Parsing the Content in Capstone Engineering Design Courses

***Dr. Michael D. Boyette* [1]**

Abstract – Engineering programs accredited by ABET must include a capstone course sequence to comply with ABET's criterion 3(c) and 4. In practice, students select a project and carry it through design to application. However, successful engineering requires more than technical expertise. There are "soft skills" without which, the engineer will not likely approach his professional potential. Paramount among these is the Canons of Professional Engineering. Additionally, a small book published nearly 70 years ago, "The Unwritten Laws of Engineering" by W.J. King, recognized that technical competence and honesty are necessary but not sufficient for professional success in engineering. In the words of James G. Skatoon, who revised King's book in 2001, King became aware "that the chief obstacles to success of individual engineers… are personal and administrative rather than technical". This paper discusses some capstone experiences that include a greater and greater emphasis on soft engineering skills.

Keywords: ABET, soft skills, capstone course, professional conduct

INTRODUCTION

All academic engineering programs accredited by ABET must include a capstone course sequence intended to comply with the requirements of ABET's criterion 3(c) and criterion 4. ABET criterion 3(c) requires the outcome that students have "… 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". ABET criterion 4 simply mandates a continuous improvement of pedagogy by "…assessing and evaluating the extent to which both the program educational objectives and the student outcomes are being attained." [1] In simple terms, the student should be able to demonstrate a sufficient level of engineering competence by applying his newly attained engineering knowledge to some practical "real world" problem and the program should be continually seeking and using feedback to improve course delivery and outcomes.

In general practice, the senior students under the direction of their instructor, select a project relevant to their course of study and through a series of steps, carry it through design and construction to testing and application. How this is actually accomplished and what metrics are used to judge success varies widely from department to department. This is best reflected in the many survey studies conducted over the years on how capstone courses are taught. One of the most recent by Susannah Howe [2] of Smith College, compared the results from a survey of 444 programs to

[1]The Department of Biological and Agricultural Engineering
North Carolina State University
Box 7625
Raleigh, North Carolina 27695
mike_boyette@ncsu.edu

determine how capstone courses differ across departments and institutions and how capstone courses in general have changed in the 10 years from a previous study by Todd and Magleby [3].

Capstone courses reflect the constraints and resources available to the instructor and will necessarily change from time to time. Further, according to Howe, half of her responses were from capstone programs less than ten year old. As anyone familiar with developing a new course or academic program knows well, it may take as long as 5 years to settle on and adjust a reasonable body of course material and even then is should be constantly "tweaked." Not incidentally, the added work of developing a capstone course is that the instructor must also secure the necessary faculty/ industry sponsors along with funding.

The summary message is then that most capstone programs are constantly in flux such that there is not necessarily one dominant model. This is because instructors are always searching for the right content mix to satisfy needs, requirements and limitations of ABET, the institution, potential employers/grad schools, departmental resources and their own understanding of what should constitute the "capstone experience". From the standpoint of pedagogy, this "let a hundred flowers bloom" approach is undoubtedly good. From the standpoint of an instructor trying to develop a new capstone course from scratch, the broad range of possibilities can be daunting.

In the Department of Biological and Agricultural where the author teaches, the capstone experience (or as we call it, senior design) is a two semester sequence in the student's senior year. According to Howe's paper, of those institutions on the semester system, a one semester capstone sequence is most common (60 percent) followed by two semesters (40 percent). A three semester sequence is not unknown but is rarely reported. Given the volume of course material necessary to satisfy ABET, it is likely that a few of those departments choosing the one semester option are relying on the inclusion of capstone material from other courses, e.g. engineering ethics.

THE CHANGING NATURE OF CAPSTONE DESIGN

Traditionally the major emphasis of the capstone sequence has been design – specifically the practical application of accumulated engineering knowledge and skills to solve some technical problem in the student's area of interest. The author of this paper has been involved in senior design for thirty-six years; first as a student, then as an industry sponsor, later as a faculty mentor and for the last eleven years as the instructor of the capstone courses in the Department of Biological and Agricultural Engineering at North Carolina State University. This long-term experience with one department's capstone experience is probably not unique but it does provide a perspective as to just how course content has changed over more than a generation. Thirty years ago and before, almost all students in our department shared one major characteristic – they came off the farm. This is no longer true with only about 5 percent are now off the farm.

The students entering our department from a rural/farm background often came equipped with significant hands-on experience and practical ability that greatly complemented their engineering education. To a degree, this was true of other engineering disciplines as well. Most all types of engineers who were undergraduates in the 1950's and 1960's can fondly recall working on automobiles, building model airplanes and constructing short wave radios - all hobbies that provided creative outlets and honed practical skills [4]. Unfortunately, these and very few other practical hands-on creative outlets are widely available to most students today.

If the essence of engineering is creativity and with design being the expression of creativity, how have departments adapted the capstone experience to the new student realities? Some would argue not very well. Every experienced engineer knows that the real payoff in engineering is the opportunity to see a design that once only resided in your head now standing before you doing what you designed it to do. This is really what the capstone experience is all about. I tell my students that they have earned their wings in physics, chemistry, solids, thermo, differentials, etc.; now it is my job to teach them how to fly. After all, flying (the practice of engineering) is why they came to school in the first place.

But course and curriculum committees must deal with demands from many sources coupled with the limitation of maximum required credit hours. Not only is there no course time for building practical hands-on skills but university safety committees as well as ABET have come down very hard on departments that allow students to work untrained and unsupervised with even the simplest hand tools. The bottom line is that the nature of design in the capstone experience has changed. Capstone projects more and more are considered complete when a nicely done report with a well-researched background, a succinct problem statement and a reasonably creative solution with calculations and drawings is delivered at the end of the semester. No prototypes, working or otherwise, are required which is unfortunate since the very human impulse to "build something" is what prompts many bright students into engineering in the first place. Even sadder is that no prototype also means no testing and the frequent complaint "How are we going to know if we have really solved the problem?"

SENIOR DESIGN IS MORE THAN JUST DESIGN

Even though design is the essence of engineering, it has long been recognized that successful engineering requires much more than simple technical expertise. The hay days of the lone practitioner engineer is long over. Modern society is very interdependent and modern engineering is the arch typical team sport. Each spring, I take my senior design class to a local plant belonging to a large multinational agricultural machinery manufacturer. There they get to see engineers – some being our own graduates – interacting with each other and with engineering colleagues all over the world via the internet. I am always amazed at how my once shy and reserved former students have quickly matured into confident and competent worldly-wise engineers.

Like a lot of academic departments, we have an advisory committee made up of distinguished engineering professionals and potential employers from government and industry. It is their job to advise us on ways to help us do our job better which include what sort of things we ought to be teaching our students. Perennially top on their list is "teach them to work well with each other" and "to understand that when they work for us they are representing us to the world". It goes without saying that courses should reflect the perceived needs and aspirations of society as it relates to our engineering graduates. In fact, it may be argued that ABET's major function is to determine what graduates should know and enforce that standard in engineering schools. ABET criterion 3(c), referred to above, is wholly devoted to including realistic constraints such as "economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability" into the capstone design experience. These are the so called "soft skills" without which, the engineer will not likely ever approach their professional potential. Paramount among these skills is the ideas of accountability embodied in the Canons of Professional Engineering. The Canons rightly form the basis for most of the currently used engineering ethics text books taught during the capstone experience or in a separate course in engineering ethics.

So along with a suitable project, an understanding of the engineer's duty to society as embodied in the Canons and ABET's soft skills, what other soft skills would be wise to include in a capstone course? In a thoughtful piece in the November, 2011 *Prism*, Henry Petroski makes a good case for more emphasis on communications:

"Engineers are expected to be able to translate modeling and computational results into jargon-free English so their managers and their company's clients can grasp what has been done. The engineer is expected not only to be able to do this in written words on paper or screen but also to be able to do it in spoken words before a design conference or project review and, increasingly, interested citizen groups." [5]

So engineers who can articulate well, either written or verbally, almost always find the road to success shorter. But what else might be required? We all have known competent, ethical and well-spoken people who have not enjoyed the most successful of careers. For some, that question was answered nearly 70 years ago by the publication of the small book "The Unwritten Laws of Engineering" by W.J. King. [6] King recognized that technical competence and honesty are necessary but not sufficient to professional success in engineering. In the words of James G. Skatoon, who revised King's book in 2001, "the originating author (King) admitted to having become very much aware…that the chief obstacles to success of individual engineers… are personal and administrative rather than technical in nature”. This little book, still in print and available from ASME, is a gold mine of the softest of the soft skills. In our present age when faith and loyalty are not words always associated with the employee-employer relationship, it is very refreshing to read on the first page that a young engineer is urged that “however menial and trivial your early assignments may appear, give them your best efforts.” The faithful discharge of duty and loyalty to the public, one’s employer and the profession are themes that permeate the King’s book. These ideals also underpin the Canons of Professional Engineering, but unlike the Canons which tell us what to do, King’s book tells us in detail how to do it.

STRIKING THE RIGHT CAPSTONE BALANCE

The world of the 1950s and 1960s undergraduate engineering experience is long gone and is not likely to return. Today’s students generally do not have the practical skills or the opportunity to acquire those skills as students in the past. Further, the nature of engineering has changed – at least in this country. Where once our engineering graduates found most of their employment in manufacturing, now most find employment in government and large consulting firms where ‘building something” is not always the prime pursuit. In this case then, more emphasis on the soft skills may be the correct course. And even if most graduates go on to careers somewhat removed from the practical application of engineering, is it necessarily wise to deemphasize the design experience in undergraduate education? Can we so heavily weight the capstone experience with soft skill development as to relegate the technical design aspects to a poor second place? Or should, as some are suggesting, devote the soft skills to their own required course – perhaps engineering ethics and more?

Perhaps to answer this question, we should make a thorough normative inventory (parsing) of the skills engineering graduates should acquire from the completion of the capstone experience and see how the typical undergraduate engineer curriculum could address them. Not on this list is the collection of technical skills in the key areas of science and math. These included in the body of knowledge tested for in the Fundamentals of Engineering exam and are assumed to be the necessary pre- or at least co-requisite to the capstone experience.

Certainly on top of the list is all that is encompassed by the design experience. Selecting or being given an open-ended problem is a singular experience in the education of most engineering students. With design, unlike math and science problems, an educated judgment is often required and there may be no truly correct solution but just some more correct than others. This is real world and this is real engineering and is likely as not to cause many students considerable initial anxiety. Nevertheless, to assume their positions as productive members of society, young engineers must start somewhere and the classroom is the proper place. Besides, nothing builds confidence better for the graduate than the successful completion of a design project. For a great many graduating students it is the defining experience of their senior year. No matter how much we want our graduates to be adept in the soft skills, we must never relegate design to a secondary place in the capstone experience.

A SUSTAINABLE SOLUTION

For sure, engineering education has changed and will continue to change based on the collectively felt needs of society. For a variety of reasons, the need for soft skills among engineering graduates will continue to be important and will grow in importance. Many capstone programs, including our own, have tried to integrate the soft skills somehow into student design process. Whether it is service learning which tries to integrate the capstone experience into the immediate needs of society or some formal or informal partnership with industry, it often appears that the soft skills get de-emphasized and lost in the process. Unless the instructor is unusually diligent in making sure the soft skills are taught at every opportunity, it is not likely the results will be successful. Students are the first to be aware of this. We have had them remark on course and instructor evaluations that it felt like two important and related subjects (soft skills and design) were competing for attention. It is becoming increasing clear that what the engineering curriculum needs is a separate course dedicated specifically to the full range of soft skills. The body of knowledge that would constitute a soft skills course is extensive and too important to warrant attempting to plug it into odd spots of a course primarily about the mechanics of design.

What would such a course be called and how would it be taught? First, soft skills are about professional conduct – how one thinks and responds to the many and varied ethical situation that occur daily throughout ones career. In this regard, the course could be presented like a course in philosophy where concepts based on some fundamental rules - perhaps the Canons of Professional Engineering – provide the logical basis for all right actions. Not only would the course include engineering ethics per the Canons of Professional Engineering but also content like that in "The Unwritten Laws of Engineering" which is really based on the finer points of the canons. To add practical substance and cautionary tales, there would be a place for case studies of engineering disasters and even those celebrated examples (e.g. LeMessurier) where engineering professionals did the right thing. The course content would certainly include the legal issues of engineering; especially product liability, a little of the history of engineering and even business etiquette. Some would argue that some of this content would better be addressed in an introductory engineering course but how can student fully apply soft skills to engineering knowledge that don't yet possess?

There are obvious problems with adding a new course to an already overloaded engineering curriculum but doubtless a course in engineering ethics and the soft skills would qualify as a required humanity. This approach would probably be accepted by many departments if the course was taught concurrent with the capstone design course. What we know that does not work well is to try to integrate such a huge and important body of material into a course ostensively devoted to the formal design experience.

CONCLUSION

As engineering educators, it is our job to prepare the next generation of engineers for successful, productive and satisfying professional lives. Engineers have long suffered from the reputation of detachment. Thankfully this is changing as engineering education more and more stresses the soft skills that encourage a holistic approach to engineering. The time has come to give this important subject the prominent place it deserves. Only by being engaged and responsive to the wider world around us can engineering reach its full potential.

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Michael D. Boyette, North Carolina State University

Michael D. Boyette is a professor of Biological and Agricultural Engineering at North Carolina State University. He presently teaches senior engineering design and conducts research in bioprocessing. He is a member of ASABE, ASHS, ASEE, Gamma Sigma Delta and is a registered professional engineer.