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

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Abstract

For many senior undergraduate engineering students, the capstone design project is their first substantial experience implementing the design process. As such, some capstone teams experience difficulty with the design process when they do not grasp the importance of understanding customer needs and establishing design requirements before proceeding to subsequent portions of the project. This frequently leads to serious issues as teams realize their design or product does not do what the customer wants it to do. In an effort to help students better understand how gathering customer needs and translating them into requirements will impact the overall project; some capstone students were given the opportunity to participate in a mini design competition where they were tasked to construct classroom demonstrations. These students were given two weeks, before they officially engaged in their year-long capstone design project, to go through the entire design process and 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 process as part of their initiation into their capstone project, but did not have the opportunity to experience an initial implementation of the design process prior to their full implementation for their capstone project. This set of students forms the control group.

It was hypothesized that using the students’ time in the design competition would get students more excited for their capstone project, help them be more comfortable using the lab equipment, and most importantly help them better understand the design process. Both quantitative and qualitative measures were used to assess the utility of the mini design competition. To measure student understanding of the design process, a quiz was administered both before and after the mini design project and scores from the experimental and control groups were compared. Additionally, students were asked to rate their level of motivation for their capstone project and their familiarity with lab equipment.

Early qualitative assessment by capstone instructors indicates that students who were exposed to the mini design exercise have a better understanding of why they are using the design tools on

their actual capstone project. Additionally, quiz scores indicated a slightly more rapid increase in understanding of the design process. However, familiarity with lab equipment and interest in their project were unchanged by the mini design competition. Initial results indicate that mini design competitions are beneficial in increasing overall productivity of capstone teams and are an effective investment of student time. 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, particularly 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; especially if the project is a "real – world" design such as those that are industry sponsored or national competitions. [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 a misunderstanding of 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 methodical system used understand a need then to generate and evaluate potential solutions to fill this need. While the specifics of how the design process is taught vary between institutions the overarching concept remains the same.[11] [12] [13] [14] The design process taught 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

Our capstone course is a two semester long course 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 become 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. 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.

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 pervious 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 when no mini completion was held. 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]

One concern initially concern was that by using two weeks of class time to hold the design competition; the teams would not be able to progress as far in the design process as teams who did not participate in the competition. However, experience showed that students participating in the competition were able to make the same progress within the first semester as those not participating and as previous year's teams.

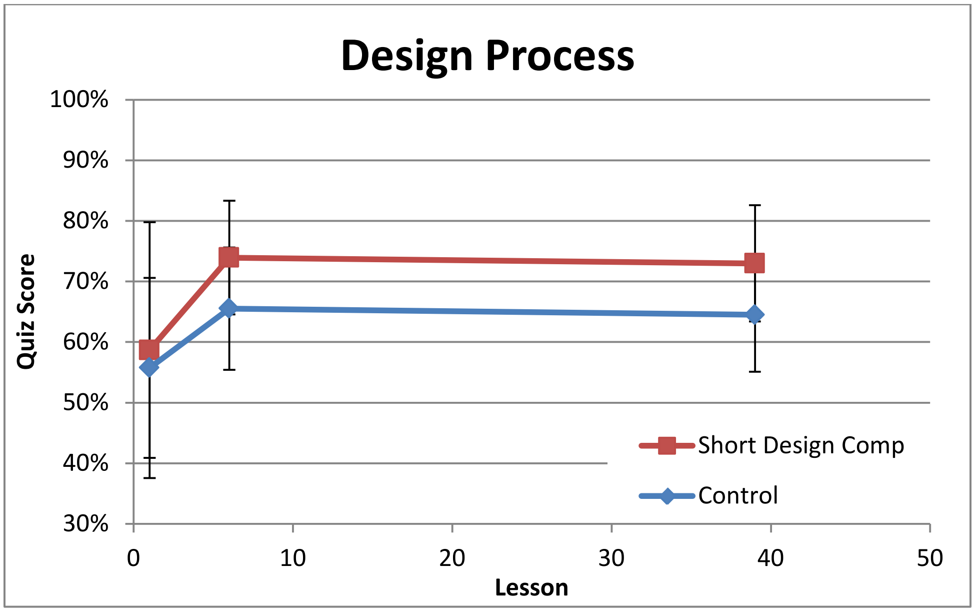

Figure 1. Design process quiz scores
Error bars indicate a standard deviation for each of the data sets

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. The differences in initial quiz scores between the control and experimental group did not show a significant difference leading to the observation that both groups started with a roughly equal understanding of the design process. 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.

After students had taken the design process quizzes they were asked to anonymously report their level of familiarity with lab equipment. 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.

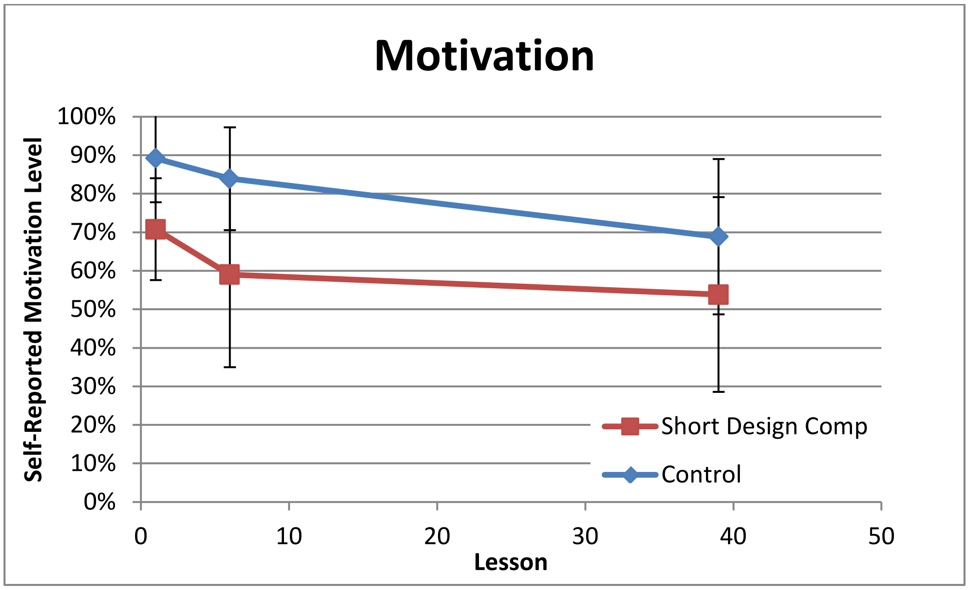

Figure 2. Self-reported motivation level

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

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. 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.

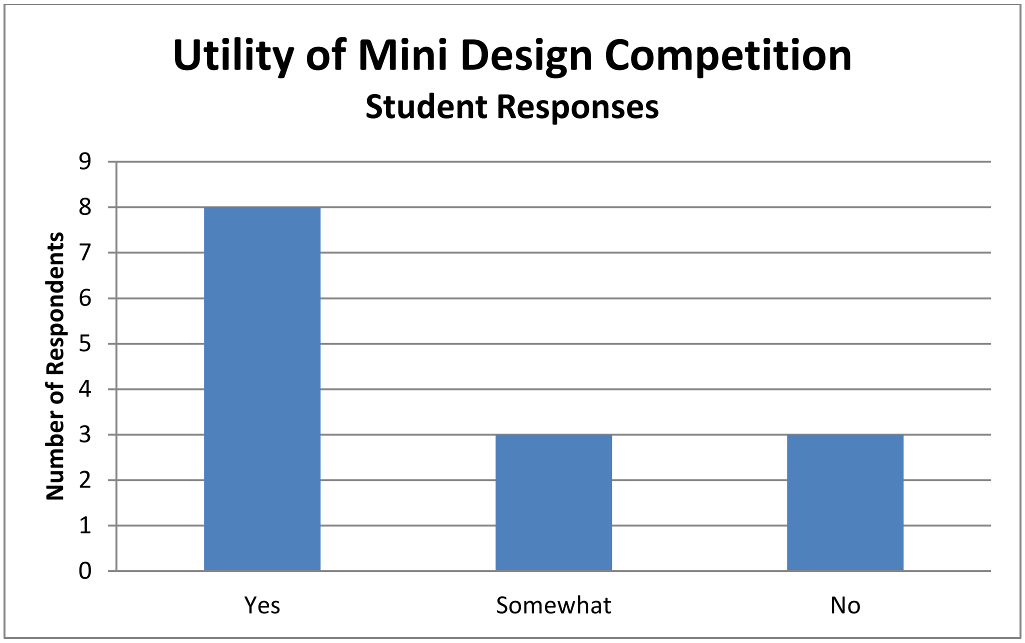

Figure 3. Student assessment of utility of mini design competition

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 confirm 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 produced a significant improvement in student desire and ability to follow a systematic approach to design. Capstone mentors also observed that the purposefully vague problem statement and scoring criteria used in the design competition was a useful 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 in learning early in the course.

During subsequent applications of this tool in capstone courses 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 tying it to grades helps to better prepare students for design review and sponsor presentations they will give as part of their capstone project and other presentations throughout their careers. 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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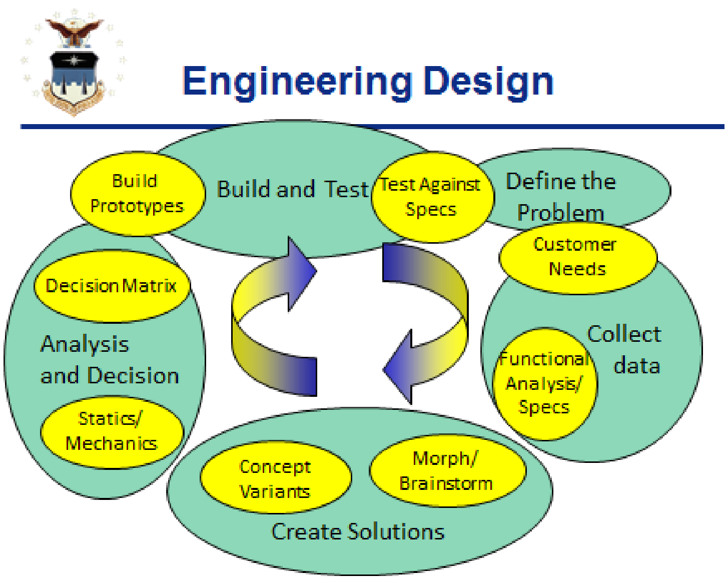
Appendix – Design Process Handout

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).

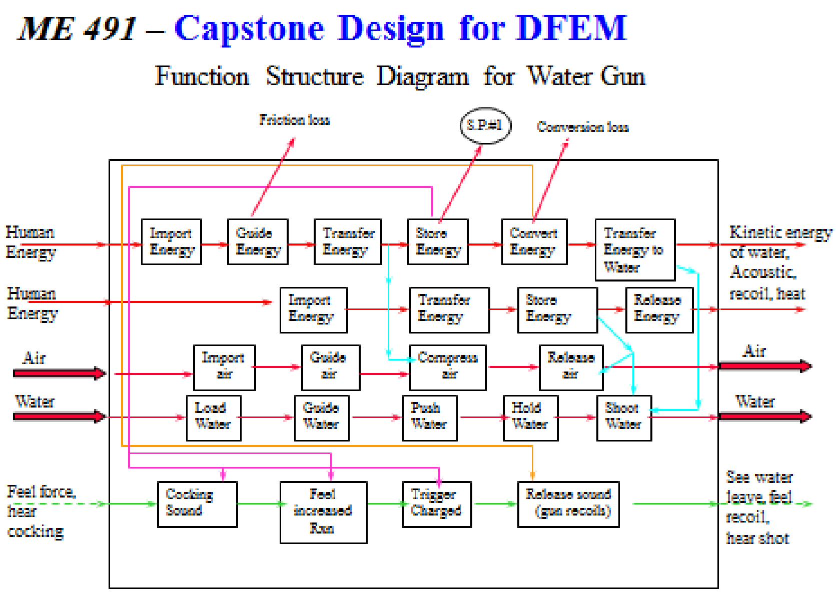
Below is a VERY brief review of the design process



Customer Needs Development

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

Functional Analysis:



Overview of Specs:

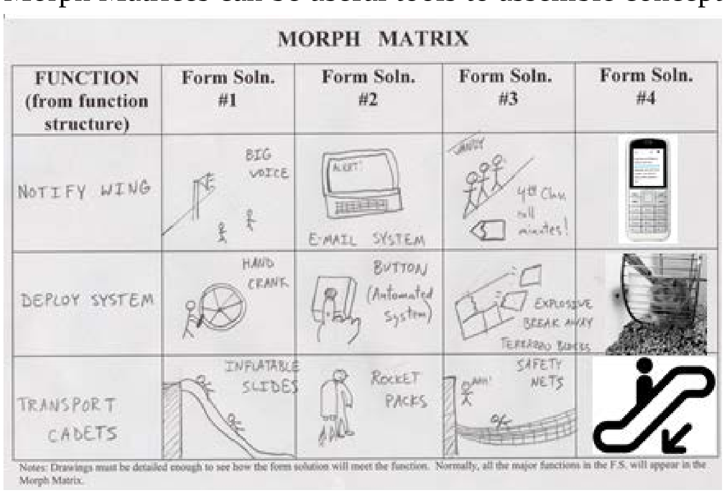
Engineering Specifications (specs) are not the same as CN, but are related to them. The specs are **<u>quantifiable</u>** representations of what the product must do. Sometimes these are called "engineering requirements" in the design literature, so we'll use these 2 terms interchangeably. These should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