Cramming Twenty Pounds into a Five-Pound Bag: Increasing Curricular Loads On Design Students And Enjoying It!

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INTRODUCTION

Design has grown both as a discipline and as a domain. As a result, the number of topics to be covered in an undergraduate design course has also grown dramatically. Mechanical engineering students need a working familiarity with the various new design methodologies, proficiency with powerful Computer Aided Design (CAD) and solid modeling tools, and exposure to modern manufacturing methods. Industry (and ABET) demands that they be able to work in teams, and be effective communicators. Of course, they need to "do" design, that is, to demonstrate "the ability to work professionally in both thermal and mechanical systems areas <u>including the design and realization of such systems</u>."[1]

How can we pack all these important design topics into an already crowded first design course without turning students off to engineering? This is especially true at the United States Air Force Academy, where a student's life is highly structured. In response to this apparent paradox of increasing design topic instruction without impacting student motivation for engineering, professors in the Department of Engineering Mechanics redesigned ME 290, the cadets' first design course. We increased the amount and rigor of design methods taught, as well as added an additional design contest into this semester long course, raising the total design contests to three. In addition, we also increased the role of peer-to-peer teaching in the course. The end result has been both increased coverage of course material, as well as improvements in student performance and attitude. In this paper we reveal our secrets for increasing student load while making them happy.

CONTEXT

ME290 is the sophomore level introduction to design course at the Air Force Academy in the mechanical engineering curriculum. It introduces students to the design process, pumps them full of enthusiasm for engineering design, and gives them several hands-on design opportunities. It gives them a roadmap for their follow-on engineering courses and, most importantly, experientially demonstrates the value of these future courses in "filling their analytical and design toolbox." In fact, the design toolbox has evolved into an integrating metaphor now used throughout this and follow-on engineering courses.

ME 290 got a powerful jump start through the Herculean efforts of University of Texas Visiting Associate Professor Dr. Kris Wood, and Air Force Academy Assistant Professor Dr. Dan Jensen. They introduced formal design methods and a serialized design process focused on function, dividing the semester into methods to assist with the redesign of existing products and the original design of new products. A key element in this course was the use of hands-on experiences through the use of “reverse engineering” projects.[2]

After running successfully for a few years, the course was stable enough to weather a few design modifications. We canvassed our faculty and our Air Force constituents for their suggestions on course content and process enhancements. Unfortunately, the list of suggested enhancements appeared to be overwhelming. The changes ranged from increasing the number of design projects, switching CAD packages, integrating a new textbook, increasing manufacturing content, the list went on. At first glance there were too many needs to be addressed in a single semester. After some careful consideration, the teaming team settled on the following five needs to be addressed in the coming semester. A veteran design instructor made the bulk of the changes to the course. The modifications were the institutionalized in a sustainable fashion by team teaching with two additional instructors the next semester.

NEEDS TO BE ADDRESSED

The following five items are the critical issues our constituents recommended we add to our first Engineering Design course:

1) Better CAD/Solid Modeling Skills
The baseline CAD software was Mechanical Desktop, a package that required much classroom instruction time and did not expose the students to the advanced world of solid modeling. Additionally, the CAD tools were used for documentation purposes after the design was complete, and not during the design process in lieu of iterative prototyping. This led to a student perception of CAD not as a tool but as an academic chore.

2) Improved teamwork skills
Although thrust into teams throughout their USAFA careers, our cadets received little to no team-specific training before they enrolled in our design course. As a result, team meltdowns occurred often, and "hero-based" design was rampant. This gave rise to an academic environment with a degraded climate causing negative impacts to student learning and satisfaction.

3) Improved ties between theory and practice, as well as understanding of design methodology in context
As with much of engineering education, there was a marked gap between the students mapping of theory to practice. The design methods taught in class along with the analytical tools covered in previous courses were not fully integrated into the students' problem solving processes. Students are hungry to start cutting metal. In the past, the formal design methods were introduced to the students in a prescribed sequence. Each time a tool was introduced it was not put in context of a greater design process, only as something that had to follow the previous process. This serial presentation of formal design methods to students masks their view of the overall process.

4) Increased product realization competency with lab equipment
In an era where many undergraduate institutions are eliminating their student machine shops in response to liability and safety concerns, we believe that the best way to learn engineering is to do engineering, hands-on. In the past our cadets simply watched shop technicians fabricate wood and metal parts, rather than creating the parts themselves. Under this training program, students were not adequately familiar with the equipment in the lab. As a result, student design projects and prototypes were of low manufacturing quality, student confidence in their hands-on design and manufacturing skills was reduced, and there was an increased risk of safety violations due to lack of experience.

5) Increased awareness of advanced manufacturing technologies
One identified weakness of our undergraduate mechanical engineering curriculum was the lack of manufacturing technology coverage beyond basic machine shop processes such as milling, turning, or welding. The typical Air Force engineer is a program manager more than an engineer. As such, our engineering graduates need a broad understanding of various modern manufacturing methods, particularly those used in the aerospace industry. Many undergraduate engineering programs have a separate manufacturing course, such as at MIT and Stanford. Given the current cadet course loads there was no room to include another course to cover this vital information.

IMPROVEMENTS

When considering these five items as critical additions to an already full course, the task seemed daunting at first. Surprisingly, the changes we made to ME290 synergistically addressed all these issues. Additionally we added an additional design project, as well as increased the complexity of the final team design project. Here's what we tried:

1) Better CAD/Solid Modeling Skills
Using our site license with AutoDesk, we were able to obtain AutoDesk's new solid modeling tool, AutoDesk Inventor in the fall of 2000. Inventor proved to be a welcome, user-friendly replacement for Mechanical Desktop. Mechanical Desktop required almost 40 hours of classroom instruction to bring student competence to a level where CAD was a useful asset in the design classroom. We first implemented Inventor in the course with only three hours of classroom instruction. Cadets were given a series of assignments to develop their CAD skills, from documenting an existing artifact to prototyping their own designs in CAD. By the course mid-point, our cadet teams were able to use Inventor as a design tool to build their CAD "prototypes" before they were given their raw materials for the final design contest. This use of CAD as a design tool tremendously improved the quality, complexity, and success of their final design projects. Because of the friendly, yet powerful series of tutorial lessons imbedded in the software, cadets quickly mastered the program, and were able to turn out impressive assembly drawings of their design projects. Several cadet teams even learned and used Inventor's animation capabilities. Overall, 100+ students were trained to use Inventor in a single semester utilizing minimal class time. Building on this initial success we have now reduced the Inventor lessons to one overview (one hour) lesson, thus permitting the cadets to self-learn using the tutorials outside of class. This significant reduction in classroom "training" time has provided much of the extra time required for our other course additions.

2) Improved teamwork skills

After consulting with domain experts ranging from Doug Wilde at Stanford to USAFA experts on teams and leadership, we developed a team-building mini-course. Most teaming efforts in engineering education tend to focus on building ideal teams through the use of personality or learning assessment models like the Meyers-Briggs Temperament Indicator. While interesting, these methods do not provide the students with the skills necessary to work in any team. Our goal in developing this portion of the curriculum was to help our students develop the interpersonal skills they will need to thrive as members of any team, rather than the ideal case. In order to demonstrate the importance and value of this "fuzzy behavioral science stuff" to our students, we taught teamwork in the context of their actual design projects. As teams succeeded or floundered we were able to help the team members understand the role and importance of team dynamics to the success of their engineering design project. We also allowed our students to choose their own teams, rather than forming ideal teams based on previous personality type and other performance indicators. As a result, the students were responsible for their teaming choices! Students tended to pick their friends. At times there were residual students left to form teams with peers they had not worked with before. There appeared to be no performance bias. It seems the most defining feature of team formation at the Air Force Academy is which of the two dorms the students live in. Cadets seem to avoid walking the football field distance between the two buildings as if it were pure torture! The increased student responsibility for team member selection translated to more active team management by students, as opposed to the typical passive complaints to the faculty responsible for their teaming situation.

The mini-course consisted of an hour on Understanding Yourself, another session on Understanding The Context Of Your Team And Customer, and the last on skills to Identify And Mitigate Team Conflicts. After these sessions, each team had interviews with the instructor to discuss teaming issues either viewed by the instructor or revealed through peer reviews. This proved invaluable in resolving team issues before they ballooned. Additionally there were significant increases in team satisfaction. When compared to the student team satisfaction and performance in previous semesters, the terms with this added emphasis on team building not only performed better, but also enjoyed the class more. More significantly, there were no team meltdowns in the terms with the team building sessions.[3] Team meltdowns are defined as a total project stoppage and inability for the team to continue to work together.

Figure 1: Happy Designer after one of the ME290 design contests.

3) Better ties between theory and practice, as well as understanding of design methodology in context

We made improvements to this issue through aggressive signposting. That is providing the students with a big picture of what how each new topic and tool would integrate into their practice of design and help them to design better products. During the critical times of their three design projects, we highlighted examples of analytical techniques as useful tools to decrease their design risk. Also, throughout the course, we used signposting to put their efforts and the design tools they were learning in context of an overall design process. The following two process diagrams were used throughout the course to map where the students were in the design process, as well as how the tools they were learning and using would positively impact that process.

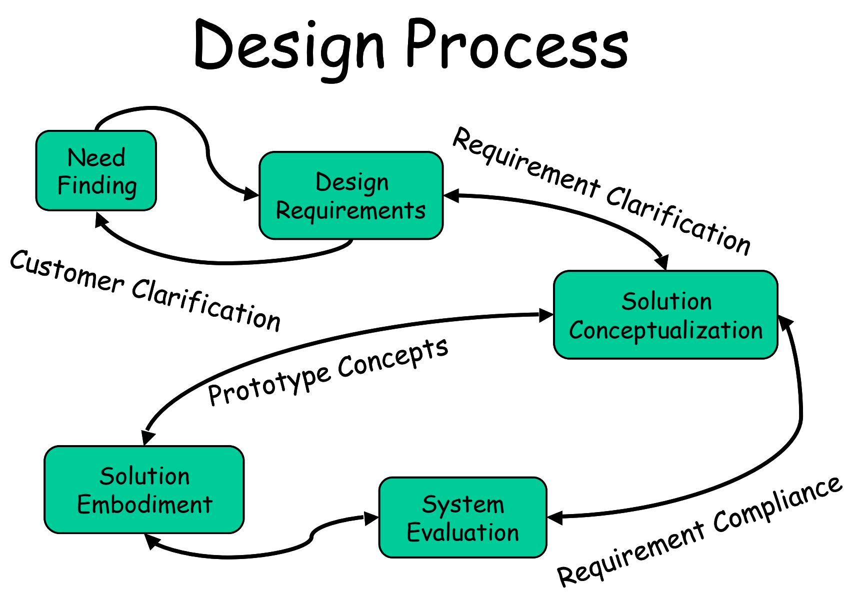

Figure 2: Design process used to show the context in which the various design methods are used.

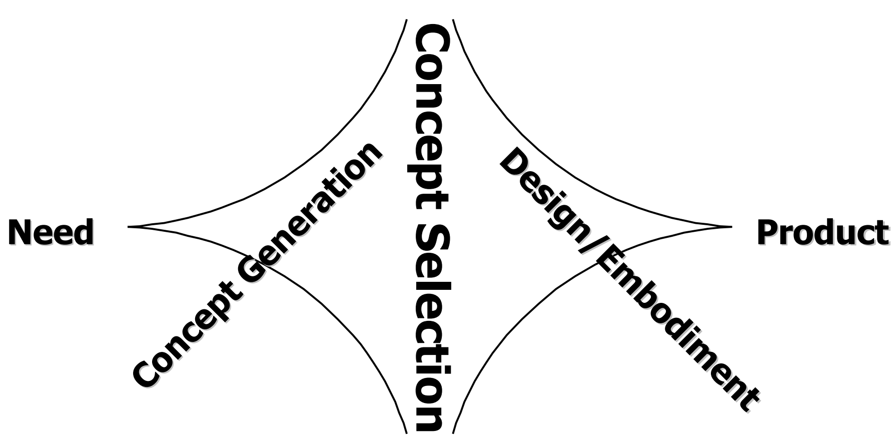

Figure 3. Another design process representation showing the evolution of the solution space. This representation is also used to illustrate when and what benefits the different design methods provide.

This signposting improved performance all around. Quantitatively on the midterm, students performed well as compared to the past years. Qualitatively, the student appreciation of the methods and the integration of course material into their problem solving processes proved to be significant. Students commented that with the strategic view of the various design tools and methods, they could better develop their own tailored design process rather than applying a rote sequence of steps. This shifted design from a more mechanical process of drudgery to be viewed as the creative process we all know and enjoy. This was a critical element in increasing student satisfaction with the course.

4) Increased product realization competency with lab equipment

We were able to make radical improvements in our lab equipment training by restructuring student training to allow more hands-on time with the equipment under supervision of our lab technicians. Of course, all students were given complete safety-in-the-lab training, and required to wear a personal lab badge while working on their design projects. The lab badges indicated which equipment and tools the students were permitted to use and operate. Additionally, students were required to complete manufacturing projects before receiving competency marks on their lab badges. The lab technicians also developed complete documentation to be used as student reference materials during after-hours shop use. The manufacturing projects also factored into the student's ME 290 course grade.

To further increase student "ownership" of the product realization process, instead of a design textbook, each student was required to purchase a prescribed set of hand tools, as well as a toolbox. End of course critiques documented universal student appreciation of the required "lifetime" toolbox purchase, as well as the increased confidence in hands-on use of basic shop tools and equipment. Not only are the students safer, more proficient and more efficient, the lab technicians' view of our students has improved as well. Additionally, in place of a required design textbook we posted extensive course notes in modular form on the course website.

Tools required
Drill bits (from tiny up to 1/4 inch or bigger if you want)
two phillips screwdrivers, large and small
two regular screwdrivers, large and small
allen wrenches, metric
allen wrenches, english
tape measure, 25 ft
small carpenter adjustable square
pliers, normal
pliers, needle nose
vise grips, one pair
decimal inches steel rule (not available from bookstore)
dial calipers (optional but really nice to have, also not available from bookstore)
metal scribe (not available from bookstore)
very small combination wrenches (sized from Number 8 to 1/4", not available from bookstore)
nut drivers or socket set of similar small sizes of the combination wrenches

Table 1: Tools required for "life-long" design learning toolbox purchase

5) Increased breadth in manufacturing technologies

ME290 is a two-hour class. Early in the semester, the second hour was used either for shop training, self-paced CAD training, or project time. Given the overloaded and highly structured Air Force Academy cadet environment, it is often difficult for cadets to schedule team time outside of class. We assist with that by giving them significant amounts of time to work together. During the second half of the semester when they are working on their final design contest, both hours of class are given to the students. There is an exception. We take back the first fifteen minutes of those classes and have the students give manufacturing briefings to their peers in class. Students give briefings on a specific manufacturing technology that interests them. They cover aspects such as raw materials used, associated costs, examples of products using these technologies, and environmental impact. The students giving the presentation have gained in depth knowledge of their manufacturing technology of choice. The rest of the class gains at least a surface level understanding of this technology. Through this significant peer-to-peer learning, students gain not only in-depth knowledge of one manufacturing method but also a working knowledge of at least 25 other technologies.

PROMISING RESULTS

In each of the five areas of concern, we made significant course changes to improve the learning and satisfaction of students and faculty. Each of these changes was not radical in itself. It was the application of these changes in concert that led to such drastic improvements in student performance and satisfaction. The following two graphs document the impact these changes had on class performance and satisfaction.

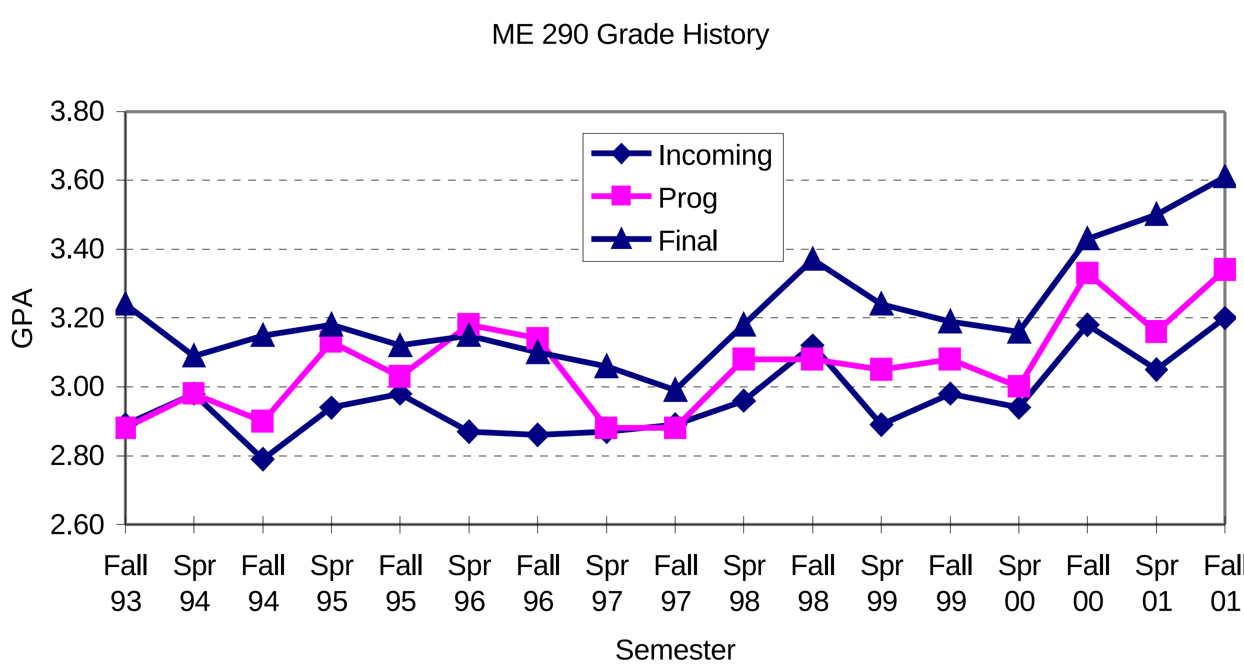

Figure 4: Grade history for every offering of ME290. Notice that Fall 00 and Spring 01 have the highest grades in course history. This high level of student performance occurred under heavy course load conditions and raised expectation levels over previous years. The incoming grade indicates the class GPA coming into the course. Prog represents the midterm grade. Final is the final grade students received in the course.

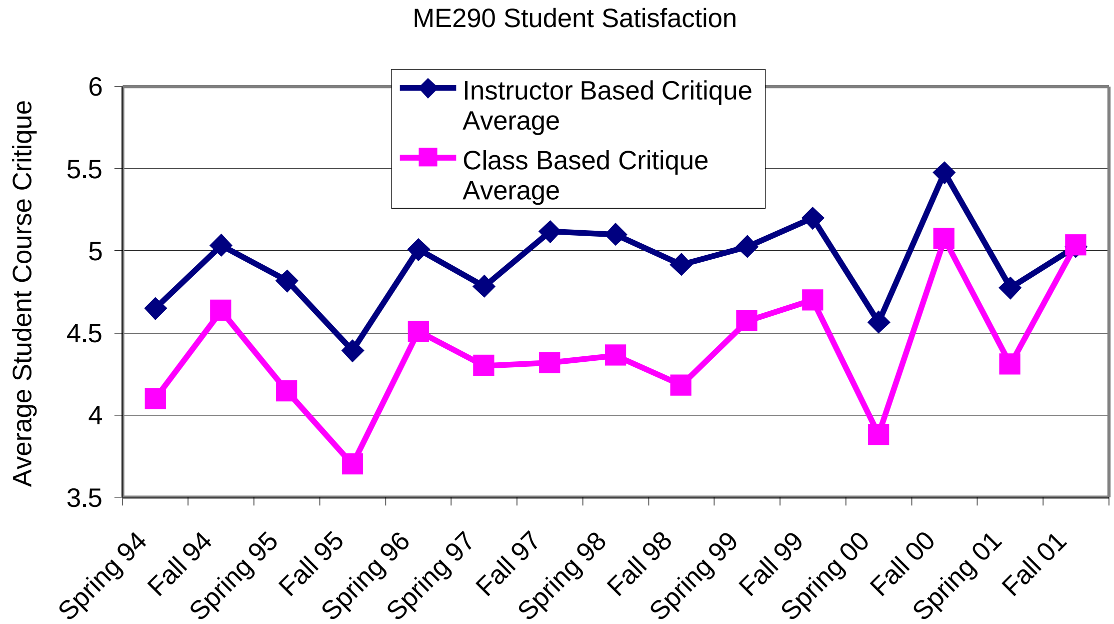

Figure 5: Graph showing historical student satisfaction levels with sophomore design course. Results are based on a six-point scale (6=Excellent, 5=Very Good, 4=Good, 3=Fair). The questions are a mixture of course content and instructor specific questions. Notice the students, as would be expected, tend to favor the instructor over the course. In every instance, the first semester these changes were implemented had the highest level of student satisfaction in course history.

Few changes were made during the most recent course offering in the Fall of 2001. Student satisfaction and performance levels were still near historical highs! The design contest continued its evolution with successful entries from all student teams confirming the success of the improved shop skills training. Two major changes to the syllabus were the removal of Function Structures and the addition of a lesson covering bearings. Function Structures were considered to be an advanced topic for this first level class. This topic is currently being considered for inclusion to the Capstone Design Course. Students are currently using Autodesk Inventor Release 5 without the use of precious classroom time. There have been no team meltdowns, owing either to the benefits gained from the team building content or simply having nicer students. The manufacturing briefs continue to pay huge dividends in terms of peer learning and efficient use of class time. The same method is being used in the capstone design course to increase the topics covered through peer learning. Signposting of the design process continues to be the best tool to teach students the context in which they are learning these design methods. Enrolments continue to grow, making Engineering Mechanics the next most popular major at USAFA, second only to Management.

CONCLUSION

The United States Air Force Academy benefited significantly from the academic innovations implemented by Wood and Jensen in 1998. This next round of innovations has addressed significant shortcomings to the course revealed by ABET reviews through the addition of critical course material. Normally these additions would decrease student satisfaction and performance as the stress on their brains and time increases. Every change made to the course has meet these critical needs while having little to no impact to student time and increasing overall student satisfaction in the course. Overall two hours of instruction were removed from the class while at least ten hours of instruction were added to the curriculum. In fact in the semesters these changes took place, the student course evaluations were the highest in the history of the course. The grades were also at an historical high. This is in an environment of increased expectations on student performance! Critical to the success of these changes have been active signposting and expectation management of the students and the faculty involved with the class.

REFERENCES

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