AC 2010-2057: JOINT MATH-ENGINEERING PROJECTS TO FACILITATE CALCULUS SUCCESS IN FIRST YEAR STUDENTS

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Joint Math-Engineering Projects to Facilitate Calculus Success in First Year Students

Abstract

It has been observed that most first year engineering students seem to enjoy and often perform well in their project and project-oriented freshman engineering course, but seem to have difficulty and often perform poorly in their first calculus course. Working from the perception that first year engineering students do not make the connection between what they learn in calculus and the problems they solve in freshman engineering, the faculty who teach the engineering sections of first semester calculus and the faculty who teach freshman engineering worked together to define projects that span both classes.

The primary goal of these projects was to show students how the concepts and techniques they were learning in math class were relevant to their future career in engineering. It was proposed and believed that if the students understood the connection between the two subjects, they would understand both subjects better and be motivated to work diligently in both subjects. Since students historically perform well in freshman engineering, the expected result, if this experiment is successful, would be improved grades in calculus.

In this experiment, three joint projects were defined to illustrate the following math concepts: (1) functions, composition of functions, discrete and continuous variables; (2) exponential growth and decay; and (3) rate of change, specifically focusing on Newton's Law of Cooling. Each project presents a fictitious real world problem that puts the students in the context of being the consulting group that needs to develop the solution to the problem. The problem must be understood analytically (the part done in math recitation and continued for homework) as well as experimentally (the part done in and for the engineering class). The students, working in small groups, must create a solution as well as write a technical report and present the problem and their solution to the class.

Approximately 130 students participated in these joint math-engineering projects. Their performance, primarily in calculus, was measured and compared to historical performance data as well as to calculus classes without the joint projects. Preliminary data suggests that these projects result in improved grades in calculus. Additionally, the student enthusiasm for these hands on projects has increased as well.

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While improved student performance in calculus was the primary objective of this effort, the experience of developing and implementing the math-engineering joint projects has resulted in improved communication between both departments and has helped the math faculty see how students work in groups to discuss and solve problems and to create reports and presentations of their work. The interactive nature of these problems, couched in engineering terms, is resulting in more student discussion of mathematics, a more interesting teaching experience for the instructors, and improved student performance.

1.0 Introduction

Difficulty in succeeding in calculus is one of the primary reasons students transfer out of engineering at West Virginia University and other colleges. Historically, calculus has served as a filter in many engineering schools[1]. Engineering schools and math departments in a variety of universities have worked together to address this problem.

At West Virginia University (WVU), the Department of Mathematics has designated its first semester calculus class as MATH 155. There are two divisions of MATH 155 currently—those who are in engineering, and those who are not. This division assures that only those students in engineering sections of MATH 155 are engineering majors. Sections of calculus reserved specifically for engineering majors make joint projects between the engineering and mathematics programs possible.

Instructors from WVU's Department of Mathematics in the Eberly College of Arts and Sciences (ECAS) and Freshman Engineering Program in the College of Engineering and Mineral Resources (CEMR) worked together to develop calculus-based projects that can be introduced in CEMR's project-based Engineering Problem Solving I (ENGR 101) course. Together, the math and engineering faculty identified calculus concepts with which MATH 155 students typically struggle. These concepts were targeted to be reinforced in the engineering curriculum.

These projects were designed to reiterate the need for students to understand and apply specific mathematical concepts in order to solve engineering problems. The goal of these projects is to allow the students to use information obtained in math and engineering classes to aid in successfully understanding topics in the co-requisite class.

2.0 Description of Projects

In order to better illustrate the connection between math and engineering applications, several topics needed to be identified as a potential crossovers points. During the summer before this program was piloted, a task force composed of both math and engineering instructors was formed to assess these topics. Based on the material covered in MATH 155 and ENGR 101, and the scheduling of these two classes throughout the semester, four potential concepts were identified. These concepts included: (1) functions, compositions of functions, and the differenct between discrete and continuous variables, (2) exponential growth and decay, (3) rate of change, and (4) optimization. Because of time constraints in class schedules, only three projects were developed. These projects are discussed in detail in the following sections.

2.1 Project 1 - EcoSkoot

This project illustrates functions, composition of functions, and the difference between discrete and continuous variables. For the first project, students were given the following project description:

In this project you work for an engineering consultant. Your company is renowned for rapidly driving down cost by streamlining design and your help is needed. You have been contracted by EcoSkoot, Inc., a startup company hoping to create a new market in low-power-consumption personal-commuter transportation. This company believes they have developed a breakthrough lightweight propulsion system. Unfortunately, the power-to-weight ratio of their pre-production system has fallen short of their design goals.

The engineers at EcoSkoot believe that if they can reduce the weight of their vehicle by 30% they will have a viable product. The existing cruise control system is a crude adaptation of a mechanism designed for a much heavier and more powerful vehicle. Your team's task is to drastically reduce its weight. The project consists of two phases: Design a system that can convert the real speed of the car into recorded speed; and, design a mechanical apparatus that either slows down or speeds up the car depending upon its recorded speed and a "speed set." In this project your job is to complete the first phase of the task.

2.2 Project 2 - Save the Snails

This project illustrates defining exponential functions and exponential growth and decay. For the second project, students were given the following project description:

The tides along the shores of a certain impoverished East African nation are unusually high for tropical waters. A coral reef fringes the coast, and forms a string of lagoons between the reef and the coast. During spring tides the sea level ebbs enough to uncover the heads of the reef and the water in the lagoon can be cut off from the sea for up to nine hours. The lagoons are a haven for rare and beautiful sea life, including certain species of nudibranch found only in these waters.

Broadly speaking, seawater in the world's oceans has salinity near to 3.5%. This means that every 1 kg of seawater contains approximately 35 grams of dissolved salts (mostly, but not entirely, the ions of sodium chloride: Na^+, Cl^-). To survive, nudibranchs require a salinity of not less than 2.4% and not more than 4.3%. Even within these limits, a rapid change in salinity could also kill them. The lagoon is fairly small, and it is feared that at spring tides, after the sea starts to ebb and before it next floods, the fresh water discharge from the power station could reduce the salinity in the lagoon to levels harmful to the nudibranchs that live there

A power station to support the growing tourist industry in the area is in the final stages of construction. A canal has been dug to allow fresh water to be diverted from a local river to provide cooling water for the plant. Cooling water will then continue down the newly cut canal into one of these lagoons. The way the canal discharges into the lagoon creates such strong

turbulence that total mixing with the solution in the lagoon is assumed to occur almost instantaneously.

Construction is close to completion and an international environmental watchdog organization has just raised a major concern. Economic constraints make it impossible to move the plant or further divert the river. Environmental concerns preclude destroying any part of the reef by, for example, constructing an undersea pipeline.

You are part of a small multidisciplinary consulting team brought in to assess the environmental threat and recommend any remedial actions if needed. As usual, you are working under extreme time pressure and within the constraints of a shoestring budget. If a simple, environmentally sustainable and cost effective solution cannot be found and implemented before the plant starts production in three months, irreplaceable undersea life in that lagoon could be destroyed.

2.3 Project 3 - Fry by Night

This project illustrates rate of change, specifically focusing on applications of Newton's Law of Cooling. For the third project, students were given the following project description:

Fry by Night dominates the late night fast food market in every sizable university town in the USA. Selling fried cholesterol between 6:00 p.m. and 6:00 a.m., the company meets the perceived nocturnal nutritional needs of the majority of its target market. The slogan "A warm one from me and your next is for free" has proved effective in promoting the sale of Fry by Night's line of beverages.

The company now wants to go global and is considering opening a branch on a Caribbean island where the company's founder has both a coastal mansion and a tax shelter. The island has a notoriously unreliable electricity supply. Most subscribers lose power for at least two half-hour periods each day, although 99.5% of the time power returns within 90 minutes and outages never occur within 4 hours of each other. Fry by Night must maintain its "Next for Free" brand image worldwide. It defines "Cold" as 10°F below ambient temperature. Ambient temperature on the island seldom exceeds 90°F.

Fry by Night has established that the thermal properties of the beverages involved are identical to those of the soda in the can provided for your experiment. A worst case scenario is assumed, wherein the effects of a power outage will be simulated by the liquid and the can containing it being immediately removed from the refrigerator.

3.0 Implementation

These three projects were implemented concurrently in both the math and engineering classes. The concepts were introduced based on the curriculum for MATH 155. Each project was group based, with each group typically containing 4-5 students. All projects were introduced in the engineering classes with a power point presentation describing the project requirements and deliverables. A workbook containing this information and all pertinent worksheets was also

distributed. Further work was done in MATH 155 recitations and engineering laboratories. The following sections discuss specific implementation in each course.

During the Fall 2009 semester, all students were concurrently enrolled in both MATH 155 and ENGR 101 project courses. These students were all first time, full time freshman engineering majors. All students were able to complete all parts of the projects.

Currently, during the Spring 2010 semester, the composition of the groups is quite different. All students are not required to be concurrently enrolled in both MATH 155 and ENGR 101. Since the project worksheets are divided by course, those students in MATH 155 are required to complete only the math worksheets and those in ENGR 101 are required to complete only the engineering worksheets. Both parts of the projects, math and engineering, were developed to be able to function as standalone worksheets, however the desirable objective would be for students to complete both sections. Because this disjoint exists, only the math worksheets will be collected and graded in math class, and engineering worksheets will be collected and graded in engineering class. It was highly recommended to the students to form groups such that at least some members were in both MATH 155 and ENGR 101 and able to relay missed material back to the group.

3.1 Implementation in Mathematics

First time full time engineering students who are calculus ready are typically required to take MATH 155. At WVU, MATH 155 is taught as a five day a week course. Three days are slated for introduction of new material while the remaining two days are reserved for recitation from previous classes. During the recitations, students typically work on additional application or exploratory problems, or take quizzes. Two calculus worksheets were associated with each engineering project. The material needed to comprehend these worksheets was covered in MATH 155. The content of the worksheets led the student to develop the analytical model for the specific engineering problem and then to apply it to a couple of different scenarios related to the specific engineering problem. Although projects were discussed by the instructors in calculus 1, most of the worksheets were completed under the supervision of the recitation leaders.

Students worked in groups of 4-5 (some groups same as engineering groups, but many were different) to complete the calculus sections of the project workbook. The students submitted these assignments as part of their grade for calculus. Once graded, the worksheets were returned to the student so that they could be used in the engineering classes.

3.2 Implementation in Engineering

While concurrently enrolled in MATH 155, engineering students are also registered for engineering problem solving. This introductory class is offered two days a week, on days after calculus recitation. In addition to the specified curriculum, time was dedicated to study these three projects.

Before the calculus recitation sessions, typically, engineering class time was dedicated to collecting experimental data. This data would be used to help the students understand where the mathematical theory was coming from, and would also be used in later engineering simulations.

For the first project, EcoSkoot, the students outfitted a remote control car with a device to measure the rotation of the wheel (quarter rotation, half rotation, and full rotation). The student operated the car on a premeasured course. This known data was used to determine velocity characteristics of the car and was then used to predict distances of unknown courses. The students were then able to use concepts of discrete and continuous functions to model this scenario.

For the second project, Save the Snails, students worked in an engineering laboratory to create a scale model of a tidal saltwater lagoon. Students had a basin of known size and were able to calculate the percent of salt by mass needed to mimic the real world situation. Students then, using discrete measure, simulated the inflow of freshwater into the lagoon. Salinity measures were taken throughout the simulation period. This process was done using multiple discrete measures. These experimental results, in conjunction with mathematical concept such as definition of exponential functions and exponential decay, were used to build an experimental model.

For the third project, Fry by Night, students again worked in an engineering laboratory to experimentally validate Newton's Law of Cooling. The groups used digital thermometers to determine the rate of change of temperature of a cold soda can as it acclimatizes to ambient temperature. The experiment was run for 90 minutes in order to obtain an appropriate "cooling constant". This value was then used to project how the same liquid would cool from other initial states and in other ambient temperatures. The experimental data was used to show how such a process closely resembles the mathematical concept of exponential decay.

After gathering experimental data, student groups could then use the concepts that they have learned in MATH 155 to validate experimental results, and extrapolate real world scenarios posed in the project description.

In the first project, students used the discrete data that they obtained experimentally and created a continuous function that could be used to predict unknown distances. In the second and third projects, after gathering experimental data and validating the formulas and methods learned in calculus, engineering students developed simulations. These simulations were used to model, with certain accuracy, the real world situations proposed in each problem statement.

3.3 Final Report and Presentations

After completion of laboratory experiments, math and engineering worksheets, and engineering simulations, the students were required to present their findings in the form of a technical report and presentation to their peers. Technical reports and power point presentations are already a component of the engineering course (verbal and written communications). The report includes an introduction to the problem and problem statement, summary and background of the math needed to solve the problem, discussion of the methodology used to complete the laboratory

experiment and engineering simulation, results, and the groups' conclusions and list of recommendations. The deliverables included with the technical report are: completed Gantt chart (scheduling), completed math and engineering worksheets, group contract, and group logbook. The groups were also required to present one of the three projects. These presentations to peers focused on the groups' understanding of the mathematics concepts as well as their implementation in engineering applications.

4.0 Results

In the Fall 2009 semester, this experiment was tried across two sections of engineering problem solving in conjunction with five sections of MATH 155. The results discussed here will report the outcome from the two engineering sections and three calculus sections. Of the 128 students in ENGR 101 and 231 students in MATH 155 in the Fall of 2009, 78 students took part in this experiment (i.e. students were in a section of ENGR 101 and MATH 155 that dedicated substantial time to these linked projects). The results reported here track only those 78 students. Additionally, four instructors (one from engineering and three from math) are tracked in these results. Table 1 shows a summary of the final grade distribution for all ENGR and MATH courses for the 78 students included in this experiment.

Table 1 - Final grades for ENGR 101 and MATH 155 for Fall 2009

	Fall 2009	
	ENGR	MATH
A	33.33%	11.54%
B	42.31%	23.08%
C	14.10%	30.77%
D	6.41%	6.41%
F	3.85%	17.95%
W	0.00%	10.26%

It is worth noting in this table that none of the ENGR 101 students in this experiment withdrew from the course during the semester. Additionally, as shown in Figure 1, approximately 90% of the students passed ENGR 101 with a C or better, with over 75% receiving a final grade of A or B. This pass rate is consistent with the 6-year trend for ENGR 101, which also averages around 90%[2].

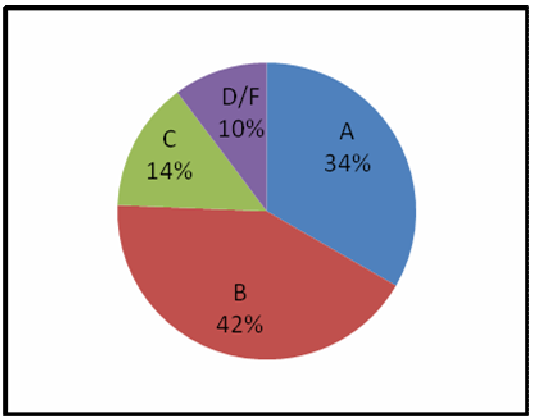

Figure 1 - Grade distribution for Fall 2009 ENGR 101 students

Results from this experiment also show that the pass rate for MATH 155, for students monitored in this experiment, was approximately 65%. The data is presented in Figure 2. This pass rate is approximately 5% higher than the overall 6-year trend engineering student pass rate for MATH 155, which averages around 60%[2].

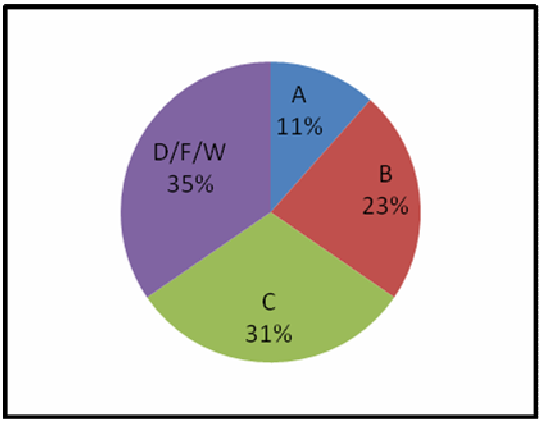

Figure 2 - Grade distribution for Fall 2009 MATH 155 students

Data gathered by the CEMR Office of Academic Affairs[3] and the Freshman Engineering Program[4] shows that the D/F/W rate for students taking MATH 155 is typically more than 40%. The 78 students enrolled in these courses concurrently showed a significant decrease in the D/F/W rate, to approximately 35%.

Because most of the instructors (engineering and mathematics) have taught for multiple years, historical data is available to show how these experimental projects have influenced students taking both ENGR 101 and MATH 155. The performance of students who took both ENGR 101 and MATH 155 from these same instructors over the past two years was analyzed. A summary of this data can be seen in the Table 2 below.

Table 2 - Historical data for ENGR 101 and MATH 155

	Fall 2009		Fall 2008		Fall 2007	
	ENGR	MATH	ENGR	MATH	ENGR	MATH
A	33.33%	11.54%	40.48%	7.14%	69.23%	0.00%
B	42.31%	23.08%	42.86%	28.57%	15.38%	38.46%
C	14.10%	30.77%	9.52%	26.19%	15.38%	38.46%
D	6.41%	6.41%	4.76%	9.52%	0.00%	0.00%
F	3.85%	17.95%	2.38%	7.14%	0.00%	7.69%
W	0.00%	10.26%	0.00%	21.43%	0.00%	15.38%

The data presented in Table 2 contains those students enrolled in ENGR 101 while concurrently enrolled in MATH 155 (with only same instructors who participated in the Fall 2009 experiment) during the Fall 2008 and Fall 2007. The number of students monitored in Fall 2009 is 78, the number of students monitored in Fall 2008 is 42, and the number of students monitored in Fall 2007 is 13. Table 3 shows the change in grade distribution for only these students between Fall 2007 and Fall 2009.

Table 3 - Change in grade distribution between Fall 2007 and Fall 2009

	Change between 2009 / 2008		Change between 2008 / 2007	
	ENGR	MATH	ENGR	MATH
A	-7.14%	4.40%	-28.75%	7.14%
B	-0.55%	-5.49%	27.47%	-9.89%
C	4.58%	4.58%	-5.86%	-12.27%
D	1.65%	-3.11%	4.76%	9.52%
F	1.47%	10.81%	2.38%	-0.55%
W	0.00%	-11.17%	0.00%	6.04%

These results show that the D/F/W rate of MATH 155, since the conception of these projects, has dropped approximately 3.5%. Additionally, the number of students withdrawing from MATH 155 during the semester has dropped by over 11%. This data show that students who are enrolled in ENGR 101 with these projects were more likely to remain in calculus as opposed to previously recorded years. It is our hope that the higher calculus retention rate is due to the experimental projects introduced in math and engineering. These results look promising to students who are enrolled in both math and engineering classes who work together on these projects. Results for the Spring 2010 semester are still pending.

5.0 Conclusion and Recommendations

Most first year engineering students enjoy and thrive in an experiential-based learning environment. Engineering courses have used hands-on projects to fulfill this need for its students. However, these same students lack this experiential approach in other mandatory

classes. This problem is prevalent in calculus 1. Working from the perception that first year engineering students do not make the connection between what they learn in calculus and the problems they solve in engineering, a method of introducing engineering-type projects was developed that span both classes.

The primary goal of these projects was to show students how the concepts from math class were relevant in engineering, and vice versa. It was proposed and believed that if the students understood the connection between the two subjects, they would understand both subjects better and be motivated to work diligently in both subjects.

To accomplish this, three joint projects were defined to illustrate mathematical concepts used in engineering. These concepts included functions and composition of functions, exponential growth and decay, and rate of change focusing primarily on Newton's Law of Cooling. In the fall semester 78 students took part in both the math and engineering sides of this experiment while over 200 additional students took part in one of the two courses.

These projects were successfully accomplished by constant communications between engineering and math professors. Weekly meetings, project updates, and assistance in class from recitation leaders in both math and engineering classes. Additionally, the instructors associated with these classes were the members of the task force that developed these projects. Most of the success of this program can be attributed to the fact that there was working knowledge of all aspects of all projects at every level during this introductory program.

Final results show that, after the implementation of these joint projects, the D/F/W rate dropped by 3.5% in MATH 155, Calculus 1. Additionally, the number of students who withdrew from MATH 155 dropped by over 11% compared to the previous year. Grade distributions in both classes, but primarily in calculus, also saw an improvement.

These joint math-engineering projects were piloted with only students in first semester calculus and calculus-based engineering design. Because of the results we have seen, it may become possible to export this type of project-based, experiential learning to second semester calculus and second semester engineering design, and also to pre-calculus and its engineering design cohort.

While improved student performance in calculus was the primary objective of this effort, the experience of developing and implementing the math-engineering joint projects has resulted in improved communication between both departments. These projects have also facilitated the math faculty to observe students working in groups to discuss and solve problems and to create reports and presentations of their work. The interactive nature of these problems, couched in engineering terms, is resulting in more student discussion of mathematics, a more interesting teaching experience for the instructors, and improved student performance.

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