COMBINED FRESHMAN-JUNIOR COURSE PROJECTS

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ABSTRACT

A multi-year, multi-discipline course project was developed that involved freshmen engineering students in EGR 101 - CAD/CAM, and Product Design and Manufacturing/Mechanical Engineering juniors in EGR 345 - Dynamic System Modeling and Control. Teams of students from both courses designed and built mechanisms to point towards one of four targets and then shoot a ball using compressed air. The freshmen were allowed to manually control their devices using push button based controls for motors and pneumatics. The juniors designed machines that were fully autonomous using a microcontroller. The student teams then competed head-to-head.

The intention of the paper is to describe the projects from a pedagogical perspective so that others might implement similar projects at other institutions. To do this the paper will describe the project and competition in detail, including examples of entries produced by the freshmen and juniors. Numerous anecdotes are provided.

1. INTRODUCTION

Project work provides an excellent opportunity for students to apply theoretical knowledge to real problems. Typically projects are isolated to individual courses to simplify the management of the projects. However, by expanding projects to go beyond course boundaries we can create some interesting new learning opportunities. Consider a project that bridges two different courses, students are able to work with peers on a larger project covering a greater breadth of disciplines. Or, consider a project that bridges different program years, removing the comfort of working only with peers.

The curriculum at Grand Valley State University has been designed with a major emphasis on project work (Jack, 2004). This culminates with the senior project capstone experience in EGR 485 and 486, with projects done for local industries (Ray, 2006). Project work begins in the first freshman engineering course EGR 101 - CAD/CAM, and continues until graduation. In our early explorations of alternate pedagogical approaches to project work we began by seeding junior level teams of five with one or two freshmen. In these teams the freshmen from a limited number of EGR 101 laboratories were matched with student teams in EGR 345 - Dynamic System Modeling and Control. In the fall of 2003 these teams had to design and build a gantry crane that would compensate for payload sway. In the fall of 2004 the teams designed and built small scale self balancing robots modeled after the Segway. Within the teams the freshmen took leadership roles in the design and build of the mechanical parts of the project, while the juniors focused on the design and construction of the controller. The freshmen on these teams got a unique look ahead to the expectations of junior level students, while the juniors were able to practice skills such as delegation, mentoring, project management, and teamwork. This model was very encouraging, but because of the much larger freshman class it was not scalable.

In the fall of 2005 an alternate approach was used to overcome the scaling problem of the earlier project approach. Instead of creating combined teams, the EGR 101 and 345 students were organized into separate teams that would compete against each other.

Student teams were required to design and build a machine that would shoot balls at one of four targets using compressed air. Targets were activated randomly and were deactivated once hit. The devices were placed on a competition field as shown in Figure 1. Over a two minute interval the team that scored the most points would win the round. The detailed rules are available on the course web page (Jack, 2006). The devices built by the freshmen were manually controlled, while the juniors were expected to design a fully automated device using a microcontroller.

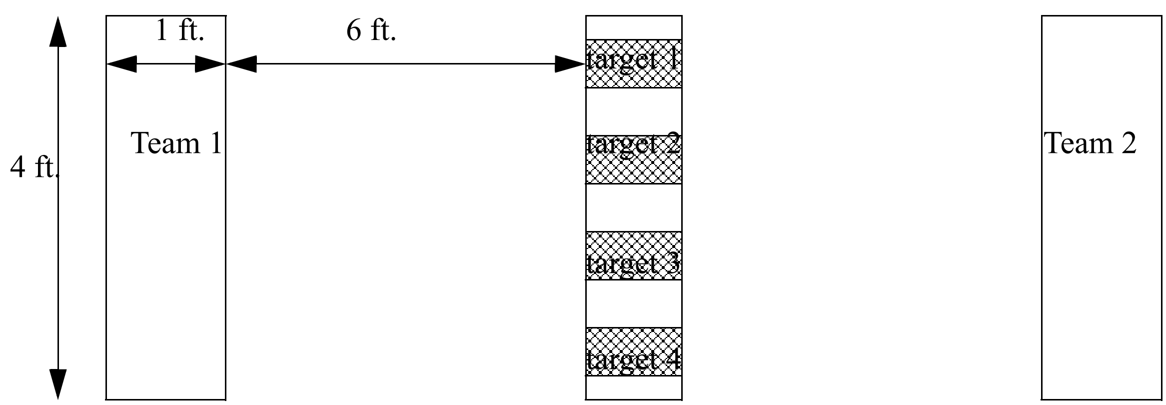

Figure 1 - Competition field layout

Beyond the competition, course grading was used to drive other design elements including a low mass, low cost, and small geometry. These requirements were customized for each class, with the expectations for the juniors being greater.

The project began in September for the juniors and in October for the Freshmen. In both cases intermediate reports were required before construction began. After construction was complete all teams were expected to qualify for the competition. The first round of qualification was done semi-formally in laboratory settings. Teams that did not qualify for the final competition were allowed to compete for final competition slots in a ‘wild card’ competition. Finally the qualifying teams competed head-to-head.

The resources required for these projects were insignificant beyond previous needs, except for approximately 20 combined hours of faculty time for coordination. EGR 101 used its existing project budget of approximately $2,000 for materials for 180 students. EGR 345 does not require a project budget because students have always purchase their own materials, with the exception of normal consumables. The competition field was built using surplus materials and available electrical equipment.

2. EGR 101 - AN INTRODUCTION TO CAD/CAM

The freshman level class "EGR-101 An Introduction to Computer Aided Design and Manufacture" is a required class of all incoming engineering students, common to all engineering disciplines. Perhaps the course itself has outgrown its given title, because the title no longer does justice to the variety of topics that are currently in the course syllabus. The class covers a wide range of engineering material including traditional design methodologies, hand sketching, orthographic and isometric representations of objects, mechanical machine components, introductory electrical circuits, manufacturing processes, and a sampling of other pertinent subject matter. The class is as much an introduction to engineering as it is an introduction to the school of engineering. There is also a lab component associated to the course that reinforces many of the lecture topics, but also stresses computer aided design, CNC milling, teamwork, and technical communication. The software that is currently used in the course is PTC's suite of Pro/Engineer Wildfire CAD/CAM tools. Students enrolled in EGR-101 experience a series of increasingly complex design projects which last for similarly increasing durations of time. The semester begins with short design activities that last only a couple of hours during the scheduled lab period, and ends with a large scale design project that is spread out over the final seven weeks of the semester.

For the competition, students were organized into design teams of two students assigned by their lab professor. The basic stages of the project were:

- October 19 - Students were officially introduced to the project and their team.
- October 26 - Conceptual designs were submitted and cardboard prototypes of these concepts were built.
- November 2 - CAD assemblies of the designs were created, and individual components began to be constructed using the CNC mills.
- November 9 - Construction of the physical machines continued, while the designs were documented with dimensioned and toleranced drawings of the components.
- November 16 - Physical assembly of the machines continued with preliminary test being run.
- November 30 - Qualification rounds for the final competition were held.
- December 3 - The 'wildcard competition' was held
- December 8 - The final competition was held

The stated objectives for students in EGR-101 are itemized below. These were used as the rules in the final project competition, and to determine project grades for the students.

- The entire machine must initially fit within a 12 inch cube (one cubic foot). Before a round of competition begins, teams will be allowed two minutes to assemble their machines during which this size restriction may be exceeded.
- The machine must weigh less than 3 kilograms.
- No manual interaction is allowed with the machine during competition except through the electric and pneumatic controls.
- The machine will be allowed to hold a payload of 30 balls that must be loaded into the firing mechanism using the machine's controls.
- All structural components must be constructed of plastic provided to you by the school of engineering.
- The overall rating of each machine and its performance will be evaluated using the following equation:

$$S = H^{-2}(4)^{\frac{C}{80}}(10)^{-B}(10)^{-T}(2)^{\frac{L}{3}}M^{4} \qquad (1)$$

where

H = the total points scored in a 2 minute interval

C = total cost of parts ($)

L = largest dimension (inches)

B = build quality score assigned by judges (1=best, 0=worst)

T = theory quality score (EGR 101 students assume 1.0)

M = mass of the apparatus (Kg)

3. EGR 345 - DYNAMIC SYSTEM MODELING AND CONTROL

All juniors in the Mechanical Engineering (ME), or Product Design and Manufacturing (PDM) Engineering programs are required to take EGR 345. This course begins with system modeling techniques and ends with control system fundamentals. The laboratories in the course make extensive use of microcontrollers. The course includes a major control system design experience to emphasize the course content (Jack, 2006).

The EGR 345 students were organized into 11 teams of 5 students. These teams were selected to compliment strengths of individual students, or provide growth opportunities for challenged students. The timeline for the fall of 2005 is given below. Teams were also required to submit weekly progress reports.

Sept 3 - Teams assigned
Sept 19 - Preliminary design concept submitted with specifications
    3 conceptual designs including sketches
    one design selected using a decision matrix or similar technique
    electrical schematic sketches

block diagrams
proof of concept calculations
materials list estimate
budget estimate
Gantt charts

Sept 21 - Design concept approved
Oct 17 - Proposal submitted (minimal text)
detailed drawings (CAD)
materials list and sources for purchased items
detailed system architecture - block diagrams, schematics, etc.
special motion plans/profiles
detailed budget
mass table
calculations/simulations
testing plans
an estimate of performance
controller programs

Oct 19 - Proposals approved, mechanical building begins
Oct 26 - First mechanical test
Nov 2 - Second mechanical test
Nov 7 - First controlled test
Nov 14 - Second controlled test
Nov 16 - First draft of report posted to the web used to determine the score for competition
Nov 21 - Qualification for EGR 345 student teams
Nov 30 - Final report draft posted to the web
Dec 3 - Wildcard competition
Dec 8 - EGR 101 final project morning (EGR 345 students attend)

The juniors were required to produce a Ball Shooter that contained all electronics, mechanical components and other necessary components except for the supplied power sources. The objectives for the EGR 345 design are itemized below. The following equation was used to assess the overall score using the competition score.

- The largest dimension of the device must be under 12 inches, but smaller designs will receive more points.
- The equipment cost should be minimized. The goal of $200 or less has been specified as very important.
- Mass should be minimized, the target value is 1Kg.
- A clearly justified and supported design process. This will be judged before the competition.

- The overall performance in the competition.

$$S = H^{-2}(4)^{\frac{C}{80}}(10)^{-B}(10)^{-T}(2)^{\frac{L}{3}}M^{4} \qquad (2)$$

where,

H = the points scored in a 2 minute interval

C = total cost of parts ($)

L = largest dimension (inches)

B = build quality score assigned by judges (1=best, 0=worst)

T = theory quality score assigned by judges (1=best, 0 = worst)

M = mass of the apparatus (Kg)

In keeping with the objective of strengthening project management skills the juniors were expected to observe the fundamentals of project management. This began with the basics of teamwork and organization. The students were grouped using self evaluation forms (Jack, 2006) and input from former instructors. Once grouped students were expected to coordinate timetables, skills and tasks. This was formalized in weekly progress reports and the Gantt chart. Mechanisms were in place for dealing with personality issues but were not needed this past fall. Peer evaluation forms (Jack 2006) were used at the end of the course to adjust grades.

4. THE COMPETITION

The competition was staged to allow students to finish their first build earlier so that there was time for refinement. Most teams made changes to their designs after the first tests. In total there were 66 teams in EGR 101 and 345 combined. Initially 20 of 55 were qualified from EGR 101 and 8 of 11 from EGR 345. In the wildcard tournament only 7 teams participated for 4 spots. At that time all 7 were advanced to the final competition. The lack of participation in the Wildcard Tournament was less than expected and will be a redesign issue for the fall of 2006.

On the day of the final competition the EGR 101 and 345 teams were separated until the final 4 competitors remained. In general the EGR 345 projects were fast and accurate enough to defeat most of the EGR 101 teams. By delaying EGR 101 / 345 matchups students were able to compete on a more even playing field. By the time the final eight teams were selected the teams were more evenly matched and some junior teams were defeated by the freshmen. The final competition was between a freshman and junior team with the junior team winning narrowly. Needless to say all instructors were pleased by the level of competition and the commitment by the students.
This helped students compete against their peers and avoid competitive disadvantages

The competition became a very visual event for students to evaluate design decision and perceived biased. For example, the junior level students designed mechanisms that, when properly setup, were very fast and would easily overwhelm a manually controlled mechanism. However, slight problems, such as jamming and misalignment often crippled or halted these designs. In many highly visible cases the automated designs were not properly aligned with the targets and would always shoot faster than their opponents, but miss the targets. By contrast the manual designs normally took longer to position and fire, but when they missed they could be 'tweaked'.

The competition was built using plywood and common industrial controls hardware, as pictured in Figure 2. Although we began with ambitious plans of making the scoring system fully automated, there were problems with ball detection that required manual scoring.

Figure 2 - Photograph of competition field with controls

The typical EGR 101 design cost less than $50 and weighed approximately 1-2 Kg. The major design component was a motor/planetary gear set ($18) and a quick disconnect for a pneumatic hose. The EGR 345 designs cost between $57 and $156 with weights between 510g and 1.56Kg. Design reports for the EGR 345 projects can be found from the course main page (Jack, 2006).

Figure 3 - EGR 101 project designs

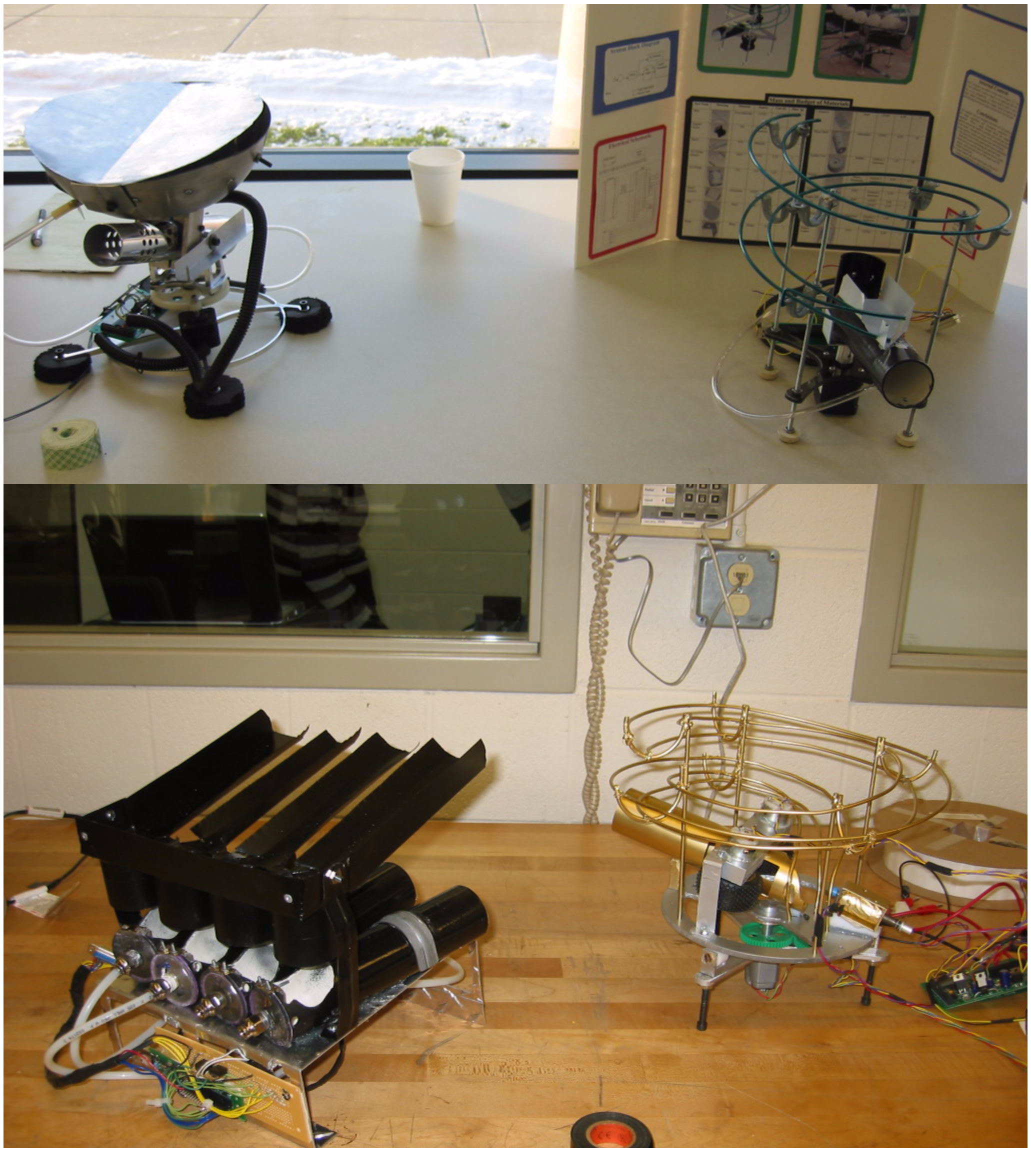

Figure 4 - EGR 345 project designs

5. CONCLUSION

Multi-year projects provide a unique opportunity for freshmen to look ahead and see what topics will arrive in later years. This competition will make it very unlikely that a freshman will claim that ME and PDM students do not need to know circuits, programming or calculus. For the junior level students they had an opportunity to see how their knowledge had progressed beyond the freshmen level, but were reminded that merely being a junior did not make them untouchable. Although the freshmen and juniors were no longer on the same teams they were very aware of the other teams. The practice field was placed in a very visible location that allowed all practice runs to be viewed.

At the time of writing this paper we are already planning for the competition in the fall of 2006. We go into this with the following lessons learned.

> Keep the competition design simple - make it so that the design require little setup or preparation. This will make the testing phases easier. The ideal competition requires no field, no rules, and the outcome is obvious.
>
> Make attendance for the final competition mandatory - Some of the benefits of the competition were lost for students who did not qualify and did not attend the final competition. These were the students we wanted to reach the most.
>
> Use a self evident scoring system - The automated scoring system added complications that were hard to detect and eliminate. The ideal scoring system should not require any judgement.
>
> Use an automated competition control system - Have a timer system that monitors the setup, start and end of the competition. Students cannot argue with a beeper or bell.

In the past DC motors have been the primary mechanical source used in many projects. This year was the first time with widespread use of pneumatics. This has been a remarkably good tool. The basic valves were supplied as a standard setup an students only needed to purchase ($1) a quick disconnect for 1/4” hose. Pneumatics provided relatively strong forces with relatively few drawbacks. The only safety issues involves loose air hoses that tend to flail when not held down.

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