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# CASE STUDY FOR INTRODUCTORY MECHANICAL DESIGN COMPETITIONS

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## ABSTRACT

Freshman/sophomore design projects provide students with hands-on experiences in conceptual design and manufacturing. For some of these courses, a design competition is used to teach the design and construction components. These competitions are often reused from semester to semester, so the students typically suffer from design fixation. When design competition tables are erected new every single semester, it requires advanced planning and high budgets. This paper discusses a case study of a different structure for introductory design courses and competitions at Harvard. We summarize a yearlong effort to improve an existing early design competition with more machine component elements and linkage design. The goal of a interchangeable design competition was to prevent design fixation while at the same time providing boundaries for students to successfully implement their robot designs, independent of their previous mechanical engineering exposure.

**Keywords**: Engineering Education, Mechanical Design, Design Competition, Best Practices.

## INTRODUCTION

Design is often taught in Capstone courses. However, more and more schools offer introductory design courses earlier in the curriculum, even offering first-year introduction to engineering subjects or through required design "cornerstone" subjects.

Early project-based experiences (such as first-year, cornerstone courses) are shown to have a large impact on engineering students. In particular, they serve to enhance student interest in engineering, improve retention, and improve results in later courses. Most universities that offer an undergraduate degree in mechanical engineering include introductory design, machine design and machine element courses as part of the curriculum. These courses cover the fundamentals of solid mechanics, factors of safety and analysis of machine components. Richardson and Dantzler [1][1][2] noted that the retention rates of students at the University of Alabama who take engineering courses in their first-year improve as much as 16%.

We see a similar improvement in second year retention rates among engineering students who take a project-base course as reported by the Gateway coalition of eight schools (Columbia, Cooper, Drexel, NJIT, Ohio State, Polytechnic Institute of NYU, South Carolina, USC). In particular, retention rates among women and underrepresented minorities are much higher. In 2003, the compared with national rates are 86% to 67% for minority students, 90% to 88% for women students, and 86% to 70% for all students [2][2][3].

One of the shortfalls of introductory design courses is that competitions are typically reused from year to year. Building a new competition requires advanced planning and a dedicated staff and budget. Most engineering programs simply do not have the resources to keep the competition "fresh." This leads to problematic outcomes. For example, students pass knowledge from semester to semester. Which can lead students tend to fixate on previous designs. This results in designs that look very similar and perform equally well from semester to semester. This phenomenon is known as design fixation. It leads designers to think of a particular concept and it limits the other ideas they are able to generate. Students developed institutionalized knowledge about the perceived best solution, which limits their creativity.

Another shortfall of introductory design course is a lack of analytical rigor. In our case, students have very little background in mechanical engineering. Courses, like the one discussed in this paper, must be able to attract students to engineering while still providing enough rigor for students already committed to mechanical engineering. In addition, introductory design course sometimes lack appropriate boundaries to the creative space, so students don't get frustrated and can produce a final product. The design space is either too open, leading students to purchase wrong parts, or too closed, where students build prototypes only out of foam core and not metals or wood.

 

This paper will discuss a freshman/sophomore level design course in the Mechanical Engineering curriculum at Harvard entitled *ES51: Computer-Aided Machine Design*. For most students, *ES51* represents their first opportunity to design and build a functioning machine. Like similar courses, a design competition is a major component of the course work.

We discuss the evolution of the course and the development of a new design competition. Our goal was to prevent design fixation and encourage more creativity in the designs by changing the design competition table every semester. This paper, and course, offers a case study for creating an introductory mechanical engineering design competition.

## CURRICULUM AND COURSE GOALS

At Harvard, the distribution of courses illustrates the emphasis on design. The course sequence for mechanical engineering typically starts with *ES51*, in which the engineering design process, graphics, drawings and solid modeling are emphasized. The topics in this course are integrated with experience of hands-on building that is described in this paper. Following the freshman year, students enroll in a number of basics and major sequence courses. These courses include solid mechanics, thermodynamics, but each of these courses also focuses on open-ended design activities. In their junior year, students will take an introductory design course, which is focused on teamwork and stepping through the entire design process in one semester. The students then apply their undergraduate knowledge in their senior design projects, which span two semesters and are done individually.

At Harvard, undergraduate mechanical engineering students typically enroll in *ES51* in their sophomore year. Harvard students do not declare their major until the second semester of sophomore year, so introductory engineering classes are very popular. There are no prerequisite to the course related to manufacturing or fabrication. The only requirements are high school math and physics. This makes the course very attractive to non-engineering students.

Students are, by large majority, complete novices in the design of electro-mechanical devices. Few students enrolled in *ES51* have had any prior manufacturing or design experience (70% are engineering majors, remainder is non-engineering including computer science). Many students indicate on surveys that they do not feel confident about their fabrication skills when entering the course. So, *ES51* must serve as an introduction to a wide range of processes.

The course goals of *ES51* are that students, after completing the course, will be able to:

1. Generate, analyze, and refine the design of simple electro-mechanical devices making use of basic physics, mathematics, and engineering principles.
2. Describe and select common machine elements such as fasteners, joints, springs, bearings, gearing, motors, belts, chains, and shafts.
3. Apply experimentation and data analytic principles relevant to mechanical design.
4. Communicate a design and its analysis (written, oral, and graphical forms).
5. Develop basic machining and fabrication skills.

It is assumed that students do not have any knowledge of solid mechanics, concepts of stress and strain are not taught.

**New Course Design**

Our fundamental goal was to evolve the curriculum at Harvard in machine design to address the contemporary needs of our students. The course balances introductory material, such as Computed-Aided Design (CAD) and prototyping, with a more advanced survey of machine elements (such as gears, motors, bearings and linkages). We pioneered a new design competition (described below) that focused the course on machine design but also allowed freshman and sophomores with no prior mechanical design experience to take it. The following additional features were added to existing course:

1. Defocus on solid mechanics instruction, emphasize on fundamentals and applications of machine elements.
2. Design competition that changes every semester, now spanning 8 weeks instead of 5 weeks.
3. Machine dissection activities.
4. Addition of linkages, cams and other machine components to the course.

Given the focus in *ES51* on machine design components, the concept of a multi-faceted design competition was instrumental to the success of the class. We increased this design competition from 5 weeks to 8 weeks and structured it as a 3 – 4 person team project. Each phase of the competition mapped back to a particular engineering theory. For example, lectures introduced motor specifications and gear trains. During week 2 of the competition, students are asked to measure and characterize motors given to them for their robots via a screwdriver dissection exercise. This expanded the students' hands-on experiences with machines and threaded the competition throughout the course schedule.

Students were asked to connect the underlying mechanical engineering theory with actual interfacing hardware by creating a remote controlled robot. These robots were powered by two electric motors, taken from a dissection activity in class. The robots must be able to accomplish certain goals – the main one being the ability to score as many points as possible during the competition.

We moved the competition to a single-elimination tournament, similarly to competitions like FIRST or others. This replaced the previous approach where one team competed on the table at a time. We also made several competition table changes, which will be described in detail below. At a high level, design concepts such as linkage or drive train design are constant, while some of the challenges for scoring are changed. Shown in Fig 1. is the design competition table from Fall 2014. Figure 2 shows the small changes to the table

Radio controllers (RC) were introduced. In the past, the robots were connected via a wiring harness to a power supply. The burden was placed on the students to build a controller that would allow them to turn the motors on and off. The RC allowed students to plug and chug their motors into the controllers. This proved very effective during the electric motor component of the lecture, as students were able to analyze the characteristics motors right away (with the setup for the design competition).

We built an extensive inventory with a focus on standardizing parts (nuts and bolts were only available in one size, 4-40). In addition, numerous gears were available with a standardized shaft size of 1/4in. This allowed students to build several iterations of their robots and not worry about having additional parts later on. This helped solve a problem we had seen in the past where the ordering process delayed…

## OUR COMPETITION TABLE: A CASE STUDY

A number of options exist for implementing design competitions in an introductory mechanical engineering course. We considered several options such as complexity of designs required to score high, tradeoffs between rebuilding every semester and design fixation, cost and staff time commitment. During the re-design of the competition table, there were three main goals.

1. Modularity: design competitions become stale very quickly. Design fixation sets in within 1-2 semesters. The ability to change components within a 3-week turn around time (January break) was critical. Figure 1 and 2 show the changes in the design competition.

The overall table size is 8ft by 6ft. The competition can be broken into 2 halves to fit through doors. Furthermore; the playing field is also broken into 2 halfs. The back and front halfs can be interchanged and therefore increase the variety of playing surfaces. Ideally, one half could be swapped out while leaving the other half to modify the competition enough to prevent design fixation.

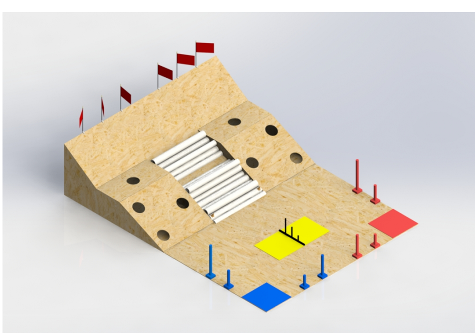

**Figure 1: Competition table for Fall Semester 2014. Main goal was to place rings on pegs (front half) or in corn holes while grabbing flags as point multipliers (back half).**

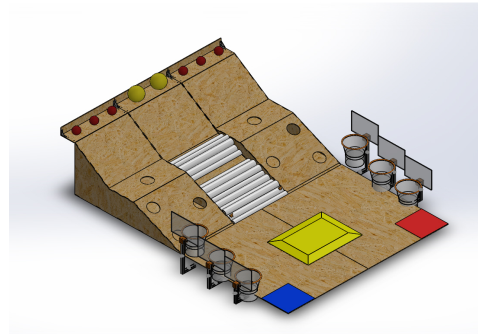

**Figure 2: Competition table for Spring Semester 2015. Additions of basketball elements (front half) and balls instead of flags )back half) required low time commitment.**

Swapping components and the manipulated objects (rings, bean bags or balls) can be interchanged. In previous years, students were shown example robots. Because of the changes in the competition, students had to completely design their robots from scratch (although motor and shaft attachments were similar). The actual table from the Fall 2014 semester is shown below.

**Figure 3: Actual competition with turf grass to cover PVC pipes.**

2. Challenges for multiple levels: Competitions should have multiple difficulty levels, not geared towards highest or lowest denominator. This means multiple goal objectives. The hope by having multiple challenges, design fixation will not set in. Student teams can pick which challenge they want to attempt. High performing teams will optimize for points, whereas lower performing teams will try for easier challenges. However, the goal is that all teams can score. Because this is a tournament, winning is only possible through design robustness, not necessarily complexity. Because rules governing the competition need to be frozen within 1-2 weeks of the semester starting, changes to the competition table are not well-received by the students. The focus on course elements such as electric motors, linkages, gears and manufacturing was also made clear in lab. For example, students had to calculate the torque required to overcome the inclined back section to score point or grab the multiplier flags. Because the motors were high RPM motors, students then had to design a gearbox to provide the correct amount of torque. Grabbing the rings required knowledge of

linkages. Although it was never specified that students had to use linkages in the competition rules, most student teams decided on them.

3. Public Viewing: the competition is raised for better viewing. In addition, the competition has 3D components to make it visually more interesting (besides providing challenging obstacles). While this has no direct effect on design fixation, the course is meant to draw in freshman and otherwise interested students in taking the course. Students are keen to share their design accomplishments with their friends and even families.

## DISCUSSION

The intent of the redesign of the competition table was to introduce a new table designs each semester while keeping the cost and time effort to build a new competition to a minimum. In the past, evolutionary convergence (there are only so many good solutions to a given problem and with repetition these solutions appear more frequently) has occurred by using the same table. Evolutionary convergence may still occur for the drive train design as students, but further investigation into how the design concepts change is needed. The main change in design is seen in how rings or balls are picked up, but the concept around how to build a linkage or drive train stays consistent and hopefully best solutions will be passed on.

Furthermore, students are given a common set of parts and a radio as part of this competition. The solution space is obviously reduced at this point. While there is a pedagogical lesson to be learned when purchasing the wrong parts, the time constraints of 8 weeks made ordering and staying within a limit stressful for students. Stock (such as gears and nuts) in the lab offers over 100 additional components to the kit.

## CONCLUSION

The move from a "static" design competition to a more dynamic approach has been met with tremendous success at Harvard. The initial increased investment in faculty time and school resources have resulted in a significant increase in student interest and motivation. Courses such as *ES51* connect classroom material directly to the hands-on design competitions. It is unclear at this point whether changing the design competition from semester to semester leads to worse design solutions. The competitions have a high impact on students. Students become more familiar with basic machine design and they are introduced to using tools and tinkering.

The incorporation of radio-controlled robots has enhanced the student's ability to design and analyze systems with mechanical components without adding additional time to wire a harness. The overarching goal for this course is to show that engineering is fun.

Assessment was currently done via the end-of-the-semester course evaluation and students responded very positively. Self-efficacy measures and other design outcome assessments are currently being developed for this course. The course description, objectives and syllabus as well as the competition rules and handouts are available electronically by contacting one of the authors.


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