Integrating History into Engineering Curriculum

Kacie C. D'Alessandro[1], *Matthew K. Swenty*[2], *and William N. Collins*[3]

Abstract – Most Civil Engineering students do not have knowledge of the history or of the figure heads that developed and perpetuated the profession they are studying. This hole in engineering curricula results in a misunderstanding of the infrastructure they will inherit, a lack of knowledge of the historical materials and methods used for design and construction, and a disconnect between Civil Engineering and society. A set of historical lessons unique to civil engineering undergraduate courses is being piloted within fundamental engineering classes to alleviate this deficiency and broaden students' understanding of their future profession. Initial implementation of historical lessons has been at three different universities in a combination of statics and structural analysis courses. This paper will focus on what has been learned through the literature on the need for history in the engineering curriculum and the experiences gained through preliminary implementation of historical lessons in fundamental engineering courses.

Keywords: curriculum, history, case-study, project

INTRODUCTION

Curricula in engineering include some credits in math, science, and the humanities. Students tend to start in math and science courses while taking a select few humanities courses required for general education requirements. Many times these outside courses are viewed as required courses for all students regardless of their major, and they do not relate to the engineering program. In the viewpoint of many students, these courses must be endured before proceeding to the "important" engineering classes. The connection between engineering and other subjects is not always clear and sometimes no attempt is made to connect them. It has been shown that subjects such as technical writing, economics, and management are extremely important and applicable to an engineer's career. However, the connection between history and engineering has not been readily taught and in some cases not even explored.

This paper will review the need for implementing engineering history and various possible methods for accomplishing this need. Finally, it will discuss some first-hand accounts of implementing engineering history into engineering classrooms through various approaches.

NEED FOR TEACHING ENGINEERING HISTORY

There are many reasons why there is value in understanding and studying engineering history. In the United States, it has been well documented by the American Society of Civil Engineers (ASCE) and others that the infrastructure is in average to poor condition [1]. Understanding why systems are in their current state is important to knowing how to fix them, how long retrofits will last, and how to communicate with the public. In addition, recognizing the history behind the methods used to design systems helps us understand that engineering theory changes and is also a relatively young field of study. Lastly, knowing the historical perspective of engineers helps us understand the importance and value of what engineers do. It also gives a person motivation and pride in their profession and a job

---

[1] Washington and Lee University; 204 W. Washington St.; Lexington, VA 24450; dalessandrok@wlu.edu

[2] Virginia Military Institute; 609 Nichols Hall; Lexington, VA 24450; swentymk@vmi.edu

[3] Virginia Tech; 200 Patton Hall; Blacksburg, VA 24060; wncollins@vt.edu

well done. Engineers themselves have noted that they would be better engineers and even prouder of their profession if they knew more about the generations that came before them [2].

The engineering history knowledge base of most young engineers, and possibly even experienced ones, is small and has been documented this way for many years. In 1962, Hans Straub noted that there was a lack of interest and literature on the Civil Engineering profession [3]. Recently, it was reaffirmed that "most young engineers know little or nothing about the history of the profession..." [2]. Many engineering faculty agree. One professor noted that students enter college without an idea what an engineer is and leave with only a vague clue [4]. This doesn't imply that students are not interested in history; they either do not see the connection, or the topic is never brought up in their curriculum.

Non-engineers have done a better job at recognizing the value in engineering history that engineers themselves do not always perceive. The directors of the Smithsonian Institute believe engineering history is important enough that they have been collecting engineering documents and artifacts for decades. There are entire displays of engineering history demonstrating early railroad bridges, early reinforcing bars, and engineering documents [5]. In addition, there is a government program called the Historic American Engineering Record (HAER) that was established in 1969 to preserve engineering through the library of congress [6]. The value of engineering history has not been entirely lost, but it may not be as appreciated by engineers because they simply are not aware of it.

Leaders in Civil Engineering have reiterated the importance in engineering history, and the challenge has been issued to teach more engineering history. In 1996, two past presidents of ASCE, Luther W. Graef and Daniel S. Turner, challenged the education activities committee to encourage the development of materials for teaching civil engineering heritage and history in universities [7]. The push to accomplish this has been slow on the whole. One problem has been that literature is "…in old books and scattered contributions to periodicals, difficult to obtain" [3]. However, some new information has been published and is ready for use. The question that accompanies the documentation of the history is now how to implement the history into the classroom in an efficient and timely manner. This all must be done during a time when many undergraduate degree programs have already reduced their required curriculum trying to force students to finish in four years [8].

The interdisciplinary approach of integrating elements of history into technical engineering courses has potential to result in improved student learning and engagement [9]. The student-centered learning approach often associated with interdisciplinary courses urges students to build on their current knowledge through methods of questioning [9]. Engineering history lessons could provide students with a means to apply their knowledge of a concept to a real-world scenario to answer these questions. This application of knowledge has potential to increase students' problem solving ability and improve their overall understanding of a concept by allowing them to apply knowledge. Personal interest is also known to contribute to motivation [10], meaning that these engineering history lessons may also contribute to student engagement by appealing to a student's personal interests and increasing their motivation to learn.

SELECT METHODS FOR IMPLEMENTING ENGINEERING HISTORY

There are many possible solutions to the deficit of historical engineering education in the curriculum and many of the solutions have been tried with varying degrees of effectiveness. Possibly the most obvious solution would be to add a course to the curriculum in place of a humanities credit. Similar types of courses such as the "History of Mathematics" or "History of Technology" have been observed [11]. While this method can be very effective, it requires an additional faculty load and the development of an entirely new course, especially if it is taught within the engineering department. Allowing a humanities professor to teach the course would likely eliminate the technical notes and connections to the engineering profession. Another downside is many students might not choose this elective, eliminating any chance of exposure to the topics. If the course is required, it must be scheduled within an already extremely tight engineering curriculum that is not usually flexible.

Another popular time to include engineering history is either in an introductory course or a senior seminar. Both courses can reach the entire spectrum of students and would provide an appropriate venue. However, the introductory course reaches students very early in their careers, before they have had any basic engineering courses or an understanding of the engineering profession. Broad lessons may be appropriate, but specific lessons that connect to fundamental engineering mechanics courses are not yet possible. The other problem is that many schools have broad general engineering introduction courses that wouldn't necessarily be suited for discipline-specific history. The opposing option is in a seminar class at the end of a student's undergraduate experience. This is a reasonable option to teach broad lessons if time permits. However, this is typically after students have had all their fundamental classes, resulting in a disconnect between lessons that are too specific to courses such as statics or structural theory.

One method that has been propagated is creating a list of the "heroes" of engineering and teaching them to students [2, 4]. This is a very innovative way to get students interested in the profession and embrace our history. However, this approach treats engineering on a very broad scale and only focuses on a few select and very famous engineers.

A different solution is to incorporate relevant history lessons into current engineering courses. The benefit of this approach is that there is no need to add any courses or completely rearrange the course material. These lessons can be taught in approximately five minutes during a lecture when the historical lesson is most relevant to the course. The brief break can be strategically incorporated into the period, providing a break in the class while still maintaining continuity because the history lesson directly relates to the engineering concepts. The lessons can intellectually stimulate students and provide them with real world examples from antiquity. The downsides to this method are that lessons must be carefully placed in the class session at the appropriate time, the lessons must be organized specifically with the current notes, and the lessons might require additional preparation.

IMPLEMENTED METHOD I: BRIEF LESSON APPROACH

Lessons are under development to implement within two Civil Engineering courses – Statics and Structural Analysis. These lessons are all designed to fit within a specific topic in the course and only take approximately five minutes to present in class. The ultimate goal is to have a collection of these small lessons for numerous topics in a series of fundamental engineering classes. Professors could then use their discretion to determine when and how to fit them into a lecture. The objective is not for these lessons to dominate the lecture but to rather augment the students' learning and stimulate further thought.

Historical engineering lessons are being developed by multiple professors at three different universities. Two different approaches are under consideration to provide additional flexibility in various teaching environments. The first is to have the professor present a case study and/or lesson that directly relates to the topic of the day. The second is to break students up into small groups and give them the opportunity to research the topic and present their findings. There are benefits of giving the students ownership versus having clear predetermined lessons presented by the professor. Both seem reasonable and are under consideration.

Lesson Ideas

One of the classes currently being analyzed for implementation is structural analysis. This class is traditionally very mathematically based and many concepts are difficult to understand and visualize. At the Virginia Military Institute, this course begins with truss analysis methods and moves into energy methods; specifically, Virtual Work methods of analysis for beams, frames, and trusses are discussed.

The first lesson that has been designed is for use when analyzing structures with energy methods, such as Virtual Work. It is based on a well-known and recognizable structure – St. Peter's Dome in the Vatican City. A suggestion is to bring up a picture (easily available online) showing the students the structure first. The following is a sample lesson:

Energy methods were first derived by mathematicians but were not generally applied to structural engineering until the beginning of the 19th century. One exception was during a crisis in the mid-18th century. During this period most construction practices in Europe were artistically based and not engineered. The results showed when St. Peter's Dome began to crack and the church feared total failure. Three individuals, Le Seur, Jacquier, and Boscowitch, trained as mathematicians, were hired to assess the problem and come up with a solution. They used the principle of virtual displacements which had been previously generalized by Descartes and Bernoulli. Through this analysis they determined that more tie rods were needed around the dome to keep it from moving outward and cracking. A factor of safety of two was used in their calculations and five ties were added around the dome made of iron. While later it was shown there were problems with some of their assumptions (they didn't take into account constitutive properties of the iron, but who could blame them – Hooke's law was not known yet!), this was one of the *first reports of using structural analysis to analyze a problem. More importantly this was a shift in the mindset that science and research (later called engineering) could be used instead of feelings or only previous experience to design and analyze a structure. [3]*

While this didn't completely change the mindset of master builders this was a very important step forward. Ideas like factor of safety and forces were applied to a real structure. These are terms that we still use today and that you will use in this class. Specifically, the methods of analysis they were developing are still used today as we will see in the lecture today.

In Statics, it is essential to connect a student's knowledgebase of foundational science and mathematics courses (e.g. Physics, Calculus) with this introductory engineering mechanics course. To build upon what a student has previously learned, a discussion on classic historic contributors can be first introduced. A discussion of Isaac Newton's laws of motion is not out of the ordinary for a Statics course because the course is grounded in these ideas; in fact, a lesson on Newton's laws is often included within the first chapter of a Statics textbook. However, including brief anecdotes related to other classic historic contributors, including Archimedes and Simon Stevin, provides students with an expanded view of how many people shaped the methods we still use today.

Brief lessons were introduced into an Engineering Mechanics: Statics course at Washington and Lee University (W&LU), the first of which included classic historic contributors. In addition to Isaac Newton's laws, the concepts of vector mechanics were first introduced through the *clootcrans* or "string of spheres" first observed by Simon Stevin [12]. The *clootcrans* was used to show the concepts of vector addition, and this vision of vector mechanics was featured on the cover of a Statics book by Stevin [12]. Archimedes' story involving King Heron's crown [12] was also discussed to introduce the concept of buoyancy with application to fluid statics.

Other brief lessons for Statics included ancient machines and catenary cables. While introducing analysis methods for "frames and machines," both modern and ancient machines were shown to the students as examples. Bolt cutters, tin snips, and a can crusher were passed around the classroom. Then, pictures of both modern and ancient cranes and digging equipment were shown to the students. These were used to show that the analysis methods could be used on machines of all time periods. They were also shown to give a brief lesson on how technology has shaped construction equipment. Historic accounts of catenary cables were discussed in the course to showcase differences between a catenary cable and a parabolic cable. A parabolic-shaped cable supports a uniformly distributed load along the horizontal length between supports, and a catenary cable supports a load, such as self-weight, that is uniformly distributed along the length of the cable itself [13]. References relating the catenary shape to a hanging chain and structural arch design were discussed while introducing historical contributors to the use of the catenary shape, including Robert Hooke [13]. This also brought about a brief introduction of Hooke's law of elasticity [13] for which students would expect to see in future engineering courses.

Initial Feedback on the Brief Lesson Approach

The brief lesson approach has been attempted at two different universities, Virginia Military Institute (VMI) and Washington and Lee University (W&LU), with two different instructors.

The lessons on Virtual Work have been used in the structural analysis class at VMI. The lesson was used approximately halfway through a 50 minute class after discussing the theory and before applying the concepts to an example problem. The background was presented along with images to orient the students with St. Peter's Dome. The student's response was overwhelmingly positive. They were more alert upon discussing this application and it helped segue into the example problem because they were suddenly more interested. A number of questions ensued about the problem and the discussion lead to questions about Hooke's Law. In the future, a lesson on Hooke is recommended in a prior lecture when discussing material properties and constitutive properties.

The lessons on classic historic contributors, vectors, ancient machines, and catenary cables were discussed in the Statics course at W&LU. Lessons on classic historic contributors and vectors were introduced within the first week of the course. Lessons including ancient machines and catenary cables were discussed in the latter half of the course while presenting specific engineering applications of Statics. Each lesson was generally used as part of an introduction to a specific topic. In the case of catenary cables, this information was strategically placed between the introductory theory and sample problem solving. This allowed a short break from delivering technical information by discussing historical contributions. The lessons provided a means to show how the methods learned in the course were developed long ago. They also show how these methods have remained constant through ancient applications up to those applications now available through modern technology. Generally, students appeared engaged in the lessons and discussions sometimes occurred as a result of the historic topics presented.

IMPLEMENTED METHOD II: PROJECT APPROACH

Another possible approach to implementing history into course materials is to incorporate historical elements into engineering projects completed by students outside of the traditional classroom atmosphere. The project approach was implemented at two universities, Washington and Lee University (W&LU) and Virginia Tech, by two different instructors.

Project Ideas

In a Statics course at W&LU, a project was developed to allow students to explore an engineering topic of choice. The project was structured to account for 5 percent of the overall course grade. The project was designed to showcase concepts learned in Statics through application, allowing students to explore a topic of engineering of their choice in more depth than could be explored during the regularly scheduled class sessions. It also gave students an opportunity to learn how to apply the concepts learned in the Statics course to a unique application. Their findings were summarized and presented during a poster session. During this poster session, they could then explore the topics their peers had chosen to research during the term. Within the project guidelines, students were required to provide four essential elements to their project, one of which was an historical or cultural element. This element was required to showcase a topic related to the history, development, or cultural effects their project topic has had over time or among a specific group of people. This element was implemented to allow students to learn how engineering evolves over time and how engineering affects the surrounding people.

In a Structural Analysis course at Virginia Tech, a project was developed to allow students to research a structure of choice and present their findings to the students in the course through a brief 5-minute presentation at the start of class. The project was structured as an extra-credit opportunity for individual students or for small groups of no more than three students, and the presentations were known to the class as “Structures Day” projects. The project was designed to bring more real-world examples into class sessions so that students could begin to see the connection between theories learned in class and the structures for which they were intended to be used. In each presentation, students presented a structure of their choice to the class, incorporating elements of history related to the structure. Following the presentation, a discussion with the class and the instructor attempted to connect techniques and methods currently being taught in the course to the structure presented.

Initial Feedback on the Project Approach

The Statics project required additional work out-of-class to manage intermediate project submittals. These submittals included a proposal of ideas, a poster draft, peer reviews, and a final poster. During the proposal phase, a meeting was required with each student to discuss proposed project topics. Although the meeting required a greater time commitment from the instructor, this time appeared to be valuable. It provided an opportunity to discuss project topics freely and without interruption from daily course management duties. It was also an opportunity for the instructor to hear more about student interests in engineering topics. Later during the course, the instructor was able to refer to specific projects while teaching lessons, and students with those topics were sometimes invited to contribute to the introductory material for a course topic while in class.

Although the independent effect of incorporating historical elements into the project are uncertain, students appeared engaged in the projects. The projects appeared to be a creative channel for students to explore an engineering topic in more depth during the semester. The project also allowed students to specifically explore topics of history and culture related to an engineering topic of their choosing. The final poster session was a way for students to learn additional topics of historical significance by viewing the projects completed by their peers. As presented previously, topics of historical significance were presented in class using brief lessons. Then, this final poster session brought forth a massive amount of historical topics at once for the students to learn. Students appeared eager to showcase their personal projects and to learn from their peers through the poster session.

The Structural Analysis project required little to no work on the part of the instructor. The instructor maintained a sign-up list for the “Structures Day” presentations and provided a computer for students on the day of their presentation. This project approach was similar to the brief lesson approach previously discussed. However, this project allowed students to prepare and provide the brief lessons on case-studies and engineering history for a specific class session. Although the presentations were not necessarily relevant to the intended lesson for that session, they often brought up discussions on theories previously discussed in the course.

Again, although the independent effect of the history component is unknown, the project appeared to positively affect student engagement. The instructor noticed that students became increasingly engaged in the presentations and discussions following as the semester progressed and as students became more comfortable with the format. Some of these discussions included more advanced structural topics beyond the intended scope of this introductory structures course. These discussions allowed students to have a glimpse into future structural design topics. In general, positive feedback was received from students, improving student interaction both during the presentation discussions and the course lessons following.

FUTURE PLANS

Additional lessons are currently being developed for both Statics and Structural Analysis. Lessons are also being developed for other courses, including Solid Mechanics of Materials and Engineering Materials Science. Additional ideas for projects are being explored to incorporate history and culture into engineering courses. Plans are also underway to explore topics of engagement, motivation, and knowledge retention.

CONCLUSIONS

A concept incorporating engineering history lessons into courses during relevant lectures has been attempted at three different universities. A select number of case studies have been used over the past year with limited but valuable feedback. In general, the students appear interested in the lessons, whether presented by the professor or by their peers. The students' attention is maintained, and brief lessons in class help to break up a class session while broadening the students' engineering knowledge. The next step is to develop a more complete lesson set that can be used at more regular intervals throughout a course and determine if students' knowledge of engineering history is actually increased. The initial feedback supports the assumption that this adds value to a student's education.

REFERENCES

[1] American Society of Civil Engineers, "Report Card for America's Infrastructure," http://www.infrastructurereportcard.org/, Accessed 12/3/13, Reston, VA, 2013.
[2] Weingardt, Richard G. "Engineering, History, and Civilization," Structural Engineer, p. 50, July 2013.
[3] Straub, Hans. "A History of Civil Engineering: An Outline from Ancient to Modern Times," Charles T. Branford Co., Newton, MA, 1960.
[4] Fredrich, Augustine J., "Heritage, Ethics, and Professionalism in Civil Engineering Education," Proceedings of the Second National Congress on Civil Engineering History and Heritage, American Society of Civil Engineers, Reston, VA 1998.
[5] Worthington, Jr., William E., "The Engineer and the Smithsonian Institute's Civil Engineering Collections," Proceedings of Civil Engineering History: Engineers Make History, American Society of Civil Engineers, Reston, VA 1996.
[6] Delony, Eric, "29 Years Documenting Engineering Heritage," Proceedings of the Second National Congress on Civil Engineering History and Heritage, American Society of Civil Engineers, Reston, VA 1998.
[7] Rogers, Jerry R., "Proceedings Introduction," Proceedings of Civil Engineering History: Engineers Make History, American Society of Civil Engineers, Reston, VA 1996.
[8] American Society of Civil Engineers – Raise the Bar, "Seeing the Future – Looking Back", http://www.raisethebarforengineering.org/seeing-future-looking-back-0, Accessed November 30, 2013.
[9] Lattuca, L. R., Voigt, L. J., and Fath, K. Q., "Does interdisciplinarity promote learning? Theoretical support and researchable questions," The Review of Higher Education, 28 (1), 23-48, 2004.
[10] Eccles, J. S. and Wigfield, A., "Motivational beliefs, values, and goals. Annual Review of Psychology, 53, 109-132, 2002.
[11] Virginia Military Institute – Applied Mathematics Department, "History of Mathematics – MA-330WX," Course Catalogue, Spring 2014.

[12] Ronan, C. A., *Science: Its History and Development among the World's Cultures,* Facts on File Publications, New York, NY, 1982, 543 pp.

[13] Allen, E., Zalewski, W., Foxe, D.M., Anderson, J., Hriczo, K., Ramage, M.H., Ochsendorf, J.A., Block, P., and Iano, J. *Form and Forces: Designing Efficient, Expressive Structures,* John Wiley & Sons, Inc., Hoboken, NJ, 2010, 620 pp.

Kacie C. D'Alessandro, Ph.D.

Kacie D'Alessandro obtained her B.S. and M.S. degrees in Civil Engineering at Clemson University before obtaining her Ph.D. in Civil Engineering at Virginia Tech. Kacie is currently an Assistant Professor in the Department of Physics and Engineering at Washington and Lee University. She teaches engineering mechanics, engineering design, and materials science courses at W&LU, and her research interests include ultra-high performance concrete, concrete structures, and engineering education.

Matthew K. Swenty, Ph.D., P.E.

Matt Swenty obtained his Civil Engineering degree at Missouri S&T then worked as a bridge designer at the Missouri Department of Transportation before returning to obtain his Ph.D. in Civil Engineering at Virginia Tech. He worked at the Turner-Fairbank Highway Research Center in McClean, Virginia on concrete bridge research before coming to the Virginia Military Institute. He teaches engineering mechanics and structural engineering courses at VMI and enjoys working with the students on undergraduate research projects and with the ASCE student chapter.

William N. Collins

William Collins is currently a PhD Candidate at Virginia Tech examining the fracture behavior of high performance steel for applications in bridge design. He attained both his B.S. and M.S. degrees from Virginia Tech in Civil Engineering. He has been involved with Bridges to Prosperity and the Structural Engineering Institute, and is currently teaching Theory of Structures (Classic Structural Analysis).