

Teaching Mechanical Engineering to the Highly Uninspired

By: MAJ Tony Jones and LTC Grant Crawford

Abstract:

It is widely accepted that undergraduates require a general education in numerous disciplines as part of being a well rounded, educated citizen. Courses in arts, humanities, foreign languages and many other disciplines populate the student schedule. At the United States Military Academy (USMA) at West Point, all non-engineering majors are required to complete a three course engineering sequence as part of their undergraduate degree program. This sequence typically begins in the fall of their junior year and can be conducted in one of seven engineering disciplines. Predictably, the students taking these sequences have tended to view this experience more as a distraction from their academic program rather than an enhancement to it.

In response to student and faculty dissatisfaction with the final course in the mechanical engineering sequence in 2004, the lead author of this paper undertook a major revision of the course prior to the fall of 2005. The primary question posed: How do I motivate a student who does not want to be here in the first place? As part of the revision process, he examined techniques that could be used to promote a team environment in the classroom. Demonstrating the relevance of the course material and increasing student involvement were also areas of focus.

These goals were achieved by implementing a program of short term goal setting and hands-on projects that supported the overall objectives of increased student learning and achievement of USMA's Engineering and Technology Goal outcomes. The results were remarkable. Students, who expressed concern about their abilities to perform well in the sequence at the beginning of the second course, completed the program wondering if they had made a mistake in NOT majoring in mechanical engineering.

This paper describes the issues, examination of methods used in other courses to enhance student motivation, implementation of techniques in the second and third courses of the sequence, assessment of the results, and recommendations for its applicability outside of USMA. Student feedback and the comparative results of student surveys from previous iterations of the course as well as current student surveys are presented. The students discuss their own motivations and reactions to the course. From the teachers' perspective, we discuss what worked well and what items could be improved or deleted. Finally, we will make the case that engineering should be an integral part of every student's undergraduate experience due to such factors as an increasingly technologically based society and the lag in engineering education in the United States as compared to the rest of the world.

Introduction

The United States Military Academy at West Point awards a Bachelor of Science degree to each graduate that completes its four-year academic program. Within this program, students are free to select one of a number of academic majors, many of which fall in the realm of the liberal arts. Because of the stress on breadth of the experience, those students desiring to major in a non-engineering discipline are required to take, as a minimum, a sequence of three courses from one of the engineering programs. They may select from Chemical, Civil, Electrical, Environmental, Mechanical, Nuclear, or Systems (Management) Engineering. Table 1 depicts the courses included in the Mechanical Engineering (ME) sequence.

Table 1. Mechanical Engineering Three-Course Sequence

| Course | Content |
|---------------------------------|--|
| Statics and Materials | Static Analysis of Rigid Structures, Stress, Strain, Bending, Torsion |
| Introduction to Thermal Systems | Fundamentals of Fluid Mechanics, Thermodynamics, and Heat Transfer |
| Mechanical Engineering Design | Design Process and Techniques, Aerodynamic Stability, Torque, Power, and Gear Trains |

The purpose of the three course engineering sequence is to accomplish the institution's twelve Engineering and Technology goals as outlined in the USMA academic program publication, "Educating Future Army Officers for a Changing World"¹. While these are specific to our institution, they represent many of the goals that most engineering programs would like for their students to be able to achieve.

Table 2. USMA Engineering and Technology Goals

| | |
|---|--|
| 1 | In an environment of uncertainty and change, identify needs that can be fulfilled via engineered solutions. |
| 2 | Define a complex technological problem, accounting for its political, social, and economic dimensions. |
| 3 | Determine what information is required to solve a technological problem; acquire that information from appropriate sources; and, when available information is imperfect or incomplete, formulate reasonable assumptions that facilitate the problem solution. |
| 4 | Apply the engineering design process and use appropriate technology to develop solutions that are both <i>effective</i> and <i>adaptable</i> . |
| 5 | Demonstrate creativity in the formulation of alternative solutions to a technological problem. |
| 6 | Apply mathematics, basic science, and engineering science to model and analyze a physical system or process; and apply the results of that analysis to the solution of a |

| | |
|----|---|
| | technological problem. |
| 7 | Work effectively as a member of a team to solve a technological problem. |
| 8 | Plan the implementation of an engineered solution. |
| 9 | Communicate an engineered solution to both technical and non-technical audiences. |
| 10 | Assess the effectiveness of an engineered solution. |
| 11 | Demonstrate basic-level technical proficiency in an engineering discipline that is relevant to the needs of the Army. |
| 12 | In response to a technological problem, learn new concepts in engineering and learn about new technologies without the aid of formal instruction. |

Background

The first course in the mechanical and civil engineering sequences is a course in static analysis and materials taught by the civil engineering faculty. It is not until the second course in the sequence that the student meets the mechanical engineering faculty. The faculty members are predominantly mid-career U.S. Army officers with a Master of Science degree in a mechanical engineering discipline, comfortable with more advanced mechanical engineering concepts, and accustomed to teaching engineering majors. A smaller segment of the faculty consists of senior U.S. Army officers and civilians who have earned a Ph.D. in their discipline.

The typical student arrives in the second course of their engineering sequence as a second-semester junior, well entrenched in their academic major. The math and science portion of their education is completed and only two engineering courses remain in the technical domain of their degree programs.

Imagine the thrill and excitement of a student who is majoring in foreign language or history when he or she walks in to that first mechanical engineering class. To assess the level of potential challenge, the faculty administers an anonymous minute-survey during the 2nd or 3rd lesson. One of the questions posed is, “What concerns you most about ME350?” On the most recent survey one student answered:

“The amount of work that has to be done for a class that is not interesting.”

This response is typical of the feedback received over the past three years that the lead author has been teaching this student audience. Students generally see the engineering sequence as a distraction from their education and, in some cases, express genuine concern that they do not possess the mathematical skills to succeed in the sequence as supported by Meyers’ observations². After considering this initial feedback in the spring of 2005, the lead author posed the following question:

“How do I motivate a student who does not want to be here in the first place?”

This led to other questions. What can the professor do over the period of two semesters to get a student excited about doing something that the student would never have chosen to do on their own? How does the professor make the student feel like they are part of the team and not an outsider? These are questions which fall into the realm of student motivation and perception.

Some Ideas on Motivation

"A soldier will fight long and hard for a bit of colored ribbon"
- Napoleon Bonaparte, 15 July 1815

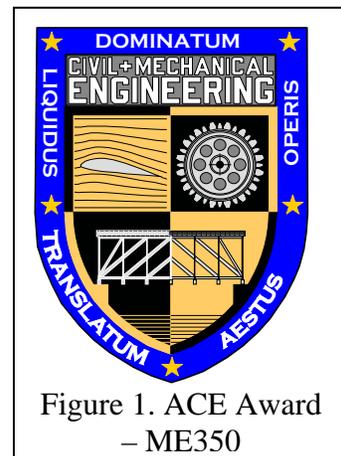
As the lead authored mused over these questions, Bonaparte's quote was one of the first thoughts that came to mind. The military is always working to find ways to motivate and inspire young men and women to do things that they would not normally choose to do and to do them enthusiastically and to a high standard of performance. What 'bit of colored ribbon' would appeal to these students and how could this be couched in a way that would make them feel as if they were part of a team?

There was another concern – time. According to Gandolpho³, "*Research indicates that undergraduates construct their attitude toward a course during the first two weeks of the semester.*" It would appear that first impressions are important. It was clear from the previous feedback that action was needed. Whatever actions were taken would need to be accomplished early in the course.

A survey revealed several examples of performance awards at the school; most involving physical and military training endeavors. The lead author looked at some other courses and found two instances in which patches were awarded to students based on a set of achievement criteria. Both of these were primarily focused on motivating individual performance. While important, the authors were also interesting in having students from different academic majors see themselves as part of one team; working together and encouraging each other to enhance their learning experience.

The ACE Award

Following the initial survey in 2005, the lead author began the semester's third lesson by telling the students that they were no longer students in a class; they were now pilots in a World War I Flight Squadron. The instructor was now their Squadron Commander and they were each given unique 'call signs' based on data the students had provided on an initial student survey. No longer were they 'students' attending 'class' to 'learn engineering equations' in order to 'pass an examination'; they were now 'pilots' attending 'flight briefings' in order to develop new 'weapons' with which to 'engage the enemy.' Those students recording at least five



victories during the course of the campaign (semester) would be recognized as ACE's and earn a patch (figure 1) and a certificate. The patch design consisted of the department's crest surrounded by five stars and five latin words; four related to the course content with the fifth (*Dominatum*: to master) on top. The lead author formalized the program with a two-page letter placing it in a historical context. A portion of this initial guidance given to the students is attached as Appendix A at the end of the paper.

Students earned victories for the following achievements.

- Maximum Score on Homework Problem Set: 1 Victory
- Maximum Score on a WPR Problem: 1 Victory
- Maximum Score on a TEE Problem: 1 Victory
- Top Score in the Design Competition: 2 Victories per Team Member

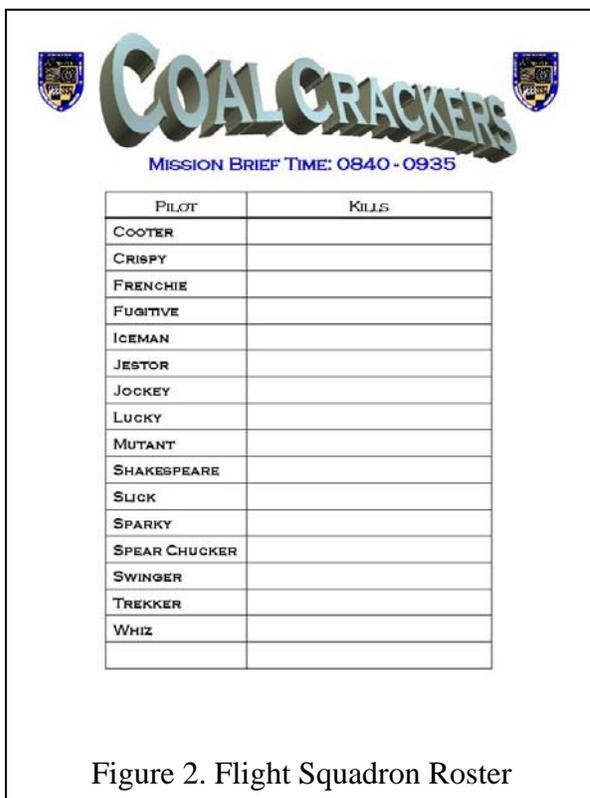


Figure 2. Flight Squadron Roster

The new 'pilots' nominated and voted for a name for their flight squadron. Those pilots who earned a victories throughout the semester were rewarded with an emblem to post on the flight section roster (figure 2) at the rear of the class.

At first consideration, this may seem a little extreme and out of character for an engineering class. When asked to provide feedback on the ACE award program at the end of the semester, one student's comment was, "It's a tad goofy, wouldn't you say?" The obvious answer is 'Yes!' It is a tad goofy, but it is also great fun and the payoff in terms of student perception and learning was much improved over the previous semester. Typical responses from the students to this request to comment on the program are best represented by the following two samples.

"It did help motivate me on the problem sets. I know that I can get a good grade on the problem sets by putting in a little effort, but in order to get a perfect score I needed to fully understand the material and needed to put in a lot of effort. This required me to go to my classmates for help and led to very helpful discussions about the material, which in turn helped me on the WPRs. All because I did not want other people to get the award and me be left out."

"This was a great idea, here's why. When I'm doing a problem set, the difference between getting a 49 and a 50 is the ten or fifteen extra minutes it takes to make sure I've got

everything squared away. But they are both A's, so who cares. However, with the ACE thing, I might actually spend the extra time, just for the fun of it. The whole package came together very well (flight names, call signs, aces, etc). I would keep it all."

The entire program was so successful that it was couched in terms of a World War II theme and repeated for the final course in the ME sequence. The second ACE Award patch is depicted in figure 3.

Additional Techniques

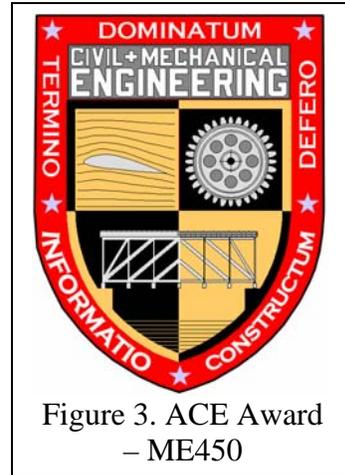
Some additional techniques were utilized in the sequence courses to maximize the role of the students as active learners. Techniques used in the final course in the ME sequence are typical and presented in this section.

The final course, ME450, focuses on mechanical engineering design. During the first day of class, students are placed in teams and told to design and build a bridge that will support a three text book load. They are given only newspaper and masking tape for materials. Within 30 minutes, the students learn that engineering is more than throwing materials together. It involves the efficient solution of complex problems using limited resources.

The instructors employ numerous video segments to illustrate key concepts. Clips from the children's movie *Chicken Little* are utilized to show the fantasy analogy method of concept development, while the movie *Chicken Run* is utilized to show the principle of thrust. Clips from *Monster Garage* and a weight room in Iraq are utilized to teach how to develop desired functions in a design process; and a discussion about the cartoon *South Park* and the evils of engineers who do not generate proper customer requirements ties into current student trends and culture. These efforts are further augmented by starting each class with music or a video clip from contemporary shows; every effort being made to tie the media into the lesson content. The effort was highly rewarding as judged by one of the students.

"I think the use of videos and slides at strategic points in the class was good because whenever I was sleepy, I would get a jolt from the audio/video explosion."

While this is an effective component of the classes, the primary key to maintaining a high level of enthusiasm and learning are the various Engineering Design Projects (EDPs) and hands on learning activities that are interspersed throughout the semester. These are the primary vehicles that are used to teach both the engineering design process as well as basic engineering skills to include modeling, problem solving, and working as a team. The EDPs are designed to be evolutionary in nature. They become progressively difficult and more complex as the semester evolves. Everything in the course supports the EDPs.



A key support are the numerous hands on learning activities scattered throughout the course. They run the spectrum from simple (several rockets laid on student desks to augment a lesson on stability) to complex (design and build a Lego transmission in class). One of the more enjoyable classes is the welding lab where students are given an opportunity to weld two pieces of mild steel together (see figure 4) and then test them on a tensile test machine. Bonus points are given to the top weld. Another example; an in-class miniature LEGO tractor pull demonstrates the principals of traction and torque as well as giving a demonstration of the calculations needed in the final EDP. These were extremely popular and instructional:

“Of all the teaching methods I have observed, I enjoy actually doing it the best. I like having demos on the desk and [being able] to move things with my hands. This is because I learn best when I physically touch things with my hands.”

“I believed that the majority of the lessons would be lectures associated with problem sets and [midterms]. However, I soon discovered that this class was a hands-on experience and beneficial challenge for me to use my creativity and exercise some of the skills that I had learned in my previous classes.”



Figure 4. MIG Welding a mild steel butt splice.

These statements exemplify a sentiment found throughout the feedback we received for the course: that hands on learning is the best and most enjoyable for a majority of the students.

The primary vehicles for the students to exercise their creativity are three EDPs. The first EDP involves putting the student forward in time by 1 and ½ years. They are now working at a remote location with no facilities for an extended period of time. Their supervisor has assigned them the task

of designing a temporary shower facility for the company. The budget is set and materials are restricted to those that are commercially available. This is strictly a paper design and for this reason is generally not favored by the students. It does, however, allow them to exercise immense freedom in their design and a chance to practice the design process prior to designing and building an actual artifact. This EDP also gives the cadets an opportunity to apply the knowledge that they have attained in previous courses. It is a good vehicle for initially teaching the design process.

The second EDP adds to the complexity in two ways: first it is an actual design that must be built and secondly it utilizes new material that the cadets have been recently exposed

to. The second EDP is styled as an over the horizon reconnaissance device. It is an extension of a water bottle rocket project used in some high schools to demonstrate physics. The extension is the fact that rather than aiming for the highest and farthest launch, the cadet EDP requires that the device carry a specified payload, exhibit maximum time in the air, and be accurate. The cadets are given a standard launch platform (see Figure 5) and are required to both model and validate their model with a test fire. On their record fire day, they must aim to land on a target within a 20 foot diameter circle at a distance of 150 feet. This also introduces a key concept of engineering design, the fact that the engineer usually has to wrestle with competing and conflicting requirements.

The second EDP was extremely popular but the need for a second test launch was felt by both students and instructors. This EDP was simple to construct and required a limited amount of material. An added benefit was the ability to demonstrate the fact that engineering can be fun to the school’s general student population. The test and record firings were executed in a central area, one of the most visible portions of the campus. It was observed by the student body, visitors, and high school students visiting the school. The recruiting aspect of this event was a pleasant surprise. The difference between EDPs one and two is easily seen by the following student comment:

“EDP#1 was somewhat boring and not as developmental as the other two. I enjoyed the bottle rocket EDP the best.”



Figure 5. Screenshot of USMA Homepage Showing EDP #2 Launch Platforms with Student Project Mounted

The third EDP is viewed as the culminating experience for the cadets and is the most difficult. It requires the cadets to design and build an “Unmanned Ground Vehicle” prototype. This is based on the need for devices to remove and defuse Improvised Explosive Devices (IEDs). This real world scenario is immediately applicable to the United States Army and the students’ future profession. This is rapidly overshadowed by the fact that there is a competition where groups take their robots and compete in a single elimination tournament. Due to this highly competitive environment, the

authors determined that a standardized set of materials should be provided to each design team. This was accomplished by augmenting the LEGO Mindstorms Set #9649 with

several additional items. These sets are issued to the students for the development and construction of their devices during the last third of the semester.

Because of these Lego sets, the third EDP would be the hardest to adjust. It is far and away the most resource intensive of the projects and requires a significant effort to pull all of the pieces together. To generate an appropriate level of excitement, the venue for the final competition required a large setup so that the 5 foot by 8 foot battle arena (see Figure 6) could be broadcast to an audience of 125 people. The greatest lesson that we learned is to have all of the required materials prepared well in advance.

This EDP was also more difficult for the students. They have a large variety of materials to choose from (as opposed to being restricted to a two-liter soda bottle) and a multifaceted problem: focus on scoring or attacking the opponent, speed verse controllability, etc.; the number of tradeoffs is significant. The LEGO sets are capable of building very complex machines but the rules of the contest limit the size that the cadets can use and a single nine volt battery power supply rewards those who design efficiently. The student satisfaction with the EDPs throughout the course is reflected in the following student comments:

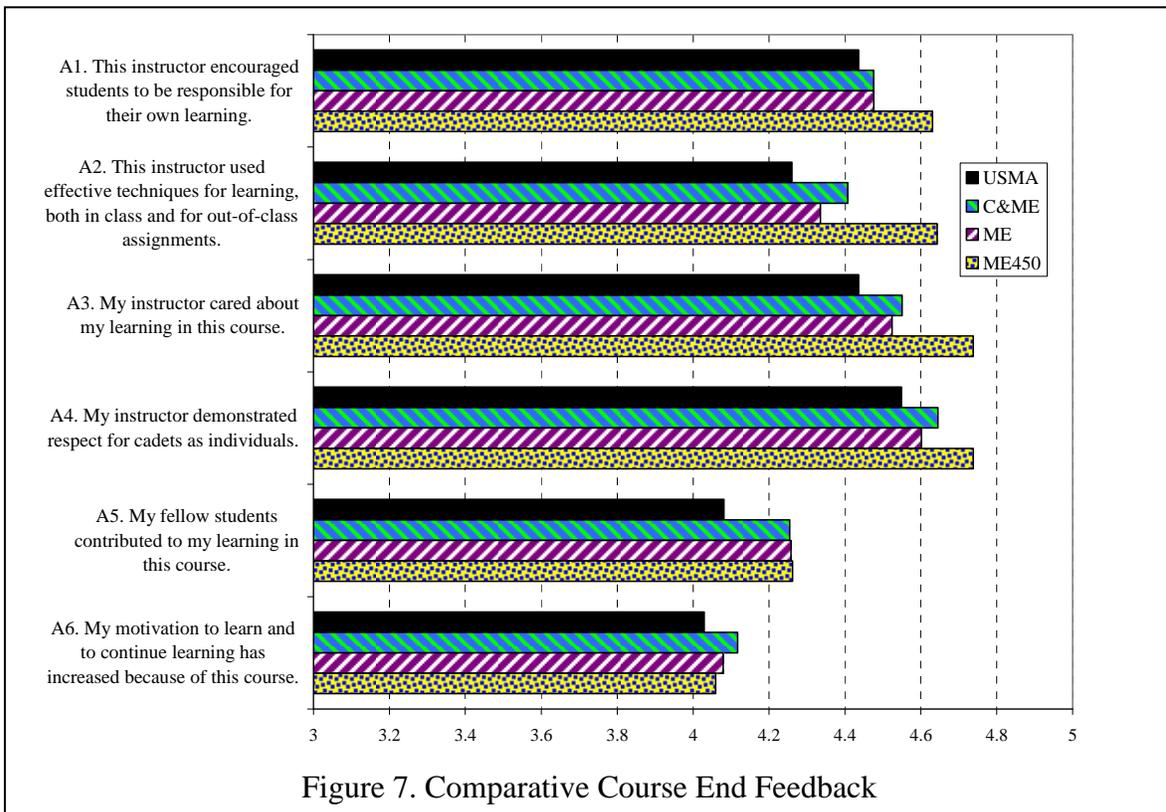
“The past 26 lessons have been quite interesting to me. However, the engineering design projects taught me the most thus far. They incorporated all of the concepts that we were learning and allowed us to see how they fit together and aided us in coming up with a sound, educated solution for the problem.”



“I think the layout of the EDPs were very well thought out and complimented the progression of the class. This is by far the best MECH track class. “

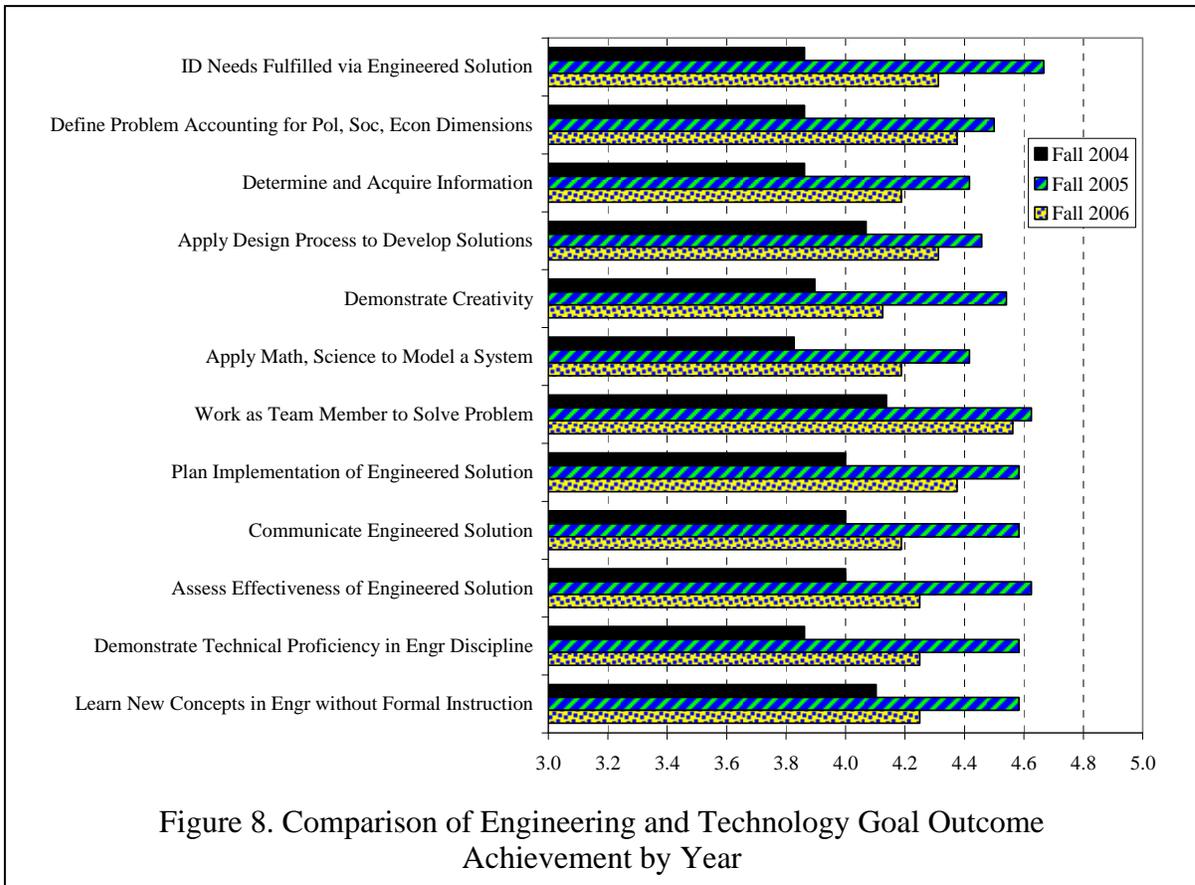
Results

Of the many outcomes desired from this semester, two stood out: a non-engineering population that has a greater appreciation for the role of engineering in our society and students who can solve problems and function as life-long learners. The ability to meet these outcomes hinged largely on the ability of the faculty to actively engage the students and motivate them. When surveyed at the end of their three course engineering sequence, the students had a remarkably positive feedback. Comparison of the non-engineering students’ responses to standard Academy-wide questions is presented in figure 7.



In all but one area, the students in the last course, ME450, rated those areas higher than all students at the academy, all students in the department, and all students in the Mechanical Engineering program.

Another telling measure of the improved perception of the course is provided by a comparison of course-end feedback asking students to assess their ability to achieve the Engineering and Technology Goal outcomes listed in Table 2 (see figure 8).



Implementation of methods in the second year resulted in a significant increase of perceived student ability. Figure 8 also shows that ratings fell in the third year. While the reasons for this are not fully understood, it may be due to an expansion of enrollment in the three-course sequence resulting in an overall incoming grade point average significantly lower than that of previous years. Nevertheless, the written comments from the non-engineering majors continue to be a cause for both joy and concern.

“I am sorry my ME sequence is over”

“My experiences with and sometimes make me wish I would have been a Mechanical Engineering Major.”

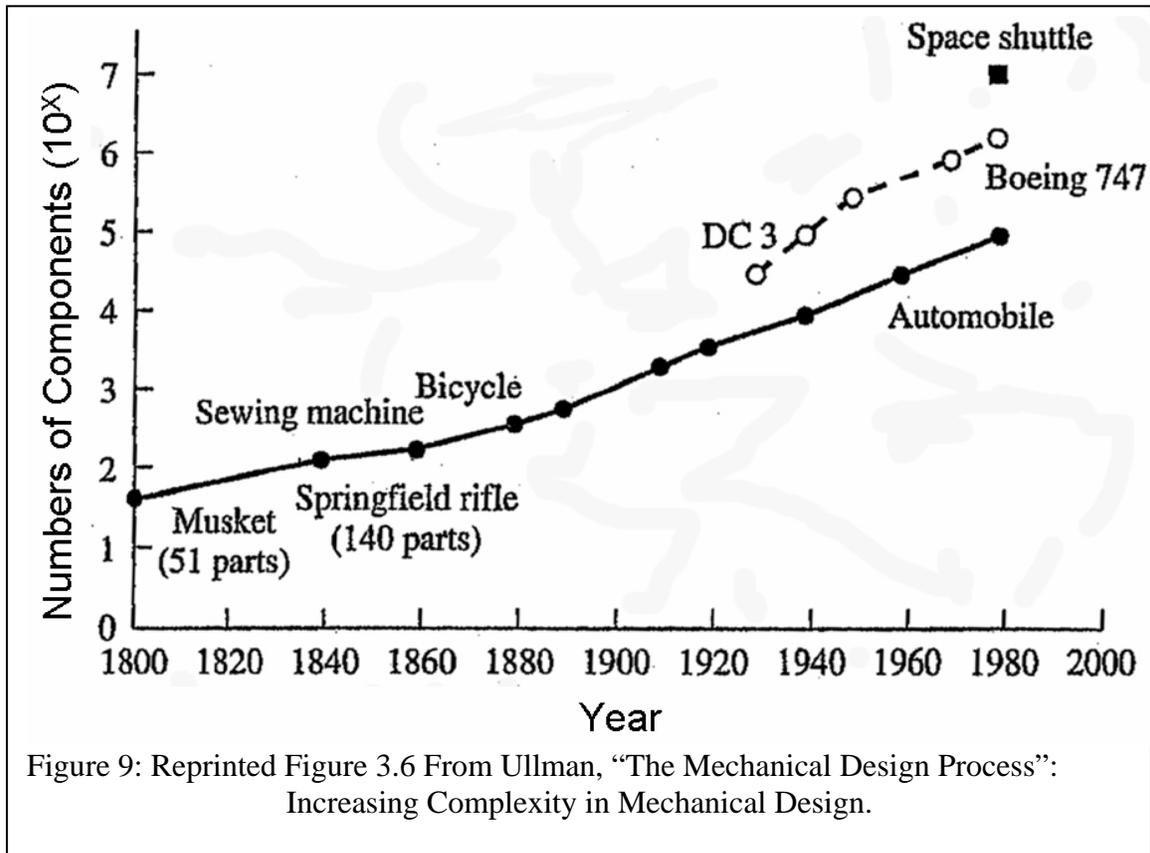
“I enjoyed the course very much and feel as if I should've been a mechanical engineering major.”

“Last year, I never would have imagined myself ranking a Mechanical Engineering class among one of my favorite courses I've ever taken. I found ME450 to be a very interesting class that challenged me in an area that I actually wanted to be challenged in.”

Are we doing enough to educate our freshmen about engineering before it is too late for them to pursue it as a career? That is a topic for continued thought and discussion.

Application to Other Institutions

The reader has now seen how this course is implemented at the United States Military Academy. This generates several questions; a key one being, “Should a similar program be instituted elsewhere – should engineering classes become part of the general education of every undergraduate student?” The reasons that the answer is a resounding YES are numerous. Figure 9 is a depiction from one of the textbooks the authors reference in the course showing the increasing complexity in the machines that make up our everyday life⁴. Technology is developing at ever increasing rates and this is a cause of concern for those who are not ready. In quoting Jacques Ellul, an English professor from Miami states that due to the autonomy of the machines of our modern world, man is a simple catalyst and the “sense of helplessness can be overwhelming”⁵. If this does not show a need for understanding engineering and the engineering design process, nothing else does. To truly be a well rounded functioning citizen, today’s graduates must have, at the least, an introductory knowledge of what engineers do and how they do it. This is as vital as being able to show a command of one’s native language or an appreciation of fine art.



Conclusions

Here are some basic facts:

- Of 1.2 million bachelors degrees issued in 2004 only 400,000 were from the United States.

- Looking at engineering specifically, Asian countries produce eight times as many engineers as the United States⁶.
- Foreign students account for 52% of Masters students and 60% of PhD students in our own universities⁷.

This will soon become a crisis of national import as we will have fewer engineers to fill an increasing number of needs.

A little effort can yield big results. Most of the techniques presented in this paper cost very little in terms of physical resources. There is a required investment of time and the most critical component is the teacher's imagination and willingness to reach out to the student. When students begin applying the principles taught in class on their own, it is clearly evident that they have developed an understanding about the relevance of engineering to their everyday lives.

Students, who have struggled in basic math and science courses and want nothing to do with engineering, can be motivated and will become excited about engineering if it is presented in a manner that is relevant and enjoyable. An effective method to accomplish these ends is to make the instruction as hands-on as possible and get the students actively involved through the use of team building techniques and group projects. In the end, it *IS* possible to turn negative perceptions into positive ones and have fun doing it.

Bibliography

1. Forest, James and Keith, Bruce – editors “Educating Future Army Officers for a Changing World”, Academic Affairs Division, Office of the Dean, United States Military Academy, West Point, NY
2. Meyers, Kevin J., “Technology and the Engineering Method for Non-Engineering Students”, *ASEE Journal of Engineering Education*, Vol. 82, No. 2, pp. 123-125, April 1993.
3. Gandolfo, Anita, “Ending and Beginning: Making Academic Transitions”, *Teaching at USMA*, Vol 10, No 10, Center for Teaching Excellence, United States Military Academy, West Point, NY, May 2005.
4. Ullman, David G., “The Mechanical Design Process”, 3rd edition, McGraw-Hill, 2003.
5. Russo, John P., “The Humanities in a Technological Society”, *HUMANITAS*, Volume XI, No. 1, National Humanities Institute, Washington, DC, 1998
6. Friedman, Thomas L., “The World is Flat”, Farrar, Straus, & Giroux, New York, 2005.
7. “Interest of US Citizens for Graduate Study in Engineering”, *Inside Engineering Education*, Report 0704A, Engineering Trends, Houghton, MI, 2006.

Acknowledgement:

This work was conducted in collaboration with the United States Military Academy (USMA) Master Teacher Program, offered through the USMA Center for Teaching Excellence (CTE), West Point, New York.

Appendix A: Excerpt from the Ace Award Program Guidance

Merriam-Webster defines the term ‘ace’ as “one who excels at something” or a “combat pilot who has brought down at least five enemy airplanes”. The use of the word in this way originated in World War I. The Germans used the word ‘kanone’ and required ten victories to earn the title. Their most renowned ‘ace’ was Baron Manfred von Richthofen (The Red Baron) with 80 credited victories, the most of any WWI pilot. While 550 British



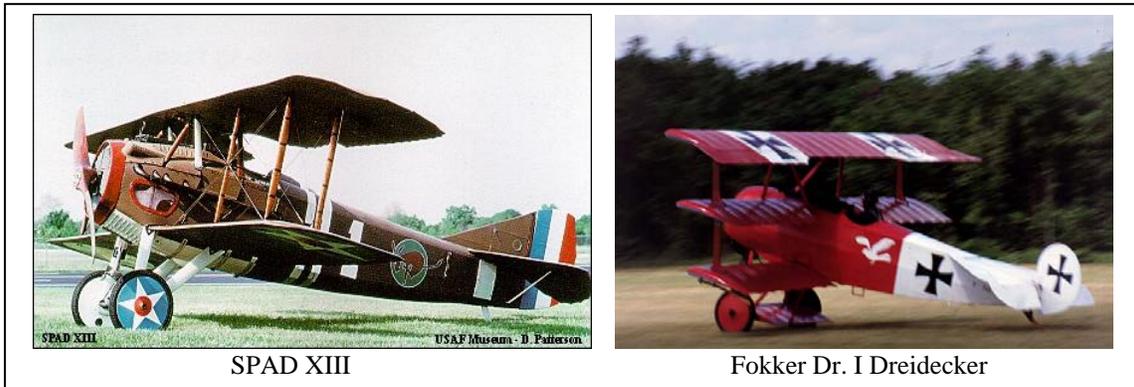
Captain Eddie Rickenbacker

pilots qualified as ‘aces’ during WWI, the British did not use the term. They felt that courage was a soldier’s duty. Of the remaining combatants, the French had 160 aces, the Italians 41, the Belgians 8, the Russians 3, and the Romanians 1. The Americans had 108 aces, the most notable being



Baron Manfred von Richthofen

Captain Eddie Rickenbacker who had 26 of his squadron’s 69 victories. Captain Rickenbacker’s airplane of choice was the SPAD XIII while the Baron favored the Fokker Dr. I Dreidecker. Both are shown below.



SPAD XIII

Fokker Dr. I Dreidecker

My job as your Squadron Commander is to assist you in developing the most potent weapon system that you will bring to the battlefield – your brain. As a valued member of your flight, your daily mission is to train and prepare yourself for intellectual combat. Combat will come to you in various forms and you will encounter numerous engagements with the enemy. If you train well, you will defeat the enemy each time. If you neglect your training, you may be the one who goes down in flames. Those who demonstrate exceptional skill during an engagement by *downing the enemy* will earn credit for a victory. Those outstanding pilots who amass five victories will earn the coveted ME350 Ace Award and go down in legend as ‘Aces’.