Creatively Including ABET Criterion 4 Into A Capstone Course

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Abstract – ABET Criterion 4, the Professional Component, addresses a number of specific subject areas appropriate to the practice of engineering. These subject areas are normally addressed in one or more capstone courses taken during the senior year. Capstone courses commonly involve a major design experience and are intended to draw together the disparate parts of an engineering curriculum. This experience ideally involves real-world problems that are often open-ended and may not involve in a meaningful way all the engineering standards and constraints required by ABET. In order to comply with the requirements of Criterion 4, instructors often result to "punch lists" or require students to apply contorted logic in order to address a component when, in fact, the problem does not call for it. Either way, it can leave the student and the instructor with the feeling they have been involved in a mindless exercise. This paper discusses some creative ways to introduce these considerations into class projects in a way that is both meaningful and appropriate.

Keywords: Design, professional component, ABET, criterion 4

INTRODUCTION

To undertake a great work, and especially a work of a novel type, means carrying out an experiment. It means taking up a struggle with the forces of nature without the assurance of emerging as the victor after the first attack.

Louis Marie Henri Navier (1785-1836)
Bridge builder and founder of structural analysis

Navier is often quoted [1] to remind engineers and especially engineering students that the practice of engineering is anything but a closed-ended exercise. Students participating in their senior year capstone courses are frequently shocked to discover that the execution of their chosen projects does not follow the neat textbook form. It is often the case that their capstone design course projects are the first open -ended projects ever attempted by them. Inputs vital to their designs may, if known at all, be poorly known. Predicting the results that may be little more than educated guesses. Dealing with the unknown, and even the unknowable, in inputs as well as outputs, is uncomfortable for the seasoned engineer and doubly so for the student.

Just as Navier said, there is a significant level of experimentation in any engineering work. We are careful to validate all our inputs, use the most appropriate design methodology and exercise the greatest care in the other aspects of the enterprise. However, until the design is proven in actual use, we are often left to wonder if our bridge will stand or our plane will fly. All engineering designs that fail share the common thread of behaving in ways the designers never intended. If the essence of engineering is design and engineering is experimentation, then as engineers, at one time or another, we all worry that our designs, once built, may not perform as intended.

Fortunately, the risk from a scientific experiment as well as an engineering design can be reduced by limiting the scope. "Bench scaling", prototyping, and computer modeling are proven ways we use to limit the risk of technology. As engineers, we are good at this. Software catalogs are filled with wonderful programs for modeling kinematics, heat and mass transfer, reaction dynamics and biological systems, among other things. No modern

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science and technology curriculum, nor any real world engineering endeavor would be complete without the aid of these valuable tools.

However, as engineering students and later as practicing engineers, we are given a problem and told to provide a solution. We then gauge our success mostly by how well our design solves the problem. The trouble with this simple minded approach is that it frequently ignores the parallel but nevertheless weighty issues associated with our designs. In our increasingly interrelated world, society questions the overall affects of engineering. Speaking of one of the world's first large scale engineering endeavors, Stonehenge, Daniel Boorstin reminds us that "men never know the power of what they have created" [2]. Therefore, in addition to pure functionality, there are other significant issues related to the design and use of technology that may be unknown or even unknowable to the designer. These issues often work at cross purposes withan otherwise successful engineering design. Even if these issues are known, they may be difficult to define and harder still to overcome. This "revenge of unintended consequences" is precisely the point authors like Edward Tenner [3] have made about the downside of technology.

Although no engineer could be expected to realistically anticipate all the unintended consequences of a design, there are lines of thought that a prudent designer should explore before considering the project complete. Unfortunately, many of these constraints are substantially outside the purview of traditional engineering curricula, although this situation is changing. To their credit, engineering educators, ABET, and practicing engineers themselves have recognized the importance of addressing societal (soft) constraints in a thoughtful way. Indeed, doing so offers the advantage of better anticipating the unintended consequences of our designs in the process of solving problems.

According to ABET Criterion 4, "Students must be prepared for engineering practice through the curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating engineering standards and realistic constraints that include most of the following considerations: economic; environmental; sustainability; manufacturability; ethical; health and safety; social; and political" [4]. When students address these eight considerations during their capstone design course, it will almost certainly be their first time doing so.

APPLYING CRITERION 4 IN THE CLASSROOM

At North Carolina State University, students enrolled in biological engineering and biomedical engineering take the same senior design course sequence. Engineering Design I (BAE 451) is a three credit hour fall semester course and Engineering Design II (BAE 452) is a two credit hour spring semester course. Teams of three to five students choose projects from among a list containing contributions from potential sponsors. The sponsors may be faculty - engineering or otherwise - or practicing professionals from government or industry. Depending on the scope, teams may conclude a different project each semester. More frequently, however, projects are carried over both semesters.

At the conclusion of each project, student teams are required to present the results of their work in both written and oral forms. In order to document the assessment of ABET Criterion 4, sponsors and evaluating faculty are asked to complete a rubric that simply asks if each of the eight considerations are "shown" or "not shown." Students are given access to the rubric so they know precisely how they will be evaluated. Being unsure of the practical definition of some of the considerations and how to apply them to their projects, students often predictably address each of the considerations in a "punch list" like manner in order to assure it was indeed "shown". This situation often requires students to apply contorted logic in order to address a consideration, and they then miss the point entirely or make the consideration in an unnecessary and inappropriate way. (Note that Criterion 4 requires the addressing of only "most" of the considerations.) Either way, it leaves the students, the instructor, and the faculty evaluators with the uneasy feeling they have been involved in a mindless exercise.

It would seem easy enough to include lecture material on the various considerations, giving practical examples. Unfortunately, when this has been done, it still frequently does not provide students with the requisite skill to confidently accomplish the considerations to their own projects. Although we do include discussion of the considerations in various lecture materials, we have found that students respond best when they have been presented with various manufactured items and assigned specifically to determine how both the design and society has been impacted through the considerations

For four years, we have been employing reverse engineering in the course as a very useful way to introduce students to the methods and nuances of engineering design. This topic also gives them an appreciation of the delicate balance of features and constraints inherent in any good design. For the first three years, each student was given the same item (a medium grade padlock) with the instructions to "take it apart, examine it in great detail, and write a formal engineering report of your findings." Students were encouraged to proceed with the analysis methodically while taking very careful notes and to discover and speculate on non-obvious design features. They were also encouraged to speculate on issues such as automatic assembly methods, service life, and aesthetics.

Additionally, the students were asked to address the "societal" considerations relevant to the design as enumerated in ABET Criterion 4. Most of the students found it very difficult to adequately address many of the Criterion 4 considerations in any meaningful way. As instructors, we first considered that a padlock might represent a poor example of the constraints. However, upon further reflection, we concluded that the problem was not with the padlock, *per se*, but with the limited perspective of the students to visualize the constraints. In an attempt by the students to "cover all the considerations," they often resorted to specious or contorted reasoning without actually articulating an understanding the concepts. For an example of the political implication, a student once made the observation that padlocks are used to lock ballot boxes. This, of course, is true, but it misses the point entirely. A broader and better observation would have been that the padlocks are used primarily to secure personal property, a right guaranteed to each individual in the US Constitution.

In order to rectify this shortcoming, at the beginning of the fall 2004 semester, each student was given a *different* common manufactured item to reverse engineer. To ensure fairness, each item was presented in a closed paper bag. Each student selected a bag without knowing its contents. Since each student has a different item, a moderate amount of collaboration between students is not only tolerated but encouraged. Most students were able to identify evidence of more than one consideration, and because there were so many different items (more than fifty students take this course) all considerations were evident in the collection of items. The collaboration among the students made it possible for all students to see each consideration in a broad context. Even if they did not see it in their particular item, they saw it in one or more items of their colleagues. It may be pointed out that common manufactured items we selected for this assignment (e.g., flash light, stapler, light bulb, etc.), form a unique subset of engineering designs that neatly embody many of the considerations addressed in Criterion 4 in a generally clear and reasonable manner. The reason this point is important is that this cannot be said for most of the engineering design problems on the list presented to the students. For example, students working on a device to wash down a dairy barn may not have difficulty defining the environmental constraints but the political constraints would be another matter.

This activity was integrated with a "library assignment" in which the students were asked to search and cite background information on their particular items. This information included specifics about the firm that made and sold the product, the industry of which it is a part, history of the product and technology, patents, any product liability cases, market share, units sold per year, and other incidental information. Although the students were not aware of it at the time, this background information was of great value when they were later addressing the Criterion 4 considerations.

RESULTS

Most students immediately recognized the coupling of the library and reverse engineering assignments was not only an efficient use of their time but exciting as well. None of the students had ever engaged in reverse engineering nor had they been given a new item and told in effect, "take it completely apart, reassembly is optional." Although it was unlikely that a particular item was completely unfamiliar to the student, few, if any of the students had any prior detailed knowledge of their items. Consequently, everyone started at the same level: discovery. Disassembly not only required some sense of how the item was assembled and the proper use of simple hand tools, but it also taught the students to be methodical, be especially observant, and to take good notes. This situation made for a very dynamic lab activity.

As students proceeded with their disassemblies, collected their information, and started with the writing of the results, they were told not only to consider how the considerations from Criterion 4 were relevant to their items but also how the considerations might impact the items of their fellow students. This cross observation provided the main benefit of the entire exercise. For example, a student with a low-flow shower head would have little problem articulating the environmental impacts of the item (less water used, less waste water to dispose of), however what about the social and political impacts. A particularly difficult concept for some students to grasp is "sustainability." This fact may be due to their scant knowledge of manufacturing processes, but when they consider an item like plastic packaging film made from fossil fuel and with a landfill life of hundreds of years, the concept becomes clearer. One student received a common plastic box cutter as her reverse engineering item. In a particular poignant commentary concerning how these may have been used on 9/11, she covered well the ethical, health and safety, social, and political considerations relative to her item. Paraphrasing the quote of Daniel Boorstin, she said she was certain the designers of her simple utilitarian device never envisioned the destructive use it would be put to.

CONCLUSIONS

The use of a reverse engineering assignment based on a simple commodity item and coupling that assignment with a library assignment aimed it researching the manufacturer and related industry appears to be a good way to provide a learning opportunity that brings to life the considerations of ABET Criterion 4. Students both enjoy the exercises as well as demonstrate their appreciation of realistic questions regarding the economic, environmental, ethical, and social impacts of the item as well as the manufacturability of the item, the degree to which its application is sustainable, and the item's effects on users' health and safety.

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