Integrating Science and Math into the Freshman Engineering Design Course

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Abstract

The application of math and science is an essential part of the engineering design process. At the University of Hartford, a freshman integrated learning block was established where engineering faculty teaching the freshman Principles of Design course worked closely with the faculty teaching Calculus and Physics in developing shared outcomes for all three courses. Previously, these courses were taught independent of each other and most students did not recognize the connection between math and science and the design process. Even though group projects in the Principles of Design course promoted creativity and the use of systematic methods for solving problems, there remained a lack of understanding among the students of the linkages of calculus and introductory physics to engineering design. Working as a team, the engineering, physics, and math faculty incorporated the physics and calculus the students were learning that semester into the design projects. These projects were assigned in the freshman design course, but were also discussed in the physics and calculus courses. An internal evaluation of the integrated learning block found that the shared projects were well received and the students gained better understanding of the interrelationship between engineering, physics, and calculus.

I. Introduction

The engineering curriculum at the University of Hartford has been redesigned with the creation of unique course combinations where the faculty from various colleges and departments work together. Engineering and non-engineering courses are combined into groups called integrated learning blocks (ILBs). Two ILBs were incorporated into the common freshman year. The first semester "Principles of Engineering" course that introduces students to the different fields of engineering was integrated with a freshman writing course (Rhetoric, Language and Culture). The second semester "Principles of Design" course was integrated with Physics I and Calculus II. A new engineering design course was created for the sophomore year that was team-taught with an Ethics in the Profession course. Faculty teaching these courses worked together to develop shared activities that reinforced the outcomes common to all of the courses in the ILB.

Design projects were usually selected as the most appropriate activity to meet the shared outcomes. This paper describes the effort to integrate Physics I and Calculus II into the freshman engineering design course. Approximately sixty freshman-engineering students were involved in the integrated learning block in spring 2001. Students could select from three sections of Principles of Design (ES 142), two sections of Physics I (PHY 112), and two sections of Calculus II (M 144). Non-engineering students were also allowed to take the physics and calculus sections that were part of the ILB. To accommodate part-time students and full-time students who were not taking both Calculus II and Physics I, a section of Principles of Design was offered that was not part of the integrated learning block. This section also emphasized the importance of math and science in the design process, but did not rely on specific mathematical and physical concepts that were being taught in Physics I and Calculus II.

II. Integration of Principle of Design, Physics I, and Calculus II

There were five faculty members involved in developing the shared activities and outcomes of the ILB. Three of the faculty members were from the College of Engineering (one each from civil, biomedical, and electrical engineering) and one faculty member each from the Mathematics and Physics Department. Joint teaching of the courses began with the faculty meeting at series of summer 1999 workshops funded by NSF (Grant No. 9872433 - Integrating Engineering Design with the Humanities, Social Sciences, Sciences, and Mathematics). Initial meetings between faculty from the different colleges were used to become familiar with material covered and the textbooks used in the three courses. The major topics covered in each of the courses are presented in Table 1.

Table 1. Topics Covered in Principles of Design, Physics I, and Calculus II

Principles of Engineering (3 Credits)	**Physics I (4 Credits)**	**Calculus II (4 Credits)**
(1) Solving Problem Methodology (2) Software Applications (Excel, PowerPoint, and MatLab) (3) Team Dynamics (4) Ethics (5) Oral Presentations and Report Writing	(1) Vectors (2) Velocity, Acceleration, and Projectile Motion (3) Newton's Laws (4) Energy, Work, and Power (5) Conservation Laws of Energy and Momentum (6) Collisions (7) Rotational Motion and Torque (8) Gravitation	(1) Integration (2) Logarithms and Exponents (3) Differential Equations (4) Trigonometry Functions (5) Improper Integrals (6) Infinite Series (7) Taylor Polynomials (8) Taylor Series (9) Polar Coordinates

After reviewing the course material and syllabi, the team of faculty members developed a list of desired outcomes shared by all three courses. At the end of each of the courses, students would demonstrate the ability to:

(1) Understand the interaction of math, physics, and engineering to solve multidisciplinary problems.
(2) Present a coherent and concise written and oral presentation of problem solutions and be able to defend the procedures and solutions.
(3) Utilize technology for problem solving and understand basic principles behind problem solving with current technology.

Not all outcomes were common to each course. For example, the following were specific outcomes of the Principles of Design course:

(1) Learn to utilize engineering methodology to solve problems throughout their engineering career.
(2) Work effectively as a member of a team.
(3) Obtain a basic understanding of the ethics required of an engineer in society.
(4) Write a technical report and make an oral presentation.

Joint projects were selected as the activity to integrate the three courses. There were a number of criteria that had to be met for a successful joint design project. First, the students should experience how the use of physical and mathematical concepts enhances the design process. Second, the projects should be fun and demonstrate to the students the importance of creativity in the design process. The final criteria for the projects were that they reinforce, but not alter, the topics covered in each of the courses.

Review of the course syllabi indicated that the first integrated design project could not be assigned until mid-semester. To establish the connection between the three courses from the first class, it was decided that the topic of the first project was on statistics and curve fitting. This was not a design project, but it was a topic that was covered in the first two weeks of each of the courses. Design and constructing a device to achieve a desired outcome was the primary goal of the final two joint projects.

III. Integrated Design Projects

Statistics and Curve Fitting Project

The first project emphasized the importance of statistics and curve fitting in analyzing data. Each course included a different exercise that used different tools to teach the same concepts. The following is a brief description of the activities.

Students determined the density of several objects (e.g., wooden block and metal cylinder) and learned about random and systematic errors that are inherent in the measurement of any quantity in the first physics lab. The measured dimensions and mass were used to calculate the best value (i.e., average) and standard deviation of the density. The second part of the lab was used to demonstrate that a "real situation" could be represented by one or more mathematical equations. In this lab, students derived a mathematical equation that related the spiral properties of a seashell. The analysis was done by "hand" and the result was checked using the regression function on their calculator.

The motion of a damped spring was studied in the first calculus lab. Velocity data was fitted to a relationship that had the form $Ae^{-Kt}\cos(Bt)$. After determining the constants A, K, and B that best fit the data, the equations for position and acceleration of the mass as function of time were determined. Students used the software package MAPLE for this lab.

Each of the Principle of Design sections had a different statistics and curve-fitting project. For example, students in one section measured their heart rate before and after sixty seconds of exercise. Statistical analysis and curve fitting of the data was performed using a spreadsheet software package (Microsoft Excel). The mean and standard deviation of the classes' heart rates were determined before and after exercise. In addition, paired and unpaired t-tests were performed to determine if exercise caused a significant change in heart rate.

While it may seem obvious to the faculty that the same topic was being taught in all three courses, many students do not always make this connection. As part of the joint project, this connection was reinforced by having the students write a report and make a Power Point presentation discussing the methodology and results of the statistical and curve fitting techniques used in each of the courses.

Tennis Ball and Water Balloon Launcher Project

The first integrated design project required the students to design and construct a three-person slingshot. The objective was for the students to be able to consistently launch a tennis ball into a box 5 inches wide by 16 inches long by 14 inches high that was 15 feet from the launch site. Also, the students had to be able to launch a water balloon (i.e., a non-rigid object) that contained two cups of water into a 5-gallon bucket 30 feet from the launch site. Each group was given 80 rubber bands, 100 paper clips, and could spend no more than five dollars on additional materials. A competition was held at the end of the project to determine the team that could hit the targets the most times. The groups were graded on their accuracy in hitting the targets, design calculations, oral presentation, and written report.

The initial part of the project followed a typical freshman design project procedure where the students used experimentation (i.e., trial and error) to determine the elastic band length and angle required to hit the target. This aspect of the project taught the student the importance of the release mechanism design. Many of the initial designs did not consistently release the tennis ball or water balloon so the students could not determine an optimum elastic band length.

To make the project more than just a trial-and-error exercise, students were required to calculate the force for hitting the target at their selected launch angle. Two cases were considered. First, the simple case was solved in which air resistance was neglected. While projectile motion, springs, and conservation of energy had been covered as separate topics in Physics I, the project required the students to combine these concepts. The second case considered included air resistance. Adding a drag force to the free body diagram was reviewed in both Physics I and Principles of Design class. The calculus required to solve the resulting differential equation was reviewed in Calculus II. The students then used a scale on launch day to measure the spring constant of their slingshot. With this information, the students were able compare the experimental determined length of the rubber band to the length calculated with and without air resistance for both the tennis ball and water balloon.

Even though most groups did not hit the target in five attempts, the students were excited about the project and enjoyed the challenge of hitting the target. The ability to calculate the force required for hitting the target varied widely among the students. Some students could easily handle the new concept of a drag coefficient while other students had a hard time applying the concepts that had been taught in Physics I and Calculus II to solve the case without air resistance. Overall, the project did demonstrate to the students how physics and calculus could be used to solve an engineering problem.

Amphibious Solar Powered Vehicle

The final joint design project required the students to design a solar powered amphibious vehicle to cross a 42-foot stream and arrive at a specified point on the other side. The students were given a motor, drive system, solar cells, and paddle wheels. They were then given the task of designing their own vehicle housing with materials that cost less than five dollars. The students also had to determine a means for measuring stream surface flow and vehicle velocity. On the day of the competition, the students were required to arrive at the test site with an equation for positioning their vehicle dependent upon stream surface velocity found at test time. This required the students to understand velocity vectors and power. Both of these topics were covered in Physics I.

There was one large competition held for all three Principles of Design sections. Several of the boats did not travel in a straight line and never made it to the other side of the stream. These groups failed to take the time to test and reevaluate their design before the competition. Some groups of students quickly discovered that wind effects could not be neglected when their amphibious vehicle was blown off course by a gust of wind. Overall, the students enjoyed the project and were able to apply the vector concepts needed to determine the correct starting position for the ideal case of constant vehicle and stream velocity. As with the previous projects, the importance of communicating the results in both written and oral form was stressed.

IV. Assessment of Principles of Design, Calculus II, and Physics I Integrated Learning Block

The primary tool used to assess the ILB was a student survey given at the end of the semester. The questionnaire was designed to determine if the students felt that they had achieved the shared outcomes and specific outcomes of Principles of Design. The students' responses reflect their opinion of whether the outcomes were achieved, but do not necessarily reflect whether they actually achieved the outcomes. Thirty-eight students completed the questionnaire for this study. One section of Principles of Design was not included in the assessment because the faculty member teaching that section had an accident and needed to be replaced mid-way through the semester.

Responses from two of the questions that indicated the student's experience in meeting the shared outcome of understanding the relationship between engineering, physics, and calculus are shown in Figure 1. Approximately 35% of the students strongly agreed that they felt comfortable using their skills in math, physics, and engineering to solve multidisciplinary problems. An additional 55% indicated that they agreed somewhat with the statement. Students were also asked how comfortable they felt explaining and defending the solutions they developed to solve engineering problems. The more comfortable the students felt in explaining their solution was an indication of whether they believed they understood the underlying mathematical and physical concepts required to solve the engineering problem. The results were approximately the same as the previous question. This further substantiated that about 90% of the students at least agreed somewhat that the primary shared outcome of the ILB was achieved.

The responses from four questions that were directed at the specific outcomes of Principles of Design are presented in Figure 2. An important outcome of Principles of Design is for students to learn a systematic approach for solving engineering problems. In this course, the students are taught the McMaster Five-Point Strategy for solving problems. In general, the students were reluctant to accept the need for these techniques to solve problems. About 70 percent of the students agreed somewhat that they feel comfortable in using the skills that they have learned in solving problems, but were not totally convinced.

Working in teams to solve problems is another important outcome stressed in the Principles of Design course. For each of the projects, the instructor divided the class into groups of four or five students. Students are not allowed to pick their own groups so that they are forced to work with students that have different interests and backgrounds. After working on three integrated projects and numerous in-class team projects, about 50% percent of the students strongly agree that they feel comfortable working as a member of a team.

The course was very successful in achieving the outcome of having students learn to prepare and present an oral presentation discussing their solution to an engineering problem. Approximately 75% of the students strongly agree that they had achieved this objective. Considering that many engineering students do not believe that writing reports is one of their strengths, it was very encouraging that about 35% of the students strongly agree and 60% of the students agree somewhat that they had learned to prepare a written report discussing their engineering solution to a problem. One reason for a high percentage of our students feeling that they achieved these outcomes can be attributed to the students being in a first semester ILB that combined Principles of Engineering (ES 141) and Rhetoric, Language, and Culture (RLC 110). One of the shared outcomes of this ILB was for the students to understand the importance of communicating effectively in both an oral and written form[1].

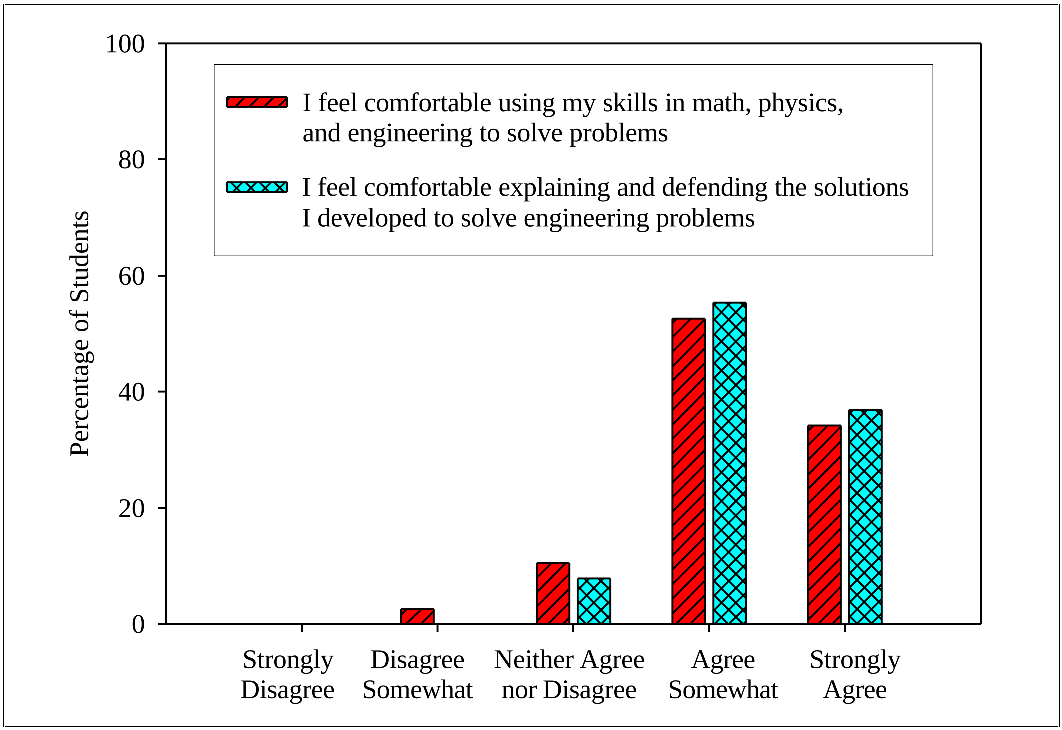

Figure 1. Assessment of Integrated Learning Block Shared Outcomes

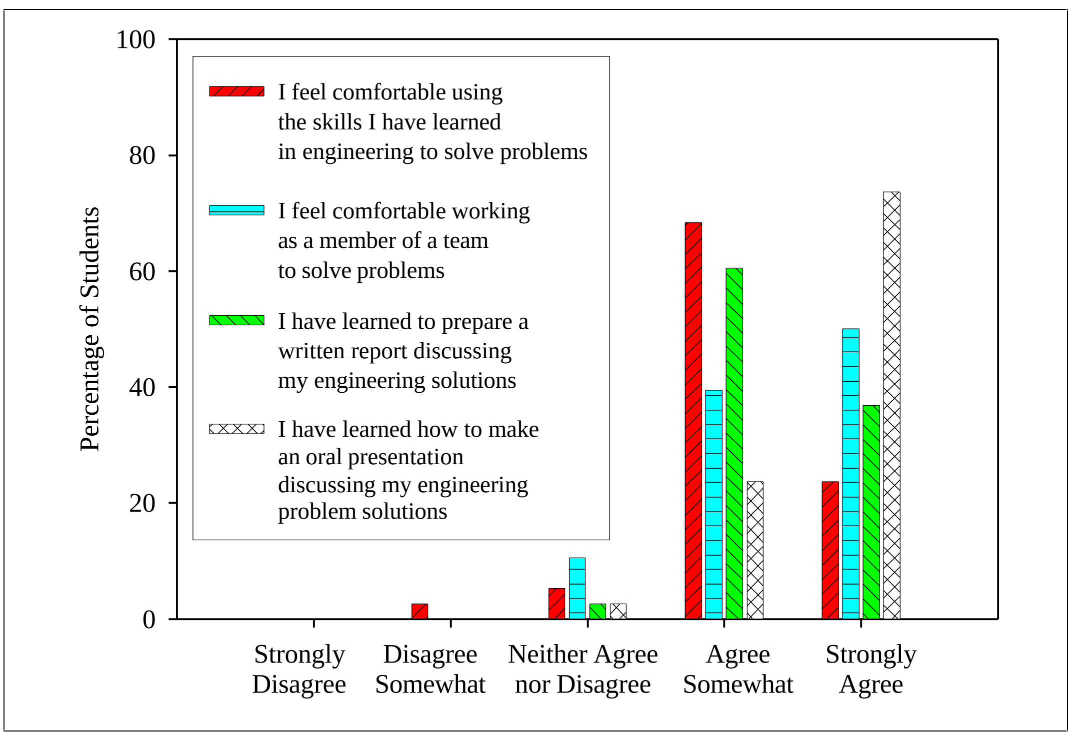

Figure 2. Assessment of Principles of Design Outcomes

An internal evaluation of the engineering, physics, and math integrated learning block was performed by Dr. Susan Coleman, Barney School of Business, University of Hartford [2]. Overall, she concluded that the ILB was very successful. The projects were well received and the students achieved an understanding of the interrelationship between engineering, physics, and calculus. Recommendations for future improvements included strengthening of the physics and calculus course involvement through the addition of more ILB sections. Students complained that they had very few options when making their schedule and the integrated learning block calculus and physics sections were not available to all students because of scheduling conflicts.

V. Conclusions

The integrated learning block successfully met the shared outcome of having the students understand the interrelationship of engineering, physics, and calculus. This was accomplished through the use of joint design projects where the importance of math and science were emphasized in the design process. The students ranked the projects as being the most instructive part of the Principle of Design course. Team teaching the courses also gave the faculty a better understanding of the topics covered in the other courses so that shared concepts could be reinforced. More data is required to determine if the integrated learning block will also have the additional benefit of increasing the retention of freshman engineering students.

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