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Using Mini Design Competitions in Capstone

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Using Mini Design Competitions in Capstone Courses to Teach the Design Process

Abstract

For many senior undergraduate engineering students, the capstone design project is their first experience implementing the design process. As a result many capstone teams do not grasp the importance of the early stages of the design process. To help students better understand how these early steps will impact the overall project; capstone students were given the opportunity to participate in a mini design competition. These students took two weeks to produce classroom demos which were evaluated by instructors for their usefulness in teaching. In the current research, this set of students forms the "experimental" group. Other students were given an overview of the design in a classroom setting, but did not have the opportunity to implement the process outside of their main capstone experience. This set of students forms the control group.

It was hypothesized that using the students' time in the design competition would get students excited for their capstone project, help them be more comfortable using the lab equipment, and help them better understand the design process. A quiz was administered to assess student understanding of the design process, motivation, and lab equipment familiarity. The scores from the experimental and control groups were compared. Qualitative assessment by capstone mentors indicates that students exposed to the mini design exercise had a more holistic understanding of the design process. Additionally, quiz scores indicated a slightly more rapid increase in understanding. However, the design competition did not appear to affect familiarity with lab equipment and or student motivation. This paper reports on the details of the mini design competition, the specifics of the assessment instruments and the details of the qualitative and quantitative assessment results.

Introduction

The capstone design course offered at many universities provides engineering students with the opportunity to apply lessons learned throughout their education. These courses are an important method used to prepare future engineers and help to fulfill many of the requirements specified by ABET. Specifically these courses meet ABET criteria 5 which states "Students must be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints." [1] Three of the important outcomes of this capstone experience involve learning about professional ethics, teamwork skills, and design methodologies. These courses also provide an invaluable opportunity for students to move beyond passive absorption of the material and apply these skills to an open ended design project. This paper focuses on efforts to improve the understanding and application of design methodologies. However, it should be noted that by better understanding and applying this aspect of the capstone experience students frequently experience beneficial effects in other key elements of the learning experience.

Capstone engineering experiences across the country are typically either one or two semesters in length. [2] Normally, if the capstone design project is a one semester course, then a separate course covering design methodology is taught previous to the capstone course. There are advantages and disadvantages of each of these approaches. If the design methodologies are taught in a separate course, the students should be well prepared to make efficient and effective use of these methods in their one semester capstone design project. However, when capstone projects are sponsored by industry or when the project is a national competition (such as the SAE Formula or Baja projects) it can be extremely difficult to complete the project in a single semester simply due to the time needed to complete a full design. Design process steps such as customer needs analysis, design requirement development, feasibility and performance analysis, manufacturing and testing all take significant time. [3] The approach detailed in this paper creates a hybrid solution between the one and two semester course strategies in that it allows for the full year long focus on the sponsored or competition project, but provides an initial exposure to the design tools prior to full immersion in the capstone project.

To make application of design methodologies successful it is imperative that students have a firm understanding of what they are supposed to be doing and why. Many educators have noted that students experience a great level of discomfort when presented with ill-defined design problems. [4] Students frequently express this displeasure when presented with a situation for which there is no closed form solution and to which there may be many acceptable solutions. Repetition is an invaluable tool to increase student familiarity and proficiency in confronting these ill-defined problems. Some universities have taken dramatic steps to increase the frequency of projects which require students to use the design process to confront these ambiguous problems. [5]

Experience with capstone teams has shown that students have particular difficulty with the early stages of the design process. Frequently these teams fail to properly understand customer needs and the importance of sufficiently translating these needs into specifications. Only late in the project do they learn that many of the design solutions they have selected do not sufficiently meet some of the key customer requirements. Unfortunately, this experience is not limited to students; industry is strewn with examples of failed products which neglected to address key customer needs. [6]

Another common problem experienced by capstone teams is that they misunderstand the purpose of the design tools. Students may see the design tools as simply a means to assign grades or a series of obstacles they need to overcome before getting to the "real" work of building their product. All too frequently students "…become so deeply involved in their projects that they fail to see "the forest for the trees." [7] This appears to be especially true for the design process steps of customer needs analysis [6] functional decomposition [8] and concept generation. [9]

To address these shortcomings it is proposed that a brief refresher providing a big picture view of the design process is beneficial. One method of providing this big picture is through the use of a mini-design competition. This competition can serve to help students better understand how design tools are interrelated and emphasize the importance of using these tools when in solving ill-defined problems. Other institutions have used these mini design projects to improve student understanding of the design process and have found them to be beneficial.[3] [7] [10] This work attempts to qualify and quantify the benefit obtained through use of these mini-design projects.

Background

The design process is a methodical system used to understand customer needs, generate solutions, and evaluate the potential for these solutions to meet the customer needs. While there are some differences in the way that the design process is taught the overarching concept remains the same.[11] [12] [13] [14] The design process, used in the Engineering Mechanics department at the Air Force Academy, consists of 7 major steps. These steps are:

- Identify the Customer Needs
- Derive Specifications from Customer Needs
- Generate Concept Variants
- Select the Most Promising Concept Variants
- Analyze the System
- Prototype the System
- Test the System

Capstone courses at the Air Force Academy are two semester in length and are taught during the senior year. Teams are composed of 2 to 11 students with the average team size being 6.4. Projects are funded by private companies, multiple external DOD organizations, the Air Force Academy, and other federal agencies. Frequently the result that these sponsor agencies find most valuable is the innovative ideas offered by students. Because the students are relatively new to the engineering field they frequently approach problems from a different perspective than those who have spent years working these issues. The heavy emphasis on creative solutions makes it imperative that students avoid becoming fixated on a single solution. By properly applying the design process they are able to generate a far greater number of useful concept variants. [15] [16]

Methods

In order to gage the effectiveness of the mini design competition in teaching design methodologies two groups were used in this study. The first group was given a mini design competition. This competition was intended to remind students of the design process which they have used in previous classes and emphasize its utility. Students were given two weeks to accomplish the task of designing a classroom demonstration to be used in an introductory engineering course. All students had taken this introductory engineering class in their freshman or sophomore year and were familiar with the course content. However, the projects were to be judged by a panel of instructors so it was important for students to understand the utility of the demonstration from the instructor's perspective.

Participants were allowed to select their own two person team for the mini design competition. They were then provided with a handout which briefly reviewed the highlights of the design process and were informed that at the end of the two weeks they would give a presentation to a board of faculty members. This handout can be seen in the appendix A. The evaluating faculty would assess both their final product and the quality of presentation. Additionally, the team who best met the instructor's needs for a classroom demonstration was awarded a gift certificate to a local restaurant. Because previous capstone teams had struggled significantly when customer needs were unclear the panel's judging criteria and constraints for the competition were left purposefully vague. Instructors provided additional guidance only when students put forward extra effort to understand their customer's needs. However, students were able to seek continual feedback from instructors to verify that their concepts would satisfy the customer's needs as often as they desired.

The second group acted as a control group for the experiment. These students attended lectures on the design process and were given team time to work on their primary capstone project but did not participate in the mini design competition. The two groups were divided by capstone project with two capstone teams participating in the mini design competition and two capstone teams acting as the control. Additional capstone projects at the Air Force Academy did not participate in this study. One limitation of this study is that the assignment of students to capstone teams and subsequently the two study groups was not purely random. Capstone team assignments were based partially on student preference and instructor requests. Another limitation is the small sample sizes used; the number of students participating in the mini design competition was 15 and the number in the control group was 18.

Both quantitative and qualitative measures were used to gage student understanding of design methodologies. To quantify understanding of the design process, quizzes were administered before and after the mini design competition. The quizzes were also administered at the end of the first semester in an effort to measure the longitudinal effects of the experience. These quizzes consisted of multiple choice and short answer questions and covered each of the major steps in the design process. In addition to the quizzes, the performance of teams who participated in the mini design competition was discussed with capstone mentors. These mentors had guided capstone teams in the past that did not participate in mini design competitions and were ideally situated to compare the performance of teams with and without this introductory experience.

Additionally, students were asked to rate their familiarity with lab equipment and provide a self-assessment of their level of motivation for the capstone course. It was hypothesized that getting students into the lab working on a project early in the semester would increase their motivation and familiarity with the lab resources.

Results

Qualitative assessment of capstone team performance by instructors indicated that the mini design competition was a valuable use of student time. This sentiment was expressed by one of the mentors who remarked that "[i]t was apparent that my team retained very little knowledge of the engineering design process from previous courses prior to this exercise. Instead of teaching them how these should be done, they actually went through the process with physical objects and in doing so greatly enhanced their learning. In addition, it was a fun way to get the semester started." [17] Also, when compared to previous teams, there was a marked decrease in the amount of student resistance encountered in the early stages of the design process. Students were more willing to spend the time to understand customer needs and generate concept variants than in previous years. Mentors were able to refer back to the mini design competition when guiding the team through the design process. This was beneficial as it provided context for learning using a recent shared experience. This type of learning environment appears to fit well within the constructivist or scaffolding theories of education. [18]

During the time that the experimental group was participating in the design competition the control group spent roughly equivalent amounts of time attending lectures focused on the design process and working on their principal capstone project. One faculty concern was that by using two weeks of class time to hold the design competition, the teams would not be able to complete as extensive of a primary capstone project as teams who did not participate in the competition.

However, experience showed that students who completed the design competition were able to make the same progress as those teams who had not participated in the competition. Capstone mentors observed that the increase in student understanding and proper use of the design tools compensated for the condensed timeline.

Students expressed that while intellectually they understand that the design process is critically important in engineering product development, it is often neglected due to the desire to rapidly produce a product. One student noted that “participation in a design process exercise greatly solidified the concepts and procedures employed during product design. Rather than a lecture that often teaches from a theoretical standpoint, this participatory exercise allowed the us to conduct our own research and apply these concepts in a hands-on application.” Developing their own “mini project” allowed the students to inject their own creativity and ideas into the design process and established the personal investment in a project which helped solidify the learning experience. Another student said that the mini design “helped me think about the individual steps in the design process and utilize the concepts of the process in a real-world design scenario.”

Quantitative measures also indicated that student understanding of the design process improved more rapidly in groups participating in the mini design competition than in lectures alone. The results of the quiz scores can be seen in Figure 1. Analysis of incoming grades indicated that there was no statistically significant difference in GPAs. Additionally, the differences in initial quiz scores between the control and experimental group did not show a significant difference. This led to the observation that both groups started with a roughly equal understanding of the design process and learning potential. The quizzes consisted of multiple choice and short answer questions and partial credit was awarded. Sample questions can be seen in appendix B.

At the end of the mini design competition the design process quiz scores for the two groups diverged. Assuming a normal distribution, the statistical t-test revealed that there is a 98% probability that the there is a true difference between the quiz scores of these two groups ($p < 0.02$). This is well within the normal criteria for “statistical significance” which is normally set at $p<0.05$. This increased understanding of the design tools carried through for the rest of the semester. While quiz scores decreased slightly for both groups, the average quiz scores of those participating in the design competition remained greater than 8% higher than the control group. Similar to the results immediately following the design competition there was a 98% probability that the end of semester scores represented a real difference in understanding.

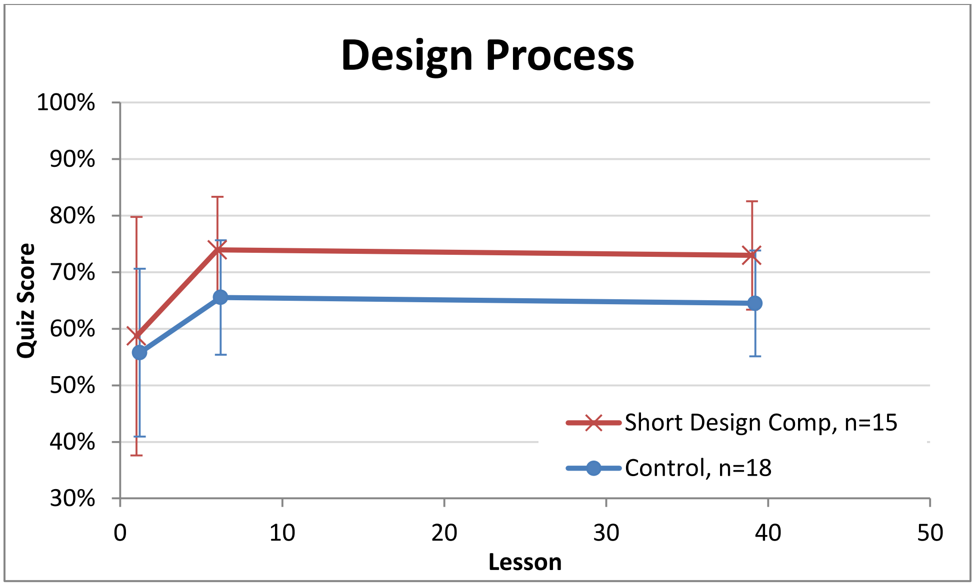

Figure 1. Design process quiz scores
Error bars indicate a standard error for each of the data sets

After students had taken the design process quizzes they were asked to anonymously report their level of familiarity with lab equipment using a Likert-style scale. The results of these surveys indicated that, although students became more familiar with lab equipment throughout the semester, the mini design competition did not play a significant role in improving this metric. Overall, there was no statistically significant difference between the control and experimental groups in self-reported lab equipment familiarity at any time in the semester. However, because this rating was self-reported and subjective in nature, future efforts may shed additional light on this topic.

Another metric tracked in this study was the students' self-reported level of motivation. The results of this survey are shown in Figure 2. At the same time students reported their lab equipment familiarity they also reported how motivated they felt towards their capstone project. In both groups the level of motivation decreased throughout the semester, and in both cases the amount of decrease was similar. Unfortunately, the self-reported motivation level was not equal at the start of the study and remained unequal throughout the semester. Further investigation into the source of this discrepancy revealed that this difference was due primarily to team members participating on the Formula Society of Automotive Engineers (Formula SAE) team. Members of the Formula SAE capstone team reported significantly higher levels of motivation throughout the semester than members of any other team. Teams not participating in FSAE showed very similar trends in motivation level irrespective of their participation in the mini design competition. This observation infers that motivation level is far more strongly influenced by the overall project focus than by the use of a mini design competition.

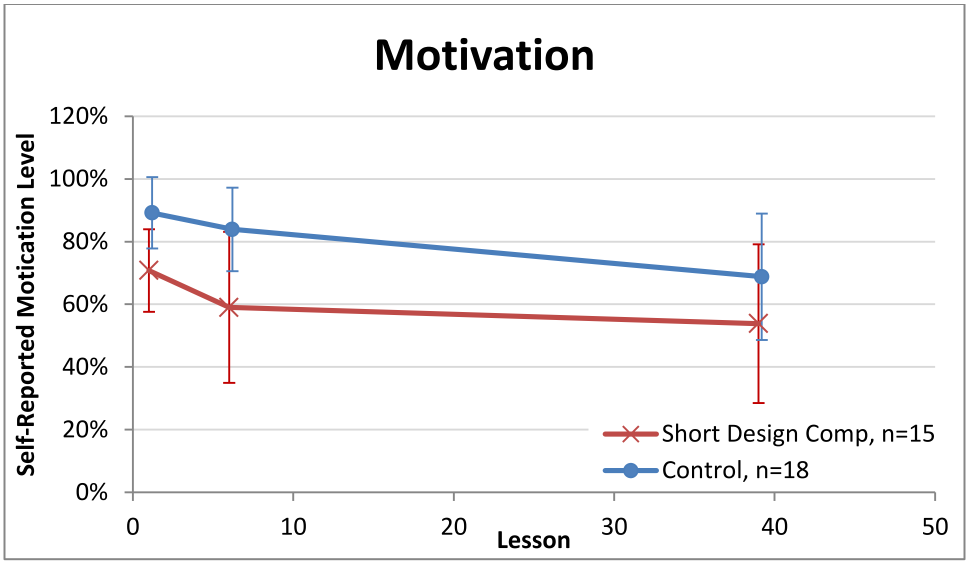

Figure 2. Self-reported motivation level

Error bars indicate a standard error for each of the data sets

After observing the difference in motivation level experienced by the FSAE team, analysis was performed to investigate whether this team's understanding of the design process or familiarity with the lab was significantly different than the other individuals in the control group. While there are significant limitations to the analysis, due to the small sample sizes, it appears that the only area in which the FSAE team performed significantly differently than other team was in the self-reported level of motivation.

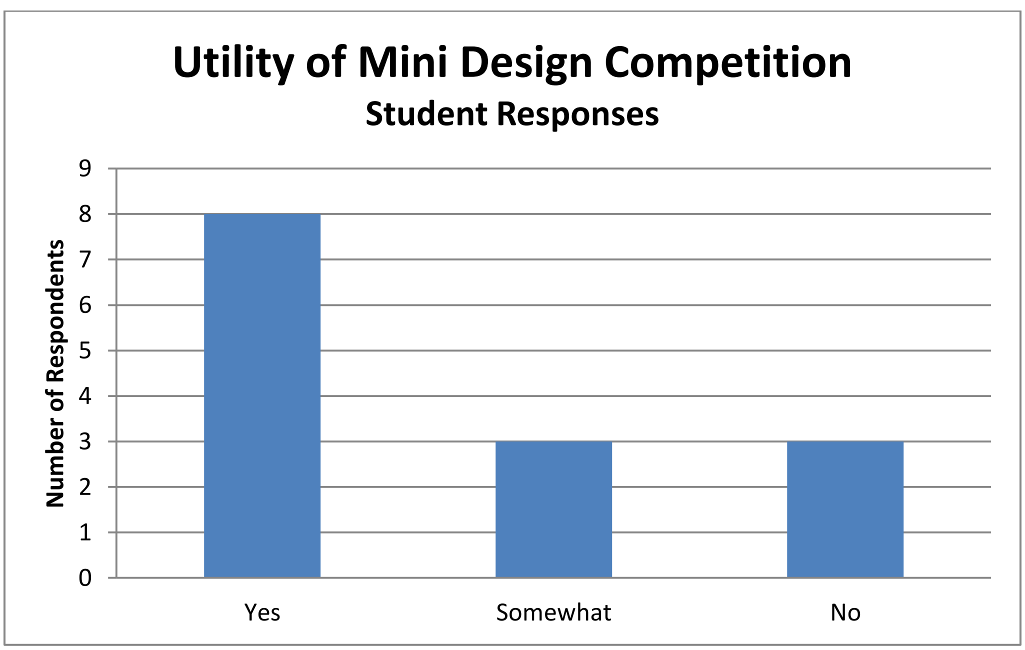

Figure 3. Student assessment of utility of mini design competition

The final question asked to students who participated in the design competition was whether or not they felt that the mini design competition had been a worthwhile investment of their time. The results of this question are shown in Figure 3. Approximately 60% of respondents indicated that they believed the design competition had been beneficial, 20% indicated that it was somewhat useful and 20% said that it was not a valuable use of their time.

Conclusion

The results of this study indicate that the use of a mini design competition at the beginning of the capstone experience is a worthwhile investment of student time. The increased understanding of design tools, and their relation to the process, appears to have improved the student's desire to follow a systematic approach to design. Capstone mentors observed that the vague problem statement used in the design competition was a valuable tool in preparing student for some of the more challenging aspects of their primary capstone experience. Students and mentors felt that the use of competition was an effective way to get students engaged early in the course.

During subsequent applications of the mini design competition, various improvements are planned. First, to increase student motivation to participate in the design competition, mentors may exercise the option to tie the competition more directly to student grades. This would be accomplished by assigning points based on the presentation given at the end of the competition. This produces the additional benefit of providing a slightly more demanding situation for students when giving their presentation. The additional stress produced by linking the presentation to grades helps better prepare students for design review and sponsor presentations. Second, competition objectives will be selected which more actively engage the students. While students were reasonably engaged in designing and building classroom demonstrations selection of a more exciting project is expected to produce more vigorous participation.

In conclusion, the use of a mini design competition at the beginning of a capstone course produced beneficial effect in student understanding and application of the design process. This effect was observed both quantitatively via quiz scores and qualitatively through capstone mentors evaluation of student performance and attitudes.

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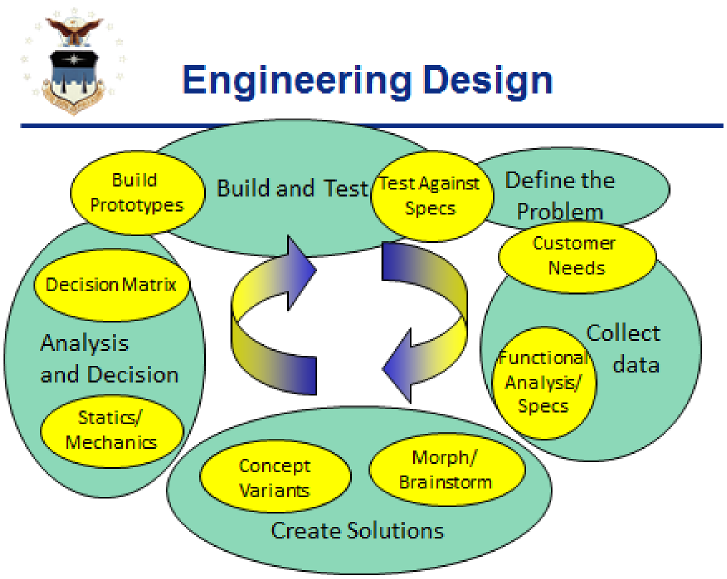
Appendix A – Design Process Handout

Capstone Mini Design Competition

One of the major difficulties encountered by previous capstone teams was an inadequate understanding of the design process. To help enhance your understanding of the design process and get you working in the lab we are going to participate in a miniature design build competition. The task is to build a classroom demo for EM 220. The instructions and requirements for the demo are purposefully vague to allow you freedom when creating your masterpiece. The only firm requirements are for a design review where you will present your concept and a final project demonstration. The design review and the final project demonstration will occur on lesson five. Hopefully this will allow you to become acquainted with the design process so you will understand how the pieces fit together and see the big picture better as we develop the design tools in more detail throughout the semester. To motivate top performance in this task you will be divided into two person teams and the winners will receive the pride of knowing they are better than everyone else on the team (and a gift certificate for dinner).

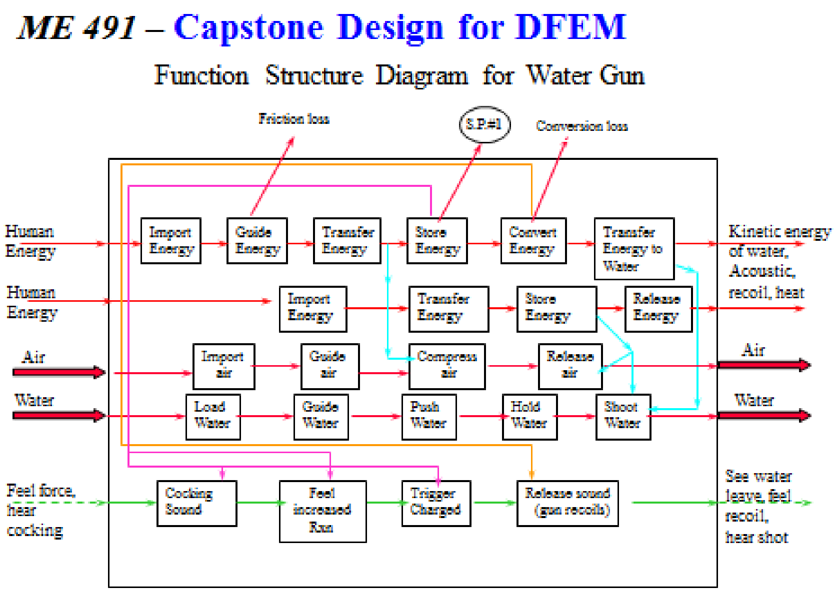
Below is a VERY brief review of the design process



Customer Needs Development

- Identify the customer
- Gather customer needs
- Group customer needs
- Prioritize customer needs

Functional Analysis:



Overview of Specs:

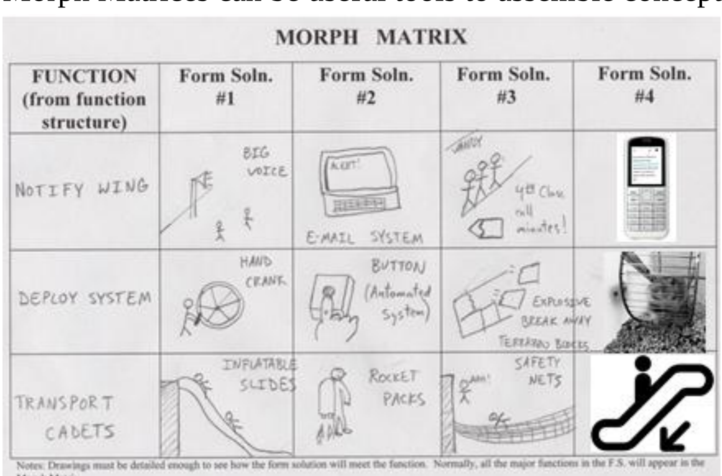
Engineering Specifications (specs) are not the same as CN, but are related to them. The specs are **<u>quantifiable</u>** representations of what the product must do. Sometimes these are called "engineering requirements" in the design literature, so we'll use these 2 terms interchangeably. These should be based on Customer Needs and they must be measurable (i.e. have units).

Concept Generation:

Brainstorming and Mind Maps are just two of the methods we will use in this class. We will spend a lot of time on this step because this is an area where cadets can make a significant contribution to solving real world problems.

Concept Variants:

Morph Matrices can be useful tools to assemble concept Variants



Decision Matrix:

ME 491 – **Capstone Design for DFEM**

Brake System Example Pugh Chart – NOT COMPREHENSIVE

C.N.	C.N. Wt.	Datum= Disk w/ steel	C.V. # 1 Drum	C.V. # 2 Disk w/ AL
Easy Activation	5	0	-3	0
Reliable	7	0	-1	0
Stops Vehicle Quickly	9	0	-2	1
Low Cost	6	0	3	-2
RATING		0	(5*-3)+(7*-1)+ (9*-2)+ (6*3) = -22	(9*1)+(-2*6)= -3

Analysis:
Perform modeling and simulation to analyze whether or not your ideas will work and how well they will work.
----------------------------The Design Review will cover the items listed above--------------------

BUILD and TEST
This is the most time consuming portion of the design process. Building prototypes and testing them against the specifications allows you to evaluate whether your design will meet the customer needs or not.

Appendix B – Design Process Quiz

MULTIPLE CHOICE

1. Is design an iterative Process? Yes / No
2. For a generic hair dryer what is the best example of a customer need?
    A. Dries Hair Quickly
    B. 50 Watt heating element
    C. Pink
    D. Weighs less than 1 pound
3. Morph matrices can be used to:
    A. Pick the optimal design
    B. Develop multiple concept variants
    C. Set up a test program
    D. Perform stress analysis
4. When selecting which design to manufacture it is important to rate potential designs against:
    A. Needs/Specifications
    B. Functions
    C. Design Intent
    D. Cost
5. Brainstorming should be limited to practical ideas in the early phases of designs. T/F

SHORT ANSWER – (no more than one sentence)

6. Who would be the target customer for a hair dryer?

7. What are 3 important qualities of a specification?

8. What is frequently the most time consuming portion of the design process?

9. What is design space and how is it used?

10. How comfortable do you feel with the lab equipment (1=not confident 10=highly confident)?
11. My current motivation level for Capstone is (1=low 10=high)