AC 2010-1044: SHORT, HANDS-ON TEAM DESIGN PROJECTS IN A FRESHMAN ENGINEERING PHYSICS CLASS

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Short, Hands-On Team Design Projects in a Freshman Engineering Physics Class

Introduction

One of the challenges of a first year engineering course that integrates traditional physics content with an introduction to engineering design is the development of suitable design projects. An ideal project is one that is challenging, fun, requires teamwork, associated with the physics material being studied, low cost, and doable in a limited amount of time. This paper describes several design projects that have been created for use in a freshman engineering physics class that meet these criteria. Various techniques related to team selection, encouraging teamwork, incorporation of physics topics, keeping costs down, project results presentations, and gathering feedback from students are also presented.

At the end of each semester of the two-semester course sequence, there is a longer, more traditional team design project that lasts several weeks. We have found, though, that using short, single-period, team projects throughout the semester has several advantages. These include:

- Students are forced to build their teamwork skills as the projects cannot be completed in the allotted time without working together. It is impossible for one person to do it all and carry the rest of the team.
- Students get the opportunity to work with different team members, as teams can be reorganized for each project.
- Many different physics topics can be incorporated into team projects throughout the two-semester course sequence.
- The projects each have an element of fun, which keeps the class exciting and students interested and motivated in the course.

By conducting the team projects during class recitation time, graduate students can be used to facilitate, guide, and coach the teams. The graduate students help with teamwork skills by helping to keep the teams organized, on task, and working efficiently. This model is also useful for physics instruction, as the graduate assistants roam among the teams informally asking leading questions, and providing answers and explanations of various concepts at the point in time in which the student's interest is at its highest.

The pedagogy behind the team projects is similar to that of project-centered learning (Sheppard et al., 2009). The objectives of these projects are similar – to have students develop teamwork skills, and to teach students basic physics and engineering design concepts in a complementary format to the traditional lecture. The projects are slightly longer, but similar in concept and objectives to the hands-on experiences at Virginia Tech (Goff and Connor, 2001), but do not span several weeks, as other freshman projects do (e.g. Ohio State, 2009).

Example Projects

The following describes five projects that have been used in a 75-minute recitation period. Approximately three short team projects are completed during the semester. The projects are designed to be primarily finished in the recitation time, with little outside time required by the team.

Paint the Jumbotron Orange

A desired outcome of a first engineering course is for students to be able to quickly estimate the answer to a problem, and determine the reasonableness of a calculated answer. We have found estimation difficult to teach, but we do use a short team project to help students learn estimation. The project is also used to have students work a scaling problem.

The students are asked to estimate the amount of paint that would be required to paint the tubular steel supports of the Jumbotron (Figure 1). The Jumbotron is within easy walking distance of the classroom, so students are able to walk around to estimate diameters of members, heights, etc. Getting the students out of the classroom and actively collecting data is an important part of this project. Teams are required to make a quick two-minute initial estimate. They turn this estimate in to the teaching assistant, who records it. The students work together in their teams to make a more detailed estimate of the amount of paint required, approximating the dimensions of the Jumbotron supports. Several cans of paint are placed in the classroom so students can see the estimated coverage per gallon. The teams are also asked to determine the amount of paint that would be required to paint a ¾ in. = 1 ft scale model of the Jumbotron. We have found that scaling is a concept students struggle with, particularly whether you are scaling length, area, or volume. The students turn in a short report that shows how they obtained their estimate (including a sketch – an important form of engineering communication), compare their final estimate the initial two-minute estimate, and the solution to the scale problem.

As students are working on this project, the graduate assistants circulate among the teams to monitor progress. They graduate assistants have been guided to look for some common mistakes, and with some questions for the teams. For example, we have an estimation problem within this problem by asking whether a gallon of paint covering 400 sq. ft is reasonable. Most students have painted a bedroom, know that it takes about a gallon, and can quickly estimate the surface area of a bedroom's walls, determining that 400 sq. ft. per gallon is a reasonable coverage. Some teams will realize that we did not specify the number of coats of paint we were going to use, and ask that. We don't provide an answer, but rather tell them they often encounter engineering problems with incomplete information, and guide them towards what to do – make a reasonable assumption, clearly state the assumption, and solve the problem based on that assumption. Teams can also struggle with the scaling aspect of the problem, with many teams scaling based on volume instead of surface area. The graduate assistants guide the teams by asking questions such as 'does the thickness of the paint film change depending on whether you are painting a large room or a small room?'

The estimation problem is the first project of the semester. It has proven to be beneficial in both getting students started working in teams, and teaching the important concept of estimation.

Figure 1: Students Examining Jumbotron Supports

Find Your Way Home With Vectors

One of the fundamental concepts of physics that students need a thorough understanding of is vectors. To help students visualize vectors, and to learn to work together as a team, students are given a nearby object on campus as their destination, with the destination having an engineering theme, such as the civil engineering steel sculpture or the mechanical engineering hybrid SUV vehicle. Students are only given a compass, and need to "vector" their way to their destination. For each leg of the trip, students record the distance using pacing, the bearing of the compass, and an estimated altitude change. The students record another set of vectors by returning to the starting point via a different path, usually going around a building a different way. Finally, one team member is required to run the complete path while the others record their time.

After gathering the data, the teams perform vector calculations and turn in a short report. The teams add the vectors from the first part of their trip, origin to destination, to obtain the position of the destination object. The teams also add the vectors of the return trip, to see how they compare. This is a good lesson in experimental error and uncertainty. Although the sum of the position and return vector should be zero, this of course never happens. This provides a good example of uncertainty in measurements, and the use of significant figures. The measurements also are used to illustrate the difference between accuracy and precision. There is no reason to suspect that the answers are not accurate, but they are not very precise.

Finally, the teams are required to determine the average speed and average velocity of their runner. This is used to emphasize the difference between speed (distance/time) and velocity (displacement/time). Often one team member will recognize that the average velocity should be zero since they started and ended at the same place. Most students in the physics class are also in a one hour Introduction to Computing course, so the data collected in this project is also used there where the students create an Excel spreadsheet to perform the same vector calculations.

The Ultimate Projectile Contest

As the name implies, this project is associated with projectile motion. The objectives of the project are for students to learn the basics of projectile motion, to design and build a simple "shooter" device, and to continue to learn to work together as a team by self-assigning various tasks. Each team of four students is given duct tape, about 3 ft of string, a ½ in. x 24 in. dowel rod, a #107 rubber band (⅝ in. x 7 in.), two ¾ in. square x 16 in. long pieces of wood attached together with a bolt and wing nut at one end, a PVC shooter body, and a plastic wiffle golf ball. The PVC shooter body is a ½ in. x 18 in. long piece of Schedule 40 PVC pipe that is epoxied to a 1-¼ in. PVC end cap with a ⅞ in. diameter hole drilled in the end to accept the ½ in. pipe. The 1-¼ in. cap is just the right size to hold a practice golf ball. Students put the materials together to build a shooter as shown in Figure 2.

The rubber band serves as a "spring", and is attached to the dowel rod and the shooter body. The pieces of wood and string can be used to build a support for the shooter. The key to the project is to build a shooter that is repeatable, both in terms of shooting angle and shooting velocity.

Students are required to complete various tasks with their shooter to learn about projectile motion. These include:

- Determining the initial velocity of the practice golf ball for two settings of the shooter (low and high) by first laying the shooter flat on the table so that it shoots horizontally. Students measure the height from the bottom of the plastic golf ball to the floor. Based on this height, they calculate the time it would take the ball to drop to the floor (vertical motion), measure the horizontal distance the ball travels, and calculate an initial velocity.
- Analyzing projectile motion by setting the shooter on a table so that it has an angle of 30° with respect to the table. Using the low setting from the first task, determine the x and y components of the initial velocity. Using a measured height from the floor to the launch point and the initial y velocity, students calculate the time for the ball to hit the floor. Using that time and the x component of the velocity, students calculate where the ball should hit the floor. Students then shoot the ball, record the distances, and see both how repeatable their shooter is, and how close they come to the theoretical value.

The final aspect of this project is a contest to see how many golf balls can be shot into a target in a 2 minute period. The target is a 16 in. diameter cylinder that is 5 ft. high and open on the bottom so made shots will fall through. The shooters are positioned 15 ft. from the target. A circle is formed around the target with eight teams shooting at once, with the rules being that each team can only use one ball, and there is no blocking or stealing of other team's golf balls. Besides being an enormous amount of fun, students quickly learn through this contest the value of teamwork. Those teams that organize themselves and truly work as a team usually do the best in the contest. The optimum arrangement is a team member handling the shooter (having the dowel rod pulled back and ready to shoot), a team member loading the shooter with the golf ball, a team member retrieving shots that are short of the target, and a team member retrieving shots that are long of the target. Students are not told this, but left to figure it out themselves, sometimes while the contest is in progress.

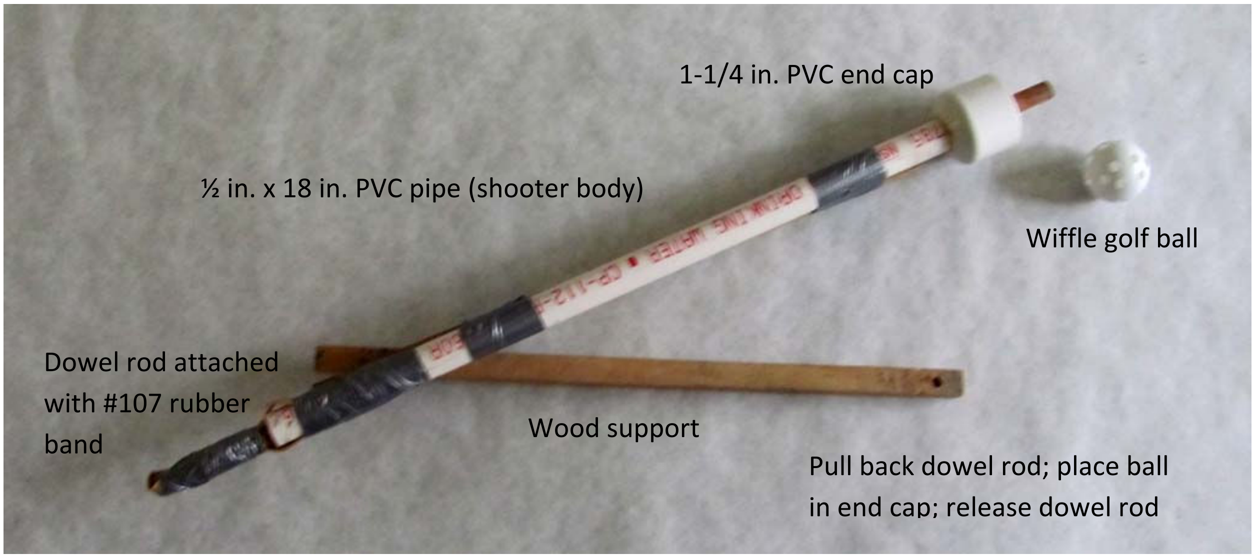

Figure 2: Typical Shooter for the Ultimate Projectile Contest

Bridge Construction for Journalism Majors

This project is used in conjunction with an introduction to two-dimensional static equilibrium. The objectives of the project are to execute a simple design to meet certain criteria, to practice drawing free-body diagrams, and for teams to learn to use aspects of various design ideas to develop one design. This project is a classic project in which students build a bridge using newspaper and masking tape. Each team has to build a bridge that will hold 10 pounds and allow a 6 in. high x 12 in. wide object to pass underneath it. Grading is partially based on the lightest bridge to hold the weight. Two example bridges are shown in Figure 3, one being a traditional truss bridge and the other a more creative design similar to a tension fabric roof.

Several features have been added to this project, as follows.

- No actual building is allowed during the first 15 minutes of the project. During the first 5 minutes, each person is required to sketch out a potential solution to the problem by themselves. During the next 10 minutes, the teams discuss the individual solutions and decide on a bridge to build. This could be one of the individually developed solutions, a combination of the proposed solutions, or even an entirely new solution.
- Teams are required to draw free-body diagrams of each of the main components of their bridge. This is to give them practice at drawing free-body diagrams, for them to see the purpose of free-body diagrams, for students to see Newton's third law (the reaction from one component is applied to another component), and to see the importance of a continuous path from the load to the support. Free-body diagrams are typically a hard concept for students and this part of the project gives them additional practice in drawing free-body diagrams in a fun and practical manner.
- The failure mode of these bridges is typically a stability failure, and not a material failure. As the students are building their bridges, the graduate assistants will casually discuss stability as they roam amongst the teams. The stability discussion is facilitated with two

simple models: three wood pieces loosely connected with bolts to form a stable triangle, and four wood pieces loosely connected with bolts to form an unstable square. The students can push down on the top of the square, and as long as everything is lined up, it is stable. If the load is just a little off center, though, the square collapses. Besides teaching the students a little about stability, this discussion serves to remind students that there are many considerations to every design.

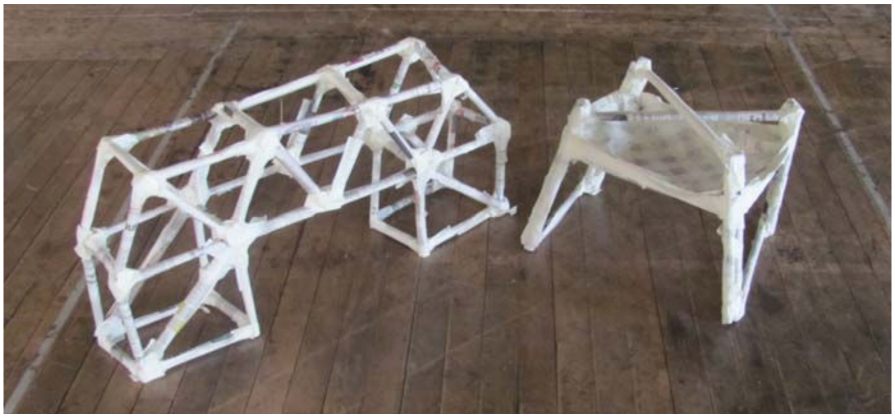

Figure 3: Bridge Construction for Journalism Majors

Dissection and Analysis of a Four-Wheeler

Rotational motion, and the related concepts, is a hard concept for students to grasp. The objectives of this project are for students to see some aspects of rotational motion, and to brainstorm, design, and implement an improvement to a product. This project uses friction cars (available in bulk from wholesalers such as dollardays.com for less than $2 a car) to accomplish the objectives. Each team is given one friction car and then several tasks to complete. A friction car, along with the drive mechanism, is shown in Figure 4.

The teams start by running the car for three tries to determine how far it will go. Each student then guesses at how the car works, and discusses this with their team. The teams then carefully disassemble the car to see how it works. The mechanism includes gearing and a flywheel. The teams are required to do a little analysis on the car, determining the distance traveled for each revolution of the flywheel. The main part of the project is for students to brainstorm on ways to improve the cars performance, and then implement some sort of improvement. An assortment of supplies is provided, such as washers (for increasing the mass of the flywheel), super glue, rubber bands, sandpaper (some students want to increase the traction), paper clips, and weights. Simple hand tools, such as needle nose pliers, slip-joint pliers, scissors, and screwdrivers are also provided. After completion of the improvements the teams retest their cars to determine the effect of their modifications.

This project has at times been followed with a discussion during the next recitation about some of the rotational aspects. The students can see the effects of gearing, and how linear velocity can be related to angular velocity beyond the simple equation of $v = \omega r$ when gearing is used. The energy storage and use of a flywheel is also discussed. For the friction cars that have been used, the rotational kinetic energy is approximately 1.5 times the translational kinetic energy. Since the energy is proportional to the velocity squared, the students see that the gearing is useful for increasing the energy storage in the flywheel. Through the use of this project, students have a better grasp of rotational motion and energy.

Figure 4: Dissection and Analysis of a Four-Wheeler

Implementation, Gathering Feedback, and Grading Projects

Team Selection

Teams are assigned in several ways. For the initial project, teams are based simply where the students are sitting (the room is set up so students sit with four students at a table). The first team project is within the first two weeks of the semester, so students are just getting to know each other. Being creatures of habit, students tend to sit at the same table, so this gives them a chance to work together as team with the students they have been sitting with for problem solving activities. For some projects teams are assigned based on a random selection. The purpose of this is two-fold. We want students to have the chance to work with a diverse group of people, both in terms of intellectual ability and personality type. Ideally a student would have at least one good team experience, and one bad team experience, helping them to learn what makes an effective team. We also want students to meet and get to know other engineering students. Anecdotally this has led to students forming good friendships and study groups that last through their college career. A final method of team assignment is self-selection. Care is taken to force this selection to be done outside of the normal class time to minimize the peer-pressure involved in having students form their own teams. Assistance is provided for those who aren't able to identify a team. An implicit result of this method of assignment is that students discover that their immediate friends don't always make the best team members.

Online Feedback Forms

To facilitate grading in a large class, much of the feedback from the projects is obtained by the use of online forms. Each student is required to fill out an online form as part of their grade.

The online forms are used both for students to record their data, as well as to reflect on their performance as a team.

The first team project that the students accomplish is usually an estimation project (e.g. Paint the Jumbotron Orange). The feedback form for this project focuses on the performance as a team. The questions asked are:

- List all the members of your team.
- Did your team choose a leader?
- Did your team make a plan before starting the project?
- Did your team divide up the tasks?
- In 2-3 sentences, describe how your team could have functioned better.

We have found that having students reflect on their team performance, and discovering for themselves how the team could have functioned better, is much more effective than lecturing on teamwork.

Typical feedback is that almost 90% of the teams did not chose a leader, but about 85% of the teams did make a plan and about 90% divided up the tasks. The comments suggest that the plans and division of tasks could have been improved, and that many teams saw communication among teammates as an area for improvement. Recognizing the importance of communication is a key aspect of this first team project.

Other team project feedback forms focus both on the technical aspects as well as the effectiveness of the team. For example, the feedback form for the Ultimate Projectile Contest project asks for the following:

- List the members of your team.
- What was the launch speed of your shooter on the low setting? (ft/sec)
- How far should your launcher shoot (theoretically) on the low setting with an angle of 30°? (ft)
- How far did your launcher shoot on the low setting with an angle of 30°? (ft) [average, minimum, maximum]
- Enter the number of team' shots made and attempted in the contest.
- Make one suggestion for how you could improve your shooter.
- Make one suggestion on how you could have worked better as a team.

As can be seen, the questions on the feedback form are designed to gather both technical information, and to have students think about design issues and teamwork issues. There are several common mistakes on this feedback form. One is giving an unreasonable answer, usually due to wrong units. Another is entering the shots made and attempts wrong (e.g. 10 shots made out of 2 attempts, instead of 2 shots made out of 10 attempts). Both give the opportunity to teach students the importance of care in their work, checking their work, and thinking about reasonableness and units.

The Ultimate Projectile Contest is typically the second team project, so students are still learning teamwork skills. Approximately one-third of the teams responded that the team functioned very well, giving feedback such as "I thought our team worked very well together, and not one person was left out or wasn't doing something" and "the team did really well over all, good communication and everything." Other teams functioned fine, but did identify areas of improvement, with feedback such as "we could have better distributed the workload" and "I would want more communication; we didn't fight or throw down, but it would have been more beneficial to discuss who would do what, and delegate tasks for each team member." Communication and efficiency in work were the two primary areas the students identified that they could work better on. About 5% of the teams were dysfunctional, with a typical comment being "one team member did not participate in any part of the activity other than the competition; he sat and sent text messages on his phone while the rest of us tried to figure out how to use the formulas to answer the questions given to us; he actually made me somewhat angry by doing that."

Uploading and Grading Reports

A few of the projects require short reports, with a longer end-of-semester project requiring a longer report. To facilitate grading of the reports, a system has been developed whereby students can upload the reports to the class web site as PDF files. Instructors and graduate teaching assistants have access to these files along with an online grading rubric form in side-by-side frames on the same web page, as illustrated in Figure 5. The left frame is for selecting the team to grade. The middle frame has the grading rubric. The right frame is the report. As the grader reads through the report, various items are checked and comments can be entered. The web page totals the score. Another web page is generated for the students to see the score they made for each part of the grading rubric, as well as comments on their report. This system has proven very useful for efficient, consistent grading of reports as well as for providing all team members convenient access to the grading results and feedback.

Conclusions

This paper has describes several short team projects that have been used in a first-year engineering course. The projects have been designed to both teach basic physics principles, to introduce students to engineering design, and to build team skills. A complete description of each of the projects is at http://ef.engr.utk.edu/ef/publications/short-team-design-projects/index.php.

References

-, (2009), Roller Coaster Design Project, Ohio State University, http://engineering.osu.edu/fe/Documents/RollerCoasterProjDescDoc_rev07_25_06.pdf, viewed on 12/1/2009.

Goff, R.M., and Connor, J.B. (2001). Hands-On Experiences in the First Year Engineering Classroom. Proceedings of ASEE Annual Meeting and Exposition, Albuquerque, NM, Session 2793.

Sheppard, S.D., Macatangay, K., Colby, A., and Sullivan, W.M. (2009). Educating Engineers: Designing for the Future of the Field. Jossey-Bass, SanFrancisco, CA.

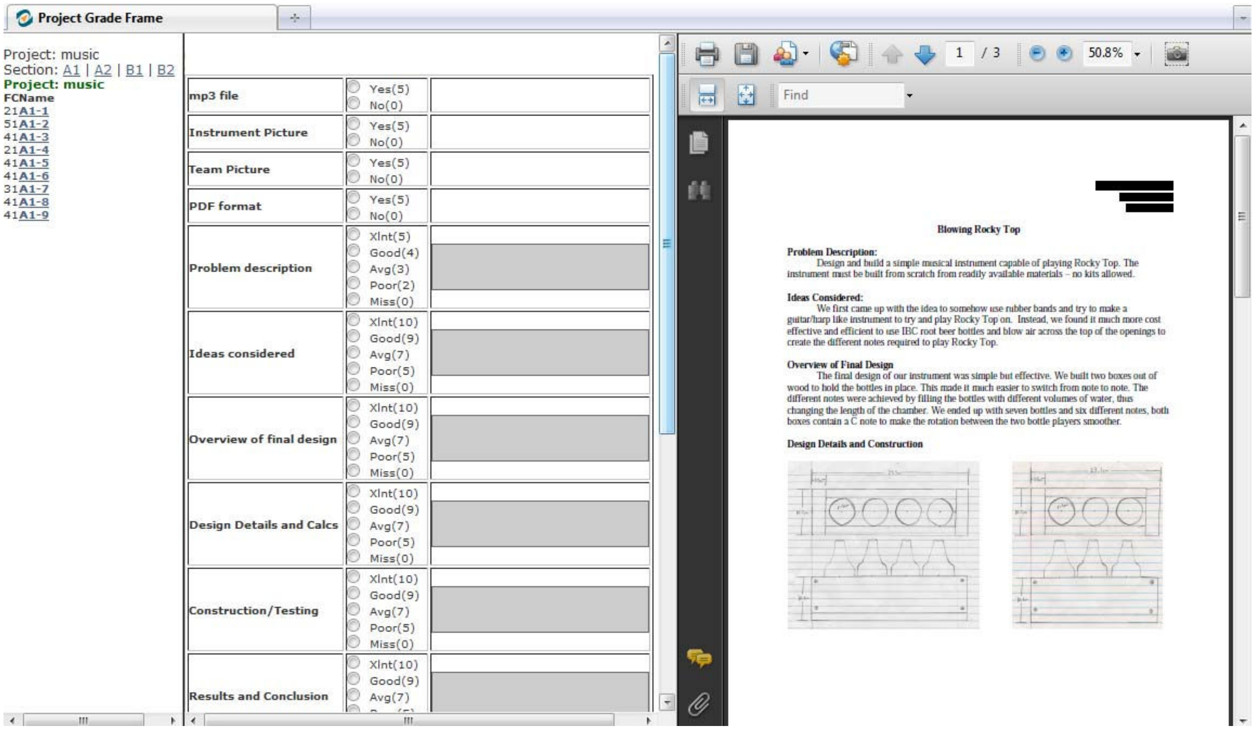

Figure 5: Online Report Grading and Feedback