2006-1676: CAPSTONE DESIGN, MECHANICAL ENGINEERING PROJECT OR PERSONNEL MANAGEMENT CHALLENGE?

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Abstract

There are approximately 275 mechanical engineering seniors at Virginia Tech who participate in one of several possible capstone design projects. The SAE Mini Baja is one of these projects and is extremely popular among students. The object of this paper is to communicate and illuminate the broad spectrum of issues encountered in a team based capstone design project.

In fall 2004, I became the faculty advisor of the Virginia Tech SAE Mini Baja team which is also one of the ME 4015 Mechanical Engineering senior capstone design projects. At first, I thought that the project would be mostly a mechanical engineering project and wondered, as an aerospace engineer, whether I was up to the task. However, as time went on, I discovered that the real challenge was not of mechanical engineering expertise, but one of team guidance and management.

This paper describes the SAE Mini Baja design competition as a mechanical engineering capstone design project and the many challenges that face the advisor and a thirty-five member team charged with designing, building, testing two vehicles as well as competing in three of the SAE Mini Baja events around the country. The vehicles are constructed in the Joseph F. Ware, Jr. Advanced Engineering Laboratory which is a model for collaborative design-build spaces. The paper also illuminates some of the tools and methods that are used to facilitate the success of the team as well as discusses some of the difficulties of working with such a large design team. Design and team assessment instruments are presented. Suggestions aimed at successful future teams and projects are also discussed.

Introduction

Design has been described as the epitome of the goal of engineering[1], as it is core to facilitating the creation of new products, processes, software, systems, and organizations through which engineering contributes to society by satisfying its needs and aspirations. Though formal definitions of engineering design vary somewhat, it is commonly agreed that design is a process, a means to an end, that is scientifically based, creative, and most often noble in its purpose as contributions are sought which satisfy human and/or societal needs. Whether the outcome of the process is a system, product, or process, engineering design serves to translate need into concepts which are realizable. Implicitly and often understated, engineering design is also *responsible*; responsible for the impacts, positive and negative, on the world it serves. Engineering design is responsible for major contributions which have defined our modern world: transportation, medicine, utilities, communication, and agriculture, among many others. Yet, the inceptions of engineering design are also directly responsible for failures which are capable of causing death and destruction: collapsing bridges, chemical leaks, electrical fires, nuclear power accidents, and automobile accidents. Further, and with much attention in recent years, engineering design is held responsible for the impact it has on life-cycle issues such as costs, usability, safety, manufacturability, serviceability, recyclability, sustainability, disposability, and quality; ultimately, determining the success or failure of products and organizations. Indeed, design is considered an issue of national importance[2]. *Good* design practices can be observed, but *how* can the expertise and methodologies employed be captured, transferred, implemented, formalized or improved? *Why* are some people more likely to be good designers? These are just some of the questions that researchers and practitioners have sought to answer.

In engineering education, students (undergraduate and graduate) are often involved as participants in various design projects and work as research team members. As part of their education, students may have received some guidance on how to perform in a team and how to proceed through the design process, though this can vary widely from one engineering discipline to another. The goals of a senior capstone design project are: 1) to have students implement methods for proceeding through a complex design project, 2) to assess student designs, 3) to train students to be more effective team members, 4) to create opportunities for students to exercise being a team member and 5) to create opportunities for students to be more effective facilitators and leaders of design teams.

Conducting a search of the ASEE data base from past annual conferences from 1996 to present, one can discover close to 100 papers dealing with teaching engineering design. Most of these papers discuss the introduction and implementation of more effective approaches to teaching design for faculty of particular courses. This body of work has expanded the horizons of design education with many outstanding new avenues of teaching design from hands-on design-build experiences[3] to reverse engineering and dissection laboratories[4] to creativity and communication courses[5]. There have also been advances with numerous service learning[6], industry collaborative[7] and other innovative design projects[8]. These approaches and activities have made major contributions that have altered the techniques and pedagogy of teaching engineering design available to faculty.

One such popular design activity is the senior capstone design-build project known as SAE Mini Baja. At first glance this capstone project would seem to be a complex technical challenge for both students and faculty. As one proceeds through the process, it becomes evident that this project is labyrinth of personnel and management challenges. This paper illuminates this capstone course designed to teach undergraduate mechanical engineering students the landscape of design and how engineering design is practiced in industry.

Course Design

This course is designed to include a common lecture hour each week where all the students enrolled in a mechanical engineering capstone design course are expected to attend. In this lecture session, students are exposed to such topics as ethics in the workplace, global issues in engineering practice, engineering economy review, proposal and report writing, presentation coaching, sustainable design, kinematics and suspension highlights as well as other topics of general interest to seniors working on any design team. The course also includes two 1-hour and fifteen minute “laboratory” meetings. In these meetings the individual project teams meet and work through project business that include design group formation and design sessions, design issues, progress presentations, purchase requests, publicity and fund raising, etc.

This capstone course is a two semester sequence. The first semester is primarily setting up design groups and the design of individual aspects of the vehicle and coordination and integration of all of the vehicle subsystems. The second semester is primarily spent building the vehicle, testing, redesigning and competing in international competitions with the vehicle. Mechanical engineering capstone courses are writing intensive and include design briefs, design proposals, progress reports, written course feedback, final report as well as at least two oral presentations by each team member each semester.

The objectives of the course include the negotiation of the engineering design process through this design-build project. Capstone design also targets many of the ABET a-k criteria. One of the main objectives is for students to have an experience of functioning on a team that has relative independence. To simulate an after graduation work environment, the team is allowed the greatest measure of freedom in how it is formed and in their day to day interactions with one another. A hands off approach was taken by the instructor to give students the greatest measure of freedom. When conflicts developed it was up to the design group leaders and the overall team captain to resolve the issues with minimal guidance from the instructor.

Team Structure

The team this past year consisted of thirty-five senior mechanical engineering students along with roughly seven underclass volunteers. During the first week, several design groups were formed and group leaders surfaced. The design groups were Frame and Safety, Suspension, Drivetrain, and Body/Flotation. During the second week a team captain was elected from among those that aspired to this position by secret ballot after presentations from the candidates. There was also a graduate assistant from a previous year’s team that was actively involved as a consultant to the design groups and for general oversight of the component purchase and build process.

The course policy sheet is shown in Figure 1. It includes the general expectations for the students as well as grade breakdown and participation guidelines.

Mini Baja Vehicle Design

To give the reader some appreciation of what is involved in this capstone design project, the following is an excerpt of the description of the design of the Mini Baja Vehicle written by and from the perspective of the 2004-2005 Mini Baja design team and edited by the authors:

The Virginia Tech Mini Baja vehicle was designed to satisfy the objectives and rules of the 2005 SAE Mini Baja competition. Comfortably seating a passenger in excess of 6’ 5” and weighing over 250 lbs, the vehicle is built for off-road enthusiasts ready to tackle the rigors of any terrain.

Course Policy
ME 4015 Engineering Design & Project - Mini Baja
Fall 2005, CRN 93757

Faculty Advisor: Author

Purpose: To participate a member of a team in the design, documentation, construction and testing of a Mini Baja vehicle for success in the 2006 SAE competitions.

Format: Every enrolled student is required to attend the regular ME 4015 project meetings on Tuesday at 4:00-4:50 PM in 206 Randolph Hall and Thursday at 9:30-10:45 AM in 209 Williams Hall, and the ME 4015 lecture on Tuesday 9:30-10:45 AM in 1670 Litton Reaves.

Requirements/Grading:

a. **Bi-Weekly Timesheets:** Because of the short time frame and intensity of work required to prepare for the competition, we expect every enrolled student to log a minimum of 15 hours per week. You will not receive full credit unless you average this amount of time. Report time worked on the biweekly report form (see Blackboard web site). Time includes actual lab and lecture time, plus all work performed in direct support of the project (not travel time). Attendance at all lectures and lab meetings is expected. Time must be recorded daily to be counted.

b. **Logbook:** Everyone working on this project is responsible for keeping a logbook whether enrolled in the class or not. Your logbook helps the advisor determine your contribution to the project (if it's not in your logbook, you didn't do it). Purchase a National® Brand Computation Notebook #43-648 75 sheets, 4 x 4 Quad., 11 ¾ x 9 for $16.39

c. **Oral Presentations:** Each ME 4015 student will give at least two oral presentations that will summarize progress and design work as well as a sales presentation of the final vehicle design.

d. **Written Proposal and Report:** A team project proposal will be due on September 22 and a team final written report will be due on Dec. 2. All students in a design group will receive the same grade, but report effort should be considered in the peer evaluation.

e. **Design Binder:** Each design group should keep one common Design Binder to keep track of important information that is normally not included in the individual logbook. This is also a reference document for future teams. Your group will continue to build on your design binder from Fall into Spring. This binder will be assembled continuously.

f. **Peer Evaluation:** This should be a combined measure of the productivity of an individual and that individual's ability to facilitate progress of the team and to help others be productive. Good team members bring out the best in their peers, take leadership roles when appropriate, and communicate continuously and effectively.

g. **Instructor Evaluation:** I will be looking for people who work hard, set good examples, take leadership roles and produce results. Expect a low score if you are habitually late to meetings and don't volunteer for additional assignments (tours, lab cleanup, web page development, proposal writing, etc). It is also possible to Fail this course.

Course Grading :

	Lecture Activities and Quizzes	15%
	Productive Hours Worked	15%
	Logbook	10%
	Oral Presentations	10%
	Proposal and Written Report	15%
	Design Binder	10%
	Peer Evaluations	10%
	Instructor Evaluation	15%
	Total	100%

Letter Grades are assigned as follows: A > 92 , B >82, C>72, D>62

The Fine Print:

As you probably know, the Mini Baja senior design project is a popular choice. We currently have 25 students enrolled, but there are many more who would like to add the course. Unfortunately, our resources will not allow us to add all the students who have requested this course. Rather than randomly deciding who should get in, additional requirements are being placed on students taking this course. If you enroll in Baja, your grade in ME 4016 (2nd semester) will depend on your willingness to work during class breaks. To be eligible to receive an A grade, you must stay in Blacksburg and contribute to the project 8 hours a day for at least ***two*** *weeks of the following three breaks: Nov.19-27, Dec 16 - Jan.16, and March 4-12. To be eligible for a B grade, you must work at least* ***one*** *of those breaks. In other words, those who don't work over the breaks will start the grading process with a C.*

Figure 1. Capstone Design Course Policy for Mini Baja

The vehicle makes use of key features including, a continuously variable transmission, reinforced drive train belts, and exceptional vehicle performance. For these features and more, the approximate prototype cost is $7,200. Representing the perfect balance of performance, safety, and cost, the vehicle offers an exciting driving experience for the off-road enthusiast.

The vehicle embodies the result of six months of design and fabrication. The team used the Kano method of design[9] as a guideline to meet and exceed customer needs. To identify customer needs, the team as a whole brainstormed ideas that lead to be the best qualities that customers wanted to have in an off-road vehicle. Including but not limited to, excellent performance, smooth ride, comfortable seating, aesthetically pleasing appearance, and maintaining a high level of craftsmanship throughout the project. To this end, the leadership divided the team into four design groups: Frame & Safety, Suspension, Drive Train, and Body/Floatation. The following describes the responsibilities of the four groups.

The vehicle's frame provides the foundation for implementing the team's design goals. The wielded 1020 mild steel is both a mounting platform for the mechanical systems, but also a collision resistant roll cage for the driver. Every component is constrained by the physical dimensions and properties of the frame. Thus the performance, safety, comfort, maintenance, and aesthetic appeal originate with the frame design.

The vehicle's ability to traverse rugged terrain lies within the suspension design. The primary purpose of the suspension system is to act as a flexible link between the vehicle and the ground. It promotes effective propulsion by keeping the tires in contact with the terrain. Steering is also facilitated through constant ground contact. The vehicle's suspension utilizes a front double A-arm design for independent travel and steering coupled with trailing arms for rear wheel drive. Vertically mounted coil over shocks with external reservoirs maintain ground contact while absorbing the variations in terrain. The result is a highly maneuverable vehicle that is comfortable to drive.

The continuously changing demands of off-road driving demand an adaptable drive train that provides acceleration and torque as the situation prescribes. SAE regulations limit the vehicle's engine to an unmodified 10 horsepower Briggs and Stratton single cylinder block. To transform this power into efficient propulsion, a form of transmission must be added. A transmission converts the regulated 3800 RPM into slower speeds with higher torque. Furthermore, a link between the engine and the tires must be established to transfer power without constraining the suspension's flexibility. The continuously variable transmission (CVT) was selected based on its ability to automatically adjust gear reductions. It is augmented with a further reduction from a wide Kevlar reinforced belt.

The vehicle's outer shell is composed of a collection of protective and aesthetic materials for the purpose of providing a finished surface. The body/floatation design group began by researching the Mini Baja Rules pertaining to the body and external features. The body's primary goal is to protect the driver from debris as the vehicle traverses the terrain. In addition, the body is responsible for prominently displaying the team's markings for identification during the competition. Finally the body adds the visual styling of a finished product expected by the consumer. With driver safety in mind, the team proceeded to design numerous body styles from the shapes available by the frame. The team selected fiberglass as the primary material for the body panels. To facilitate maintenance, quick release quarter turn clips were installed on the front and rear paneling. Closed cell high density foam sheet was used for floatation.

Figures 2 thru 5 show some of the design details of the Mini Baja vehicle.

Figure 2. Photograph of the vehicle's frame

Figure 3. Front right isometric of frame

Figure 4. Early driving tests

Figure 5. Front suspension

The vehicle itself was constructed in the Joseph F. Ware, Jr. Advanced Engineering Laboratory[10] (Shown in Figures 7 and 8). This is the home to many of the capstone design-build projects at Virginia Tech and includes a welding shop, machine shop, CAD laboratory as well as several design bays for manufacture and assembly of large complex system projects including SAE Mini Baja, Formula SAE, Autonomous vehicles, Hybrid electric vehicles, steel bridge, design build fly and others.

Figure 6. Ware Lab Lobby Figure 7. Ware Lab Machine Shop

The vehicle the team designed and constructed met and exceeded all of the Virginia Tech Mini Baja team's expectations. The team had a complex design task to accomplish and succeeded in its execution. However, this was not done without some cost along the way.

The Design Team – Size, Interactions and Conflicts

This is a senior design team. Their next step will be working in industry. Consequently, seniors should be allowed the opportunity find their own way for the most part. Having worked with design teams in the past, the authors were aware of potential conflicts and personality issues. However, most of the teams had been eight members maximum and primarily underclass. we were completely surprised by the ability of members in a large (35 member) team of seniors to drop from view without notice. Some of the design group leaders proved strong, competent and self motivated, but lacked the ability (or interest) to invite and include all members. Within design groups, some members were willing to do what ever it took to get the job done and some were not. These knowledgeable go getters also tended to take on too much themselves. They apparently did not want to take the time to delegate or explain tasks to others who were less sure about the direction in which to proceed. This tended to create two classes of team members. As a result, some team members became alienated and felt that they were being excluded from the design groups. These "excluded" members consequently took up peripheral positions and when it came time for peer evaluations, they didn't fare well. Once this situation became evident, measures were taken to gather feedback from all members and to address the issues. It turned out to be an intervention that was too late coming.

The team captain, although having good management skills, did not have good technical skills and was not ultimately respected by some of the team members. The leadership of the captain was compromised by this lack of respect and following. Since a hands off approach to the team was being taken by the instructor, the team captain was where the buck stopped. Several attempts at coaching the team captain met with mixed success as he was, as the second semester went on, becoming alienated from the core team workers himself. Ultimately, the team went to competition without the captain.

Lessons Learned and Future Plans

Students learn lessons (whether they are full participants or marginal players), just different lessons. In the long run, letting the team be self determined and self managing is a good thing. Some students learned to be good leaders, some learned to be good workers and trouble shooters and some learned that sometimes even when you don't give it your all, you do get by (albeit with a lower grade. Some of the personnel problems grew from this hands off approach and some would have developed in anycase. At the same time, earlier interventions and a closer watch on all design groups and individuals could have prevented some of the personnel management challenges.

Clearly a smaller team is easier to deal with. It is also easier to keep ones hand on the pulse of the smaller group. This year and in future years, the plan is to keep the team size to twenty-five or less. The team is working much more cohesively this year as a result of the smaller team size as well as acknowledging at the outset the potential problems with inclusion, exclusion and cliques that can form. A "social director" was also assigned to plan and implement several team building and social events to build friendship and team spirit and to avoid members from feeling like they are being left out. The pulse of the team is also taken periodically through short papers where team members describe what is working, what is not working, and what could be improved with regard to the design process and management of the team. The team leader this year was chosen not only because he had the management skills, but also because he had the respect of the entire team as a result of being personable and one of the most technically competent students.

The team this year is much better organized, congenial, and productive as a result of the leadership, periodic feedback, and social activities. The team last year had no one that had been on the team in previous years, but the team this year has six members that were on the team last year as volunteers or special study students. This allowed some foundation for the current team. Also, some students this year were selected by application and interview. Last year's team was a completely random registration process. Students were selected by the computer filling thirty-five seats from 60 or so requests. This year we are implementing an application and interview process for all students that want to be on next year's team. This selection process is being handled by the team captain, a special study student and the six rising senior volunteers, from this year, that will be on the team as participants in the senior capstone project next year. The team is looking for personable full participants that are eager to work and learn and are committed to getting the job done. They do not need any previous mechanical experience.

In conclusion, Senior Capstone projects can be rewarding to teach/coach for the instructor as well as all of the student participants if you go in with your eyes open and continuously monitor progress of not only the project, but also of the team members themselves. Taking the pulse of the team is vitally important to the life and success of the team.

Future plans include efforts to expand the written feedback and team spirit activities. Also planned is the inclusion of even more frequent peer evaluations during the semester. In addition, our plan is to have team leadership come from previous year's volunteers. Volunteers that have a proven track record of performance and potential for leadership will be able to step into place more smoothly.

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