Projects that integrate engineering, physics, calculus, and English in the Arizona State University Foundation Coalition freshman program

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Abstract *- The Foundation Coalition at Arizona State University has been offering a novel first year program in engineering for the last three years.[1-5] This program integrates coursework in English composition and rhetoric, calculus, freshman physics, and introductory engineering concepts through student projects. The projects increase in complexity as the term progresses, to keep pace with students' increasing knowledge of science and engineering. The purpose of this paper is to describe the projects, the process used to deliver them, and their impact on the learning in this class.*

The Projects

There are three engineering projects in the first semester of the freshman program, each lasting approximately four to five weeks. The students are given a relatively brief description of each project, a kit containing the parts they may use during the construction phase, details concerning the relevant physics and calculus, and instructions concerning the learning outcomes and assessment strategies for the project. Although each project has several hard design constraints, the actual devices the student teams construct are generally quite creative. The students actually value the open-ended nature of the projects, because they can apply as much originality and creativity as they desire. The course is taught from a webpage, so the instructions, sample Excel spreadsheets, details about their documentation of the project, and so on, are found on this page.

The first project consists of the design and construction of a catapult. It coincides with instruction in kinematics in the physics course and functions in the calculus course, so the construction of a device that hurls an object is a sensible way to have students explore these topics. The catapult design must be robust and capable of launching a squash ball and repeatedly hitting a target placed 3 to 7 meters away. This project has been used in previous semesters, and for small class sizes (32) the students were allowed to construct the catapult from dimensional lumber using the wood shop in the Engineering Lab Services. With a much larger class size (80), an alternative approach is used: each student team is provided with an Erecter Set - a supply of metal straps, struts, nuts, bolts, washers, all contained in a plastic box. These sets are available through retail toy stores, typically costing about $100 per kit. Clearly, one engineering constraint in this project is that only a limited number of parts can be used in the construction. The students are taught in a mediated classroom and have access to the internet through the workstations at their tables. During the design phase of the project, many students find a remarkable amount of design information about catapults (and other medieval war engines) through searches on the World Wide Web. They are encouraged to use this information in their projects, so long as they cite the sources, of course. The students struggle with the notions of bracing and reinforcement and what type of energy source to use during the early stages of the project. At the end of the initial design and construction phase, the students try out their catapults and videotape the motion of the squash ball in flight, so that they can generate a "performance map" of the catapult. They are shown beforehand an idealized performance map. An example as depicted in Figure (1).

The videotape is used to document the performance of the catapult when used to produce minimum and maximum trajectories. The students digitize the videotape, capture the data, and plot the trajectories with Excel. They also use the curve fitting feature of Excel to see whether the trajectories are parabolic as predicted by kinematics. They refine their designs, and on the final day of the project, each team sets up its catapult to hit a target whose coordinates are given to them just before the time of their launch. They use interpolation schemes to take the data from the performance map to pick the catapult launch parameters. The teams that put effort into constructing catapults with repeatable motion are the most successful. Their catapults usually hit the target repeatedly. All of the teams document the design, construction, and operation of the catapult in a report format designed by the English instructors. The students are told that their reports will be added to the class webpage and that additional credit will be given to the teams that generate their own webpages. Some of the most intense competition among the teams is in constructing webpages with a professional format - and demonstrating these efforts to their classmates.

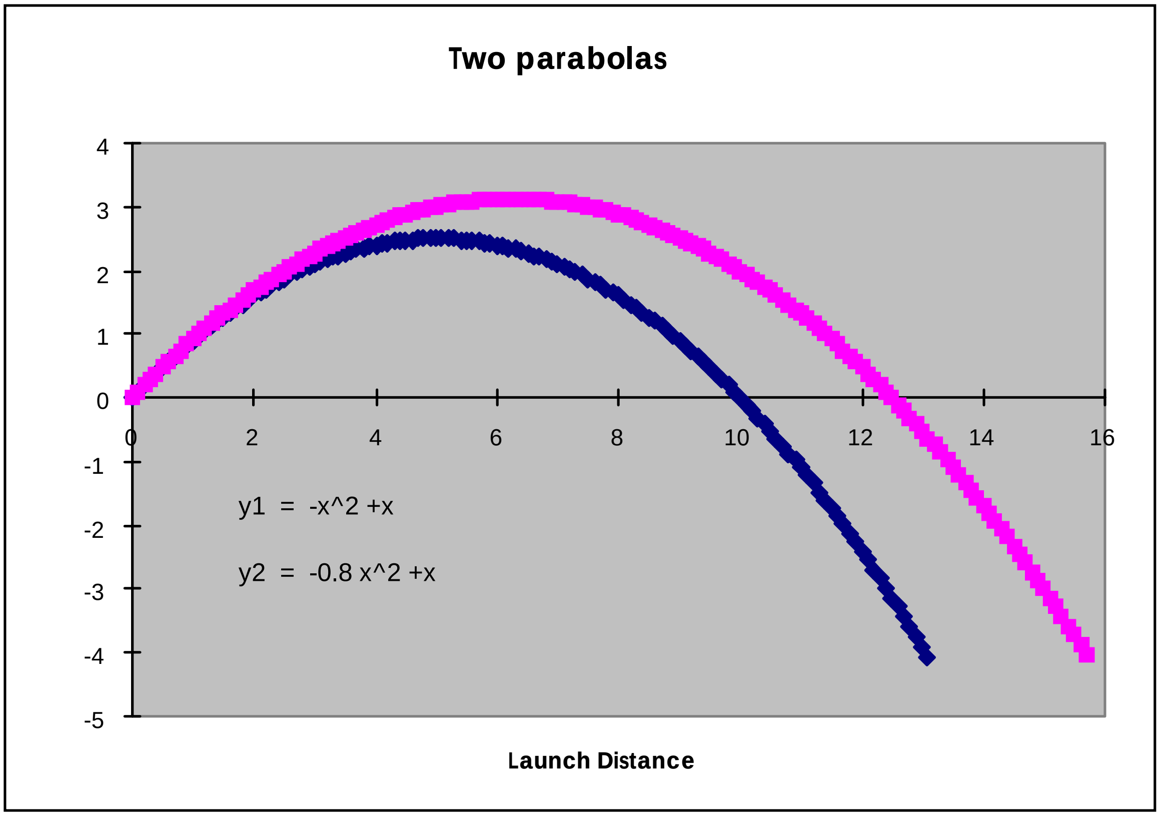

Figure (1) Idealized catapult perfomance map.

When the second project commences, the students have learned Newton's Laws, free body diagrams, and Euler's method of integration, so they apply this knowledge to the design and construction of a bungee-drop apparatus. The "passenger" at the end of the bungee cord is a raw egg, and the drop takes place at the top of the track stadium. The students are able to take a more analytical approach to this project because of their increased understanding of analytical physics and calculus. Modeling is carried out by defining the free body diagram for the motion of the egg, finding the net acceleration on the egg, and then using Euler's method of integration to solve the equations of motion for the egg on a spreadsheet. A typical result from the Excel modeling is shown in Figure (2).

The students measure the elastic properties of the bungee cord material, determine the departures from Hooke's Law behavior, and get an empirical expression for the cord elongation as a function of applied force. In the free body diagram, they consider the forces due to air drag, gravity, the cord's tension, and damping within the cord itself. In the modeling phase, the students devise a drop that would provide maximum free fall without decelerating more than three times "g." The students are shown the boom from which the egg will be dropped and have to design an attachment/release mechanism for their egg. On the day of the drop (no practice runs here), the students specify the length and number of bungee cords, set up the release mechanism, and carry out the launch. Once again the launch is recorded on videotape. The students digitize the tape and compare the performance of the apparatus (maximum deceleration, closeness of approach) with that predicted by the model. The students also document the design process, the modeling, and the performance in a webpage based report.

The third project uses the students' knowledge of rotational motion. The students are again provided with the Erecter sets and told to build a trebuchet. The trebuchet is another siege engine used in medieval days, and it largely replaced the catapult because it could throw heavier objects further than the catapult. It is powered by a falling weight, and compound rotational motion is employed through a rotating arm and sling to hurl objects. The students are learning about torque, angular momentum, and other concepts of rotational kinematics in physics, but the modeling of the trebuchet is an extremely complicated matter - too advanced perhaps for freshman students. The students are given access to two trebuchet models and allowed to examine the models for visualization and design hints. One of the models is an analysis of the trebuchet using Mathematica to solve Lagrange's non-linear coupled equations for the trebuchet. This model, available on the WWW[6], is a magnificent analysis of the trebuchet. It draws a stylized figure of the trebuchet and its complete range of motion. This is shown in Figure (4), in which the larger circle is the falling counterweight, and the smaller circle is the projectile:

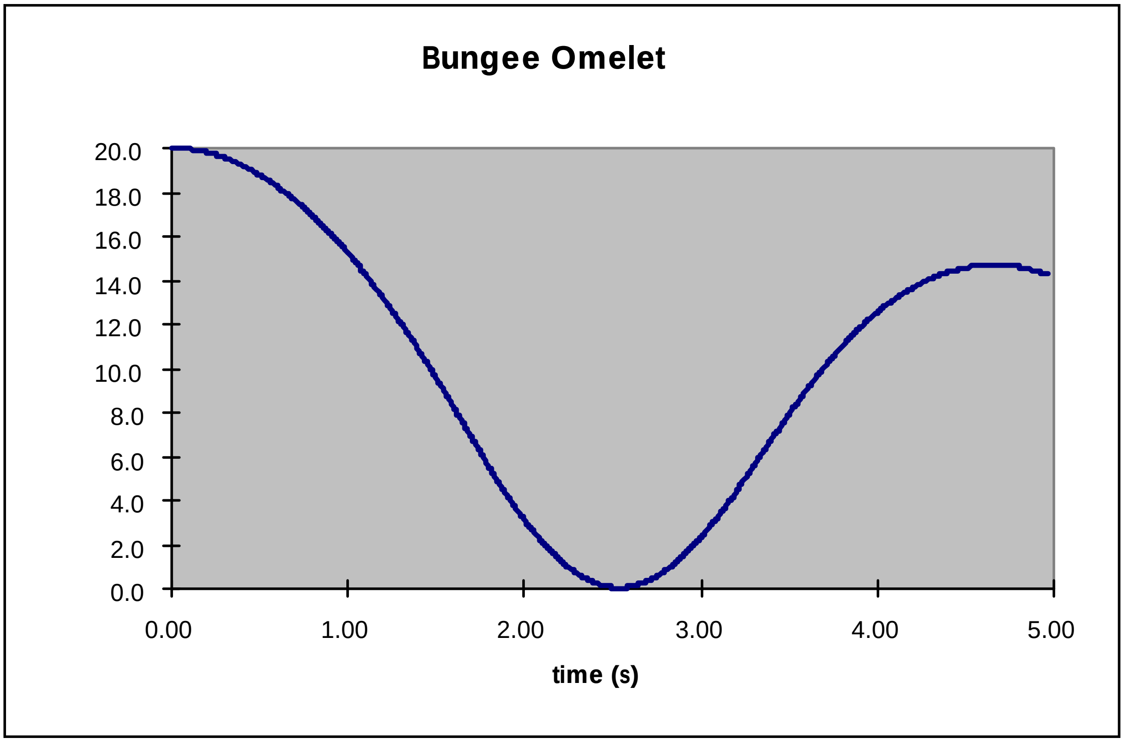

Figure (2) Idealized motion of egg in bungee-drop model

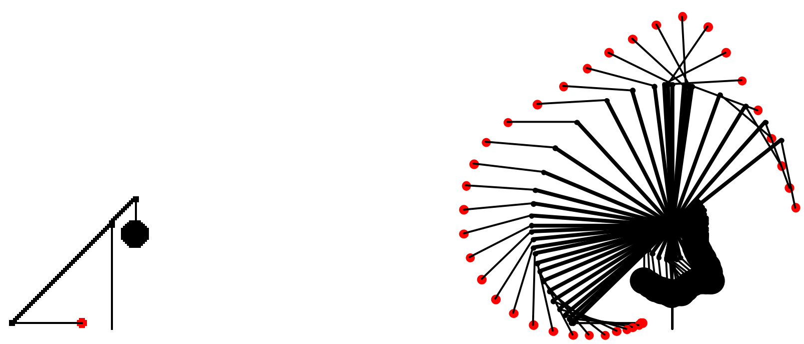

Figure (3) A depiction of a stylized trebuchet and its range of motion

This model predicts the maximum range of the projectile by calculating the range for each possible release point in the full range of motion of the trebuchet. The release point that produces the maximum launch distance is not necessarily the point in the trebuchet's motion where the tangential velocity vector is inclined 45 degrees above the horizontal, because the speed is continuously changing. This model is useful for visualizing the trebuchet operation (and to demonstrate the power of computer aided algebra software), but it does not reveal how to find the optimum release point easily. Most of the students prefer using the second model, based on conservation of energy and momentum principles, which is carried out on a spreadsheet. This model (a description of which will be published elsewhere[7]) allows the students to input projectile and counterweight masses and the sling and rotating arm lengths. It calculates and plots a projectile motion assuming that the projectile is released at the top of the rotating arm's arc, as shown in Figure (4):

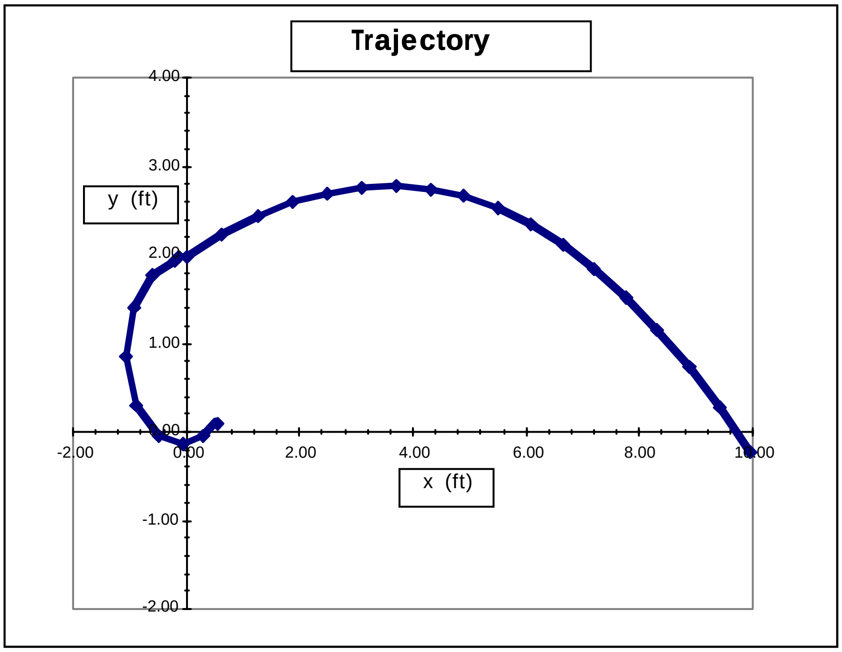

Figure (4) Trebuchet projectile trajectory as predicted with Excel model. When x is negative, the projectile is still connected to the trebuchet

The students are told that if they want to use this Excel model to predict the performance of their trebuchet, it is necessary to construct the trebuchet so that it will release the sphere when the arm is at the top of its arc. Many of the student teams are able to build an adjustable release point into their trebuchets and can employ the Excel model. Still other teams simply used elementary energy conservation methods to estimate the kinetic energy imparted to the projectile. Once again, the design and construction is constrained by the limited part set and time line. The operation of the trebuchet constitutes a major portion of the final examination in the integrated class. The students have to demonstrate the operation of the trebuchet launching a golf ball, and a measure of goodness is reproducibility and precision in repeated launches. The students are also required to document the design process and performance characteristics of the trebuchet in a written report on the day of the final. In addition, the students are asked to do both self-assessment and a critical appraisal of another team's trebuchet. So that the process is rigorous, the teams carry out these assessment steps with a Kepner-Tregoe decision analysis.

Conclusions

Both the faculty and the students feel that the projects are one of the most valuable parts of the integrated first year program. This is demonstrated very clearly by the written comments the students attach to the university course evaluation forms. Naturally, the students think the projects are fun, but nearly all also mention that (1)the projects reveal the connections among the four subject areas vividly, (2) the reporting process is challenging and interesting, and (3) they all discovered some of the wonder and excitement that comes naturally from doing creative work. The webpage for the class, which contains the student project report webpages, is found at this URL:

http://www.eas.asu.edu/~roedel/ece100a

This webpage also contains information on the materials, supplementary instruction, and logistics necessary to carry out the projects.

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References

1. D.Evans, M.Kawski, B.Doak, M.Politano, S.Duerden, M.Green, J.Kelly, and R.J.Roedel,"An integrated, project-based, introductory course in calculus, physics, English, and engineering," Frontiers In Education (FIE) conference, November 5, 1995, Atlanta, GA
2. R.J.Roedel, M.Kawski, B.Doak, S.Duerden, D.Evans, M.Green, J.Kelly, D.Linder, J.McCarter, and M.Politano, "A project-driven, integrated course in calculus, physics, English, and engineering," International Conference on Technology in Collegiate Mathematics, November 16, 1995, Houston, TX
3. D.Evans, R.B.Doak, S.Duerden, M.Green, J.McCarter, R.J.Roedel, and P.Williams,"Team-Based Projects for Assessment in First-Year Physics Courses Supporting Engineering," Frontiers In Education (FIE) conference, November 5, 1996, Salt Lake City, UT
4. R.J.Roedel, D.Evans, M.Kawski, B.Doak, M.Politano, S.Duerden, M.Green, J.Kelly, and,"An integrated, project-based, introductory course in calculus, physics, English, and engineering," Frontiers In Education (FIE) conference, November 5, 1996, Salt Lake City, UT
5. R.J.Roedel, J.McCarter, and B.Doak, "Integrated projects with MAPLE and Excel," International Conference on Technology in Collegiate Mathematics, November 8, 1996, Reno, NV
6. http://www.eclipse.net/~dimona/libtreb.html
7. L.Rhodes and R.J.Roedel, to be published