A Handbook to Address ABET Criterion Four Issues

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Introduction

The School of Engineering at Santa Clara University has developed an Engineering Handbook to address a number of issues that have often not been treated in engineering programs. These include the eight issues specified by ABET under Criterion Four, as well as three additional issues that are of particular interest to Santa Clara University. In ABET's words[1]:

"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."

In developing the Engineering Handbook, Santa Clara University has added three other considerations: usability, compassion and lifelong learning.

Criterion Four also calls for:

"a general education component that complements the technical content of the curriculum and is consistent with the program and institution objectives."

Some of ABET's eight specific considerations have close ties to the general education component, most notably: ethical, social, political and economic.

In addition to helping meet Criterion Four objectives, the Handbook is designed to serve an important integrative role, by showing students how the ABET considerations relate to the traditional technical components of the curriculum, and at the same time how they relate to the liberal education of the engineer.

The Handbook is designed to be used throughout the four-year curriculum. Faculty assign a reading from one of the chapters and then give an assignment that follows from the reading. By the time the students reaches the senior design project he or she is ready to seriously address the ABET considerations. Moreover, the student has had the opportunity throughout the four years to reflect on and take account of the relation of their technical studies to broader concerns addressed by the eight ABET considerations.

Hence, the value of the Handbook to the student is that it provides a source of information on issues that are often difficult to research, and furthermore, helps students to see the interrelationships among the various considerations.

The value of the Handbook to the faculty at Santa Clara University, and to other faculty who may wish to use the material, is that it brings together in one place material that addresses the eight ABET considerations, and that it provides a set of case studies that can be used to help students study the topic, and which can be assessed to measure student understanding.

This paper has four parts.

- Description of the Handbook
- General Use of the Handbook in the Program
- Some Specific Examples
- Conclusion

Description of the Handbook

The Handbook has an introduction and 12 chapters.

1. Manufacturability
2. Sustainability
3. Usability
4. Health and Safety
5. Environmental Impact
6. Ethical
7. Social
8. Political
9. Economic
10. Compassion
11. Lifelong Learning
12. Bringing it All Together

Each of the twelve chapters has a discussion of the issue in question followed by a number of problems or cases that students can be assigned.

Of the eleven above issues we have added three, usability, compassion and lifelong learning. The other eight are the issues specified by ABET in Criterion Four of EC2000. ABET requires that these issues be addressed in senior capstone projects. We added usability to the list because we believe that it is important for the engineer to consider in the design process the needs and capabilities of the user. Too often engineers design products that fit their own backgrounds and needs.

We define compassion as “the awareness of and sympathy for the suffering of another, and the desire to relieve that suffering.” Engineers are in a unique position to relieve the suffering of many people throughout the world. We use Chapter 10 as a means of giving our students the chance to reflect on such opportunities. The inclusion of this material follows from the University’s goal of developing in each student “Competence, Conscience and Compassion.” One of our ABET Program Outcomes in the Electrical Engineering Program is to achieve this goal in each engineering student. Compassion is an inherently difficult outcome to assess. Chapter 10 was designed to help us make this assessment.

We added Chapter 11 on lifelong learning to give us a formal way of addressing this important and difficult subject. The chapter starts by pointing out that much of what we learn will always be useful, but that there will be in addition much more that we will have to learn in the future. Bloom’s Taxonomy is then introduced as a way of understanding various stages of learning. We have adapted the taxonomy to apply more directly to engineering education. For example, under Knowledge, the Skills list was rewritten to include such terms as: Observation and recall of data, concepts, equations, laws of physics. Knowledge of engineering practice, degrees of accuracy, standards. After Bloom we move to Gardner’s Multiple Intelligences. Students learn about the concept of multiple intelligences or learning styles, and are then directed to a website that allows them to take a multiple intelligence test. The chapter concludes with sections on critical thinking, communication, and learning to study.

Chapter 12, Bringing it All Together, recognizes the fact that the first ten issues considered in this handbook can almost never be considered in isolation. In most situations issues such as health and safety or environment, for example, have economic implications, perhaps sustainability questions, social or political considerations. Many of these issues can find themselves interrelated in a given engineering development. Related to this complexity is the fact that most important engineering problems must be considered as having no unique solution that would be considered optimum with respect to all considerations. E.F. Schumacher[2] called these “divergent problems”, and he reminded us that we usually don’t like such problems.

“Divergent problems offend the logical mind, which wishes to remove tension by coming down on one side or the other, but they provoke, stimulate and sharpen the higher human faculties, without which man is nothing but a clever animal.”

We need to tell our students that most of the problems that they will face have no solution that is optimal in all regards, but that they must find a solution anyway.

General Use of the Handbook in the Program

The Handbook was designed to be used throughout the four-year engineering program. The normal mode of use is for an instructor in a course to assign a chapter or part of a chapter for students to read, and then one or more cases or problems to apply the concepts of the chapter. Sometimes the material may be closely associated with the content of the course. A Civil Engineering course in structures might address health and safety issues by assigning Chapter 4 and a case involving the structural failure of a building. But sometimes there is no apparent connection between course content and work from the handbook. In a course in electromagnetic field theory the instructor assigned Chapter 11 and four problems.

The Handbook was first introduced in September of 2003 to the freshman engineering class in an Introduction to Engineering course. Students were assigned Chapter 11, on lifelong learning, for reading, and they then took a web-based multiple intelligences test. The goal is to have each student be exposed to each of the twelve chapters at least once during the four year program.

A major use of the Handbook has been in the Senior Capstone Project since it gives instructors and students clear access to the eight issues required by ABET. These issues are introduced by means of the handbook in the Fall of the senior year, where students meets as a class to start their projects. Instructors assign readings from the handbook, and discuss considerations in class. Students are required to write a formal report on their projects, which is due in May of their Senior Year. In 2003 we began the practice of requiring a specific chapter in the report on ABET Criterion Four considerations. The first students who wrote these chapters did not have any formal introduction to this matter, and the results were rather superficial. Students who complete their reports in the Spring of 2004 will have had that formal introduction, and we will assess carefully the effect of that work.

Some Specific Examples

This section introduces some representative examples taken from the handbook.

Chapter 4 is on Health and Safety. It begins by raising some examples of major engineering failures, The Tacoma Narrows Bridge, the Challenger Space Shuttle, the Ford Pinto, and others. This leads to a discussion of why things go wrong, citing some of the things that can happen: material failure, poor design, environmental effects, human error, combinations of these. The chapter discusses unanticipated consequences, where they come from, and what if anything can be done about them. Engineering for safety is another topic. We introduce the Japanese term “poka-yoke”, which means mistake-proofing, that is, designing to thwart the mistakes that the user may make. A simple example is the drain hole at the top of a wash basin that keeps water from overflowing if we leave the water on. Another example is the car that won't start unless it is in park, the circuit breaker that trips if you try to draw too much current. We give our students the following case to let them try their hand at poka-yoke.

Case 4.4: Here is a poka-yoke opportunity that actually happened. A large device is being built on a production line. At one point a spring must be installed behind each of two switches, in a place where the spring is not visible from the outside. The procedure is for the worker to pick one spring out of a box of springs and install it. The worker then picks out a second spring and installs it behind the second switch. Occasionally the worker forgets the second spring, and the product is shipped with one missing spring. The company must then send out an engineer to correct the problem, a very expensive process. Come up with a very inexpensive poka-yoke that will prevent this problem from arising.

The solution turned out to be quite simple. The company invested in some little plastic boxes. The production line worker took two springs out of the box of springs and put them in the plastic box. The system did not move on until both springs had been used.

Sometimes engineering projects need political resolution. What is the cost of safety? Chapter 8 introduces a problem that allows students to think about what society may be willing to pay for a given level of safety. Here is a made-up problem designed to spark discussion.

A community decides to build a new school in a region that has occasional strong earthquakes. The basic cost of the school is $10,000,000. The design engineer points out that the probability of no loss of life in an earthquake over the life of the building can be increased by various additional steps in the construction. The table below gives the estimated probability of no loss of life versus the cost for the required additional work.

Probability of No Loss of Life	Additional Cost
10%	$500,000
25	1,000,000
50	5,000,000
75	40,000,000
90	500,000,000
99	20,000,000,000

Chapter 9 develops the economics of engineering systems, stressing the difference between fixed and operating costs. We concentrate on electric power generation as a practical example that is rather easy to understand. Students discover why the "free" energy that comes from the sun, the wind, the tides, is not really free because of the capital costs of such systems. At the same time they see how solar power, for example, is becoming increasingly competitive with the fossil, nuclear and hydro sources that provide most of our electric energy today. Although not presently developed in the Handbook, this gives the instructor an excellent springboard from which to discuss related issues such as the geopolitics of oil, the environmental impact of solar, the political wisdom of state support of developing energy systems, ethical issues relating to the rights of as-yet-unborn generations, and many more. The number of considerations is endless. We can't talk about all of them, but we must talk about some.

Conclusion

This section reports on our experience with the handbook to date. We considered carefully how to best make the handbook available to faculty and students. We considered publishing the handbook internally. However, that would have been quite expensive as it is, at this time, over one hundred pages in length, and we would have had to print about 750 copies. In addition, printing it in hard copy would have taken away the flexibility that we sought in an evolving tool. We considered putting it on a website, and in the end we decided to put it in the School's course enhancement software site (Angel). It was easy to do this, inexpensive, and allowed for very simple additions and changes to the handbook.

This decision was a mistake on our part. Students who were assigned sections of the handbook used it effectively with few if any problems. Faculty, on the other hand, without the pressure of a required assignment, stayed away in droves. Few faculty went into the course enhancement software to view the handbook. The exception were those teaching senior projects where the need for the material is immediate, and a handful of others who saw the broader value of the material. In retrospect we should have printed enough copies for all faculty, and made it clearer how the handbook could be used.

Faculty inertia was not the sole obstacle to use of the material throughout the various department cores. Some faculty feel that introducing non-traditional materials in their courses is not appropriate. "If it isn't circuit theory, it doesn't belong in my course." The idea of integrating material throughout the four years is not accepted by all. Some feel that integration is something to be done in the senior project, or perhaps later in life. Others believe that integration of the material will strengthen the overall education, and perhaps even create better circuit theorists. The latter hope that as ABET EC2000 ideas become more broadly understood and accepted, the value of integration will be clearer.

The Handbook is a work in progress. We are considering new sections, perhaps in the area of project management, teamwork, critical thinking, and others. It is also our hope that others will critique the material, and propose new ideas, cases, etc., so that the document grows and improves with time. In the Summer of 2004 we will do a major revision of the Handbook, making use of some outstanding critiques that we have received to date, and we will publish at least enough copies for the faculty. In addition the School has created a program to ensure continuous improvement of all of our work, called Program Improvement Process for Engineering (PIPE). PIPE will introduce in the Spring of 2004 a faculty development program that will consider important ideas in teaching and learning. One part of that program will include use of the Handbook.

It is our hope that the Hand book will continue to develop, and become easier to use, for our students as well as for any faculty and students across the world who find it effective. We also hope that users of the Handbook will offer critiques, and contribute new ideas as to how it can be more useful.

The Handbook will be placed on the website of the School of Engineering. The School's website is at: http://www.scu.edu/engineering/. The URL for the Handbook was not determined at the time this paper was written. Interested persons who have problems accessing the Handbook, or who wish to comment on the Handbook, are invited to contact the author at: thealy@scu.edu The author would be happy to hear from persons who have experience using this material.

Bibliography

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Biography

TIM HEALY received his BSEE from Seattle University in 1958, MSEE from Stanford University in 1959, and PhDEE from the University of Colorado at Boulder in 1966. He has taught electrical engineering at Santa Clara University since 1966, primarily in communications, and electromagnetics. He has also taught engineering ethics and has written a number of papers on ethics and other social issues.