Team-Based Projects for Assessment in First-Year Physics Courses Supporting Engineering[1]

D. Evans[1], R. B. Doak[2], S. Duerden[3], M. Green[3], J. McCarter[4], R. Roedel[5], and P. Williams[6]
Arizona State University, Tempe, AZ 85287
[1] Dept. of Mechanical and Aerospace Engineering & The Center for Innovation in Engineering Education;
[2] Dept. of Physics and Astronomy; [3] Dept. of English; [4] Dept. of Mathematics;
[5] Dept. of Electrical Engineering; [6] Dept. of Chemistry

Abstract

Two team-oriented, project-based exercises developed and used for student assessment in an integrated freshman program are described. These projects allow assessment of student progress toward meeting desirable student outcomes such as ability to work in teams, ability to communicate, and able to apply science and engineering to the solution of problems. One project involves measurement of the velocity of a projectile; the other one involves the measurement of the ambient magnetic field strength. Lists of parts supplied to each student team are include as are photos and sketches of the more complex pieces of equipment. Student comments and faculty roles are also discussed.

Introduction

Most teaching in engineering and related courses is still done in 50-minute lectures, supplemented by drill and practice in out-of-class homework assignments. Learning is assessed by 50-minute written examinations that test the material just covered in the class. However, nearly all of the studies on engineering education published in recent years advocate changing this common delivery, practice, and assessment process.

Project-based learning, although it is not a commonly used pedagogy, is certainly a well-known one. We have found it to be a most enjoyable and beneficial learning experience for both the student and the instructor. Yet it has not gained widespread use for a variety of reasons. The dearth of good projects at a level of sophistication matching the students' capabilities is one drawback. The difficulty of coordinating week-to-week projects with day-to-day lesson plans is another. The problem of finding appropriate assessment and evaluation strategies is a third. All of these are procedural obstacles rather than deficiencies in the pedagogy itself. Our experience indicates that project-based learning is indeed a viable and very useful means of instruction, but that its use is decidedly hindered by a lack of classroom-proven projects, learning plans, and assessment tools. Currently these must be largely developed from scratch. A database to draw upon in choosing projects and assessment methods would greatly facilitate the use of project-based learning.

The intent of this paper is contribute to that database, in particular within the realm of assessment. We offer and critique two concrete examples of end-of-semester final exam projects designed to help assess students' grasp of freshman physics, mathematics, and English. These exam projects attempt to probe the depth of students' conceptual understanding; to test their ability to solve a problem specified by desired outcome rather than by specific input; to explore their ability to work efficiently as teams, and to assess their ability to communicate effectively. The objective is thus to evaluate not just the students' knowledge of the course subject matter but also the outcomes of the semester's project-based learning. The first exam project discussed in this paper is based on mechanics concepts introduced in the first semester of introductory physics. The second derives from the study of electricity and magnetism covered in the second freshman physics semester. They were the given at the ends of those two semesters, respectively. Both projects involve design initiative, critical thinking, creative experimentation, computer data acquisition, and formal written articulation of the results. The exam projects have been classroom tested as part of actual final examinations and have been critiqued by the participating faculty members.

These projects were developed for and used within ASU's Foundation Coalition Freshman Integrated Program in Engineering (FIPE), wherein a cohort of students takes all of their Freshman classes together. Instructors in the program work to integrate and interconnect course material from the different subjects. This integration has taken the form of identifying common themes within the various disciplines then

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arranging the order and methods of presentation within the individual courses to reinforce these links. The intent is to present material from the different disciplines in a mutually reinforcing fashion, emphasizing the interconnected nature of the constituent subjects in order to better motivate the learning and to improve both retention and understanding.

In addition to the final exam project, the end-of-semester assessment in the FIPE program includes a written 50-minute comprehensive examination in each of the technical subjects. The 50-minute exams are usually given early in the morning, followed by a rest break, after which the final exam project commences. All of the FIPE assessment is therefore completed in a single day, a feature the students seem to greatly appreciate. The exam project itself is five hours in length, including a half-hour lunch break. The students work as independent teams of four, sequestered in separate rooms with inter-team communication prohibited. During the initial hour, each team must brainstorm possible solution paths, pick one or more paths to pursue, and submit a written plan of attack to the instructors. The student teams then execute their plan, evaluate the results, and prepare a formal written report before the end of the five hour period. If the initial plan proves infeasible, a revised plan of attack must be submitted. All of the course instructors are present as observers during the exam project, circulating from room to room to assess student and team performance.

Ballistic Pendulum

In the mechanics final exam project, the student teams were asked to design and use an experimental setup to accurately measure the muzzle velocity of a dart fired from a pneumatic rifle (borrowed from the physics department's "shoot the monkey" demonstration—see Figs. 1 & 2). The gun was demonstrated to the class as a group, after which the students dispersed to work as isolated teams in separate rooms. There were, of course, many workable solutions, but the most viable approach was to construct and operate a ballistic pendulum. A effective "high-tech" improvement to the classic ballistic pendulum was to use the motion detector along with the universal lab interface (ULI) and computer to measure the velocity of the block with the imbedded dart immediately after impact (rather than measuring the subsequent vertical rise of the block). Each team was supplied with the equipment listed in Table I. Items shown in boldface were those needed to actually construct and use the ballistic pendulum. Many unnecessary item were supplied, insuring that trial-and-error use of the available equipment was not a viable approach. To assure safety, the physics instructor kept physical control of the rifle and dart and was the only one allowed to actually fire the rifle as each group collected data. The pneumatic rifle and its tank of compressed gas were placed on a cart , allowing it to be rolled from room to room.

Table I. Items Supplied for Ballistic Pendulum

- **MAC computer**

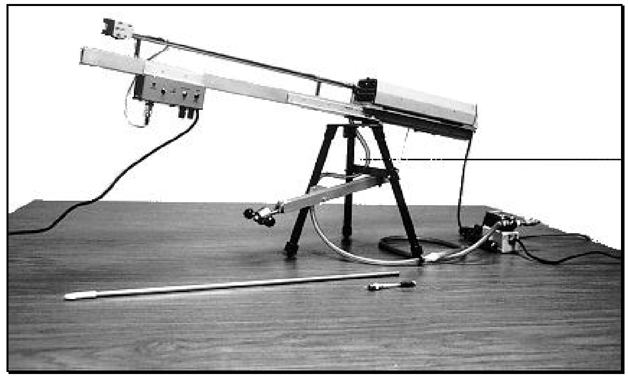

Figure 1 The Dart Gun

- **Word, Excel, and ULI software**
- **ULI**, student force sensor, and **motion detector**
- 1 mass hanger w/ 12 50-g and 2 500-g masses
- **1 bubble level**
- 1 each meter stick and 2-meter stick
- 4 **wooden blocks**, assorted sizes
- 2 **table clamps**
- 3 right-angle clamps
- 1 three-finger clamp
- 2 **long support rods (912 Lx18mm D)**
- 2 **short support rods (460 Lx12mm dia)**
- 1 ring stand with screw in steel rod (400mm long)
- 2 precision springs
- 1 tennis ball
- 1 cardboard cylinder (86 ODx128mm L)
- **1 string (about 5m)**
- 1 stop-watch
- 1 balance
- **scissors**, masking tape ruler, protractor
- paper clips, thumb tacks, **threaded metal hooks**

Students had used the ULI and sensors extensively during the semester and were completely familiar with the computer software and hardware. The teams were allowed to consult equation sheets but not the textbook, primarily to avoid cueing them to the solution through illustrations in the text of a ballistic pendulum in use. Problems involving ballistic pendulums had been

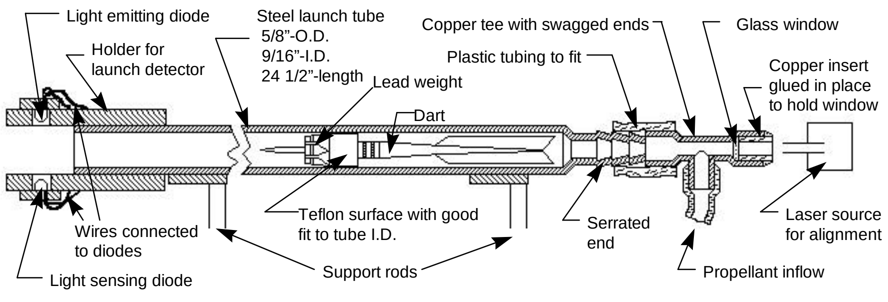

Figure 2 Cut-away of the Dart Gun

among the assigned homework, but fears/hopes that students would remember the details proved completely unfounded.

To force the students to *design* a solution rather than seek one by trial-and-error, each team was allotted only two shots of the gun for the purpose of data-taking. The underlying physical concept is conservation of momentum during the inelastic impact of the dart as it hits and sticks into the pendulum block. A key element of the design process was to estimate the muzzle velocity of the dart from the demonstration at the onset of the exam. The pneumatic rifle had a laser targeting system, allowing the students to see explicitly how far the dart dropped in traversing a known horizontal distance. Direct reference was made to this during the demonstration but not, of course, stating that it allowed the muzzle velocity to be estimated. With this estimate and knowing the mass of the dart, students could apply conservation of momentum to compute the mass of the target block needed in order to achieve a useful final velocity of the pendulum block after the darts impact. Measuring this final velocity and applying conservation of momentum allowed muzzle velocity of the dart to be calculated.

Magnetic Field Measurement

The E&M final exam project asked the student teams to measure the local strength of the earth's magnetic field. The best solution, as stated quite correctly and succinctly by one student was "to use the rotating motor-driven coil as an AC generator in the earth's magnetic field." The induced EMF could be displayed on the oscilloscope, the RMS voltage measured, and the B-field calculated using Faraday's Law. The student teams were supplied with the equipment given in Table II. Again, the items in boldface were those actually needed to carry out the generator measurement. Apart from the low-pass filters, which were supplied with operating instructions, students had used all of this equipment in labs and projects during the semester. In Phoenix, the magnitude of Earth's magnetic field is about 50 T, inclined downward about 60° with respect to horizontal. This is easily measurable but requires the use of a low-pass filter to keep 60 Hz AC line pickup from swamping the signal. Stray DC magnetic fields due to structural steel in the building can also overwhelm the earth's B-field. The student teams were made aware of these potential difficulties and prompted to find ways of checking their results.

Table II. Items Supplied for B-Field Measurement

- **MAC computer with Word, Excel**
- **wire coil, 200 turns, rotatable and motor driven** (see Fig. 3, below)
- wire coil, non-rotating, 20 turns on 30x30 cm square
- expt. setup for resonant standing waves on a string
- power supply (Pasco PI-9596, 15 VDC, 1 A)
- **oscilloscope**
- **low-pass filter (to eliminate 60 Hz pick-up)**
- multimeter
- function generator (BK Precision, 3011B)
- stroboscope
- meterstick
- **assorted test leads**
- various resistors (1 to 1 MΩ)
- assorted capacitors (0 to 1.10 f)
- 2 inductors (18.3 mH and 85 mH)
- 3 wire coils (200, 400, and 800 turns)
- tape, nails, paperclips, tacks, rulers)

Student Responses

These final exam projects appear at first glance to be absurdly simple. In fact, they turned out to be anything but simple for the students. Only a single team out of eight was able to complete the ballistic pendulum project in stellar fashion. Three or four additional teams struggled through to reasonable but not outstanding solutions. The remainder turned in fairly dismal attempts. Performance on the magnet field measurement was somewhat but not markedly better. Unfamiliarity with the test format was probably not a major factor since, in the course of the semester, several labs were presented in this format in order to prepare the students for the final exam. The poor performance is also is not a reflection on either the students or their background, since the classes performed at or above average in other

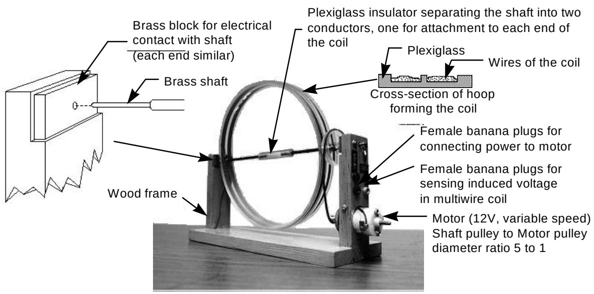

Figure 3 The Rotatable Coil

standard assessments, including the Force Concept Inventory test[2], both before and after the semester.

It seems to be the outcome-based project nature of the exam which causes difficulty for the students. Freshman university students have spent twelve years honing their study skills for success on standard 50-minute written examinations. Those skills are largely a disjoint set to the skills required for success on the final project exam. Yet for achievement in the post-university engineering environment, the problem solving skills tested on the project exam are almost certainly more important than the standard test-taking skills. Given the difficulty the students have with the exam, it seems to be successfully fulfilling its purpose of testing the desired outcomes of project-based learning. On the other hand, it is also clear that the instructors have additional work to do on *teaching* of project-based learning.

Students were asked to comment to the instructors via email after one of the examinations; here are a few of their remarks: “Concerning the final exam: I enjoyed the exam to a certain degree. I liked it how it involved stuff that we had done previously in physics labs. We almost had the right idea to solve the problem. ... As we were working time wasn't really an issue. The next thing we knew, we were writing up our report. The final was a way to make use of skills that we have learned throughout our freshmen year. So, I think that this final was a worthwhile project that made us really think” “I really enjoyed the project-based exams for both this spring and the past fall semester even though I did not get the correct answers. ....yes, I believe all of the five hours except maybe the last thirty to forty-five minutes went quickly. I also totally agree that this is a wonderful approach towards using all that we know and applying our knowledge towards a real-world problem.” “I really liked the team final project we had. I felt it did a good job of incorporating everything we learned through the year, especially in the area of team work. Five hours sounds like a lot of time, but with a project like this, it is important that the team works together to complete the task on time.” “Tell you the truth, I'm not sure I really liked the physics project or not. For the first two hours or so, I definitely did not like it. But, when we finally came up with a solution, I felt pretty good. .... I would also say that I definitely learned something. I really do understand the relationship between magnetic fields and currents better now. What could be better than a test that actually forces you to learn more about equations that you already know but don't fully understand? .... Maybe I'm just saying that because my team arrived at the most accurate solution, but I do really think I liked the test.”

Faculty Roles

The faculty who taught in the FIPE participated in the assessment of the results. Each member rotated from team to room during the examination period and each monitored a different aspect of team processing. After the examination, the faculty met to discuss and to evaluate the team process and outcomes of the exercise. In the evaluation the team behaviors and the contribution of each student to their team’s effort were evaluated. The composition instructors evaluated the written report for its “literary” merit and the physics or engineering instructor evaluated the report for its technical merit. The team and individual evaluations were made a part of the final grades in both the engineering and physics laboratory parts of the FIPE program.

Summary

This type of examination is an effective way of assessing many of the desired student attributes that are not observable in the conventional, individual, written, timed examinations consisting of more traditional, “textbook-type” problems. They can also be quite revealing about the effectiveness of educational experiences during the semester, and serve as feedback for continuous improvement of instruction. Facilities and resources are required, but with grading time, the examination is not more time consuming than the traditional examinations.

[2] D. Hestenes, M. Wells, and G.Swackhamer, “Force Concept Inventory,”*The Physics Teacher.* Vol. 30, pp. 141-158 (1992).