational materials were developed for use in a dedicated 3 semester hour university course. However, were also designed in modules so that individual modules could be used in other introductory or technical courses within engineering programs.

Course materials were developed using a case study/ case history approach. The application of case studies and case histories to engineering education has been discussed in many sources, including Newson and Delatte[8] and Yadav et al.[9].

The use of case studies is supported by sound pedagogical research. *From Analysis to Action*[10] refers on page 2 to textbooks lacking in practical examples as an emerging weakness. Much of this document refers specifically to breadth of understanding, which may be achieved through historical case studies. Another issue addressed (p. 19, [10]) is the need to “incorporate historical, social, and ethical issues into courses for engineering majors.” This need is met directly by the ESC 200 course. The Committee on Undergraduate Science Education in *How People Learn*[11] on page 30 refers to the need to organize knowledge meaningfully, in order to aid synthesis and develop expertise.

Since ESC 200 requires students to independently research their own case studies, this provides a valuable research and writing opportunity. Engineering curricula increasingly emphasize the importance of developing problem-solving skills in engineers as well as communication skills, not just imparting scientific knowledge, so the case study approach (as well as working with non-technical students) fits well with that agenda. *Transforming Undergraduate Education in Science, Mathematics, Engineering, and Technology*[12] proposes that as many undergraduate students as possible should undertake original, supervised research.

The course modules have been developed in MS PowerPoint slide format to take advantage of the photographs and diagrams available on the web. Search engines make it possible to quickly find images of historical bridges, structures, and machines. In particular, Google Patents[13] can be used to locate original patent images. In addition, the study of steam engines, and later of internal combustion engines, is enhanced using the computer animations available from the Animated Engines[14] web site, http://www.animatedengines.com/index.shtml.

Some examples of the learning modules in the course are provided below:

- The rise of hydraulic states – early civilizations arose in the Nile Valley and Mesopotamia to control water resources. The organization and engineering provided by centralized governments made it possible to control water resources and support large populations in arid areas. However, these civilizations faced long term sustainability problems, because the irrigation systems were hard to maintain and eventually had to be abandoned as they silted up. Further, over the centuries irrigation caused salt deposits to build up and reduce soil fertility[15].

- Roman engineering – the Romans built vast road and water supply networks or aqueducts. Their use of a true arch as opposed to the earlier corbelled arch made much more efficient structures possible[15] . In some respects, the quality of construction was superior to that used today, and some roads, bridges, and buildings two millennia old are still in use. Their mastery of concrete using natural volcanic cement made it possible to build strong bridge piers and harbor jetties under water[16]. One key source is the *Ten Books on Architecture* by Vitruvius[17] which provides an overview of city planning and construction practices in the early Roman Empire.

- Engineering in the new world (Maya, Inca, etc.) – recent discoveries relating to Mayan water supply systems show some of the extent of engineering development in the Americas. The extensive road networks of the Incas were roughly comparable to those of the Romans. In many respects, however, the engineering feats (and certainly the engineers) of the new world are not nearly as well documented as those of the old.

- Development of suspension bridges – the development of suspension bridges extends from Telford's Menai Straits bridge and Roebling's Brooklyn Bridge (and earlier Roebling bridge), in chapters 2 and 11 of *The Innovators* [1] on to Ammann's George Washington Bridge and eventually to the Tacoma Narrows Bridge, in chapter 8 of *Power, Speed, and Form*[2]. Using stronger materials, bridges became longer and more structurally efficient. In the process, however, the defenses Roebling used against failure – diagonal stiffening stays, deck trusses, and mass – were stripped away in a process of optimization. Adopting live load reductions and deflection theory, Ammann made the George Washington Bridge very light and structurally efficient. However, the process carried too far led to the failure of the Tacoma Narrows Bridge. As noted previously, this case study can be used to highlight the role of Emily Roebling in the construction of the Brooklyn Bridge[33].

- Development of the steamboat and rail transportation networks – mobile steam power plants first made steamboats possible, and then railroads. The process of developing steam power to overcome drag is shown through Fulton and other pioneers in chapter 3 of *The Innovators*[1]. However, the many deaths and injuries due to boiler explosions led to the development of professional societies such as the American Society of Mechanical

Engineers (ASME) to develop safe design standards and protect the public. Later, the steamboats were superseded by the railroads, addressed in chapters 6 and 8 of *The Innovators*[1]. The railroads were, in turn, largely superseded by automobile and air travel, at least for passengers. The development of these two transportation modes is discussed in chapters 5, 6, and 10 of *Power, Speed, and Form*[2]. Each of these shifts in transportation modes had important impacts on society and mobility. It is often forgotten that the railroads also displaced an earlier system of canals, such as the Erie Canal in New York State and the Ohio and Erie Canal that transversed Ohio from north to south[18].

- Francis and the Lowell Hydraulic experiments – the development of the mill town of Lowell, Massachusetts, and the development of hydraulic power, is discussed in chapters 4 and 5 of *The Innovators*[1]. The development of the mill town as a planned community had important social consequences. In order to plan and monitor the extensive network of canals and turbines, Francis carried out the Lowell Hydraulic Experiments[19], which provide an excellent case study of how engineering research is carried out to validate theory and calibrate coefficients in order to modify theoretical equations, which are then used in the design process. Another potential resource is the *History of Hydraulics*[20].

- Automobiles and the petroleum economy – the rise of the automobile for transportation is closely linked to the wider use of petroleum as a fuel. These topics are addressed in chapters 4 and 5 of *Power, Speed, and Form*[2]. Petroleum refining so as to extract the maximum amount of gasoline from a barrel of oil represented a difficult chemical engineering problem. The problem can be addressed, however, through Houdry's use of control volume analysis, which has important applications not only in chemical engineering but also in environmental engineering and other fields. The economic advantages of the petroleum based economy are well known. However, the environmental consequences can be dire, particularly as other nations such as India and China aspire to attain the standard of living enjoyed in the West. Also, the growth of the highway network, while greatly facilitating mobility, has been accompanied by massive disruption to cities and neighborhoods[21]. Although many of the case studies provide good venues to discuss sustainability, the automobile/ petroleum economy is one that students relate to readily and are eager to discuss.

- Development of geotechnical and foundation engineering – Much of geotechnical engineering practice is based on observation of performance and failures of facilities such as the South Fork Dam (Johnstown Flood), Teton Dam, and Transcona and Fargo grain towers. Because much of the development of geotechnical engineering is the result of field observations of soil behavior and failures[22] this work will make it possible to include the interesting and important discipline of forensic engineering in the course.

Other potential modules include the role of inventions[23] and the development of environmental engineering and the environmental sciences[24].

Course materials also draw extensively on the Cleveland State University Library's Special Collections for historical case study materials. As described on the special collections web site (http://library.csuohio.edu/speccoll/) "Cleveland State University Library's Special Collections provide a research facility for our students and faculty, as well as scholars and visitors from around the world. Our collections cover many topics within the field of Cleveland history, with special concentrations on the industrial history of Northeast Ohio, Cleveland journalism, and the built environment of the city. We are also home to collections of rare materials, as well as publications from the University Archives about Cleveland State University and its predecessor, Fenn College, including college bulletins, course schedules, newspapers, yearbooks, and budgets."[25] One of the class meetings is devoted to a tour of the Special Collections. Many of the materials are online as part of the Cleveland Memory Project (http://www.clevelandmemory.org/)[26].

Impact on Student Learning

To better understand how use of historical case studies can facilitate broader and deeper learning, a brief review of learning skills classification is appropriate. Learning skills may be classified into four domains, as shown in Table 1[27], with each domain being one side of a four-sided learning pyramid. At the base of each domain, and at the base of the pyramid, is the lowest level learning skill, *language development*. At the top of the learning pyramid is the highest level learning skill, *assessment*. Between these common bounds, each domain features unique levels of learning.

Table 1: Classification of Learning Domains[27]

Cognitive	**Social**	**Affective**	**Psychomotor**
Assessment			
Research	*Management*	*Aesthetics*	*Tool Usage*
Problem Solving			
Critical Thinking	*Teamwork*	*Personal Development*	*Motor Development*
Information Processing	*Communication*	*Value Development*	*Wellness*
Language Development			

Learning that occurs in multiple learning skills domains and exercises higher level learning skills is crucial to successful engineering education. This must, however, occur efficiently because engineering curricula are already overcrowded. This is one reason why historical case studies should be an essential part of engineering classes. The single activity of using a case study as part of a traditional course lesson plan simultaneously fosters learning in three different learning domains, thus making learning more efficient:

1. Affective: The story is interesting and sometimes dramatic, thus increasing initial acquisition and permanent retention of knowledge from the learning exercise because of the emotional state of the student during the learning process.

2. Cognitive: The story validates the science, showing that our engineering tools work and thus motivating the students to learn and retain more knowledge.

3. Social: Students discover or rediscover how engineering decisions impact individuals, communities, and society.

As a result of historical case study inclusion, it is anticipated that students will demonstrate an ability to understand the processes of invention and design, apply ethics in engineering, and demonstrate an understanding of the engineer's role in and their value to society. Students will also demonstrate a greater depth of knowledge by developing intuition about expected behavior of engineered systems and better visualizing the interaction of components of engineered systems. Finally, students should experience a change in attitudes about quality engineering as a result of studying the historical development of engineered systems.

It is possible an engineering history course of this nature, offered early in the curriculum, can help with retention and success of women and underrepresented minorities. Earlier work by Lewis et al.[28] suggests that it can.

Colbeck et al.[29] discuss the important role of self-efficacy in improving cognitive engagement, academic performance, and persistence of female students in science and engineering. It is also important to help by putting engineering into a framework for women, as discussed by Henes et al.[30]. Similar issues are addressed by Leslie et al.[31]. Case studies introduce issues broader than technical engineering principles such as ethics, professional responsibility, impact on the community, communication, etc., which then may aid in engaging these women and underrepresented minorities[32].

As the course is further developed, historical case studies will be developed to highlight the important roles of women and underrepresented minorities as inventors and engineers. One case will be the role of Emily Roebling as the project engineer that completed the Brooklyn Bridge, for all intents and purposes[33]. Another is the African American inventor Garrett Morgan of Cleveland, Ohio, famous for inventing traffic signals and gas masks[34].

Preliminary Results from Spring 2011 Semester

A short survey was administered to the students in the spring 2011 semester to assess the course's ability to address ABET outcomes. 20 student responses were received. The responses used a 5 point Likert scale, with 1 as strongly disagree, 3 as neutral, and 5 as strongly agree. An average score of 4, then, would be a consensus of agree. Results are tabulated in Table 2.

The strong results for f, h, and i are particularly encouraging, since these were focus areas for the course. They are also the ABET EAC outcomes that programs have difficulty addressing in the technical elements of the curriculum.

There is clearly a need for refinement. For example, it is necessary to investigate the relatively low score for outcome c so as to improve on the result. This could be because the outcome lists both “ability to design” and “realistic constraints.” The ESC 200 course focuses on realistic constraints by examining the constraints that engineers and inventors have to overcome, but is not really intended to teach design – which is the purview of subsequent courses. Therefore, this question should perhaps be broken down into two more narrowly focused questions. The survey will be repeated with the Spring 2012 course offering.

Table 2: Preliminary Assessment Results, spring 2011

Outcome		Average	St Dev	Mode	High	Low
c	an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability	3.56	1.04	4	5	2
e	an ability to identify, formulate, and solve engineering problems	4.05	0.69	4	5	2
f	an understanding of professional and ethical responsibility	4.25	0.64	4	5	3
h	the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context	4.40	0.68	5	5	3
i	a recognition of the need for, and an ability to engage in life-long learning	4.25	0.79	5	5	3
j	a knowledge of contemporary issues	4.10	0.85	4	5	2

Summary and Conclusions

This paper summarizes the development and the first offering of a new course at Cleveland State University, ESC 200 Engineering History and Heritage. The student response to the first course offering was highly encouraging. Student survey results indicated that the course seemed to be effective at addressing a number of important ABET student outcomes.

Rather than teaching engineering history per se, the course teaches engineering through historical case studies. The course provides an opportunity to integrate professional and ethical responsibility, impacts of engineering solutions, sustainability considerations, life-long learning, and contemporary issues with technical topics. The course will be offered every year, and will be further refined through the development of additional modules specific to the various engineering disciplines and civil engineering sub disciplines.

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