2006-1256: INITIAL RESULTS FROM A MATH-CENTERED ENGINEERING APPLICATIONS COURSE

Dale Buechler, University of Wisconsin-Milwaukee
Assistant Professor Electrical Engineering

Member ASEE, IEEE, BEMS

2007 ASEE Mathematics Division Chair-Elect

2006 ASEE Mathematics Division Program Chair

Director ASEE Mathematics Division(2003 - Present)

Who's Who Among America's Teachers

Outstanding Teaching Award - College of Engineering and Applied Science (2000-2001)

1999 Science and Engineering Education Scholars Program Participant

email: buechler@uwm.edu

Chris Papadopoulos, University of Wisconsin -Milwaukee
Assistant Professor Civil Engineering and Mechanics

email: cpapa@uwm.edu

Initial Results from a Math-Centered Engineering Applications Course

Abstract

Our school serves a diverse student population. Students of color make up 10% of the freshman enrollment in the college of engineering and applied science (CEAS) and 17% campus-wide. The majority of our incoming engineering students begin at the college algebra and trigonometry level. Unfortunately, only half of our freshman class achieves junior status. In addition, many of the students entering their core engineering classes are not retaining important mathematical concepts from their prior algebra and trigonometry coursework. To help improve engineering student retention as well as improving their retention of important techniques and concepts involving college algebra, trigonometry, and geometry, an optional hands-on one-credit pilot course was offered in Fall 2005. Topics were ordered to coincide with their concurrent college algebra and trigonometry classes. The topics included: units, trigonometry, analytic geometry, empirical modeling, exponential functions, systems of linear equations, error analysis, and approximation. The hands-on engineering experiments and demonstrations used for this course will be discussed. Additional in-class experimental assistance and tutoring was made available to the students in this class via a grant from the Wisconsin Alliance for Minority Participation (WiscAMP). The relative performance and short-term retention of these students will be reported.

Introduction

Engineering education at a public urban university provides numerous challenges. Most of our incoming students who indicate an engineering major at the College of Engineering and Applied Science (CEAS) do not place into calculus upon arrival. Although many of these students covered the prerequisite material in high school, they have not retained the information. These students must complete the prerequisite mathematics courses prior to entering into the traditional first-year engineering curriculum, which in turn delays their access to core engineering courses with calculus prerequisites. Roughly half of these students never make it to their junior classes in engineering. Some drop out of school. Others become disenchanted with the long list of requirements to be completed prior to entering their engineering classes, and switch majors. To combat these problems, we have created a pilot course at the freshman level for those students placed at the level of college algebra and trigonometry. This course, which applies the math the students have just learned (or previously learned) in college algebra and trigonometry to simple engineering problems, was developed to increase the student retention of key mathematical concepts and methods and to help retain engineering students within the college.

Focusing on college algebra and trigonometry is especially important to the education and retention of students of color. Consistent with overall standardized test score results in Wisconsin, students of color at UWM tend to score lower on the mathematics placement exam. In fall 2005, twelve students enrolled in the initial offering of this pilot course. It consisted of 11 male students and 1 female student. Two of the twelve students were disadvantaged minority students.

Overview of Pilot Course

In our previous paper[1] we presented the conception and design of an engineering applications course; we discuss the implementation of this course here. As was discussed in this earlier paper, this course was designed to provide a structured set of engineering applications to supplement specific mathematical topics covered in College Algebra and Trigonometry. The pilot course met once per week for 50 minutes. The course included six planned experiments plus numerous lectures to help address specific topics[1]. The topics are outlined in Table 1.

Lecture or Experiment (Assessment)	**Class Topic**	**Math Topic**	**Engineering Topic**
Lecture (In-Class)	Introduction	Problem Solving	Problem Solving Units Approximation and Error
Lecture (In-Class)	Trigometry Sign Conventions	Trigonometry Special Angles Sign Conventions	Long-term recall of Special Angles without calculators
Experiment #1 (Formal Report)	Approximation of building heights	Trigonometry	Error Analysis
Lecture	Areas and Volumes	Geometry	
Experiment #2 (Informal Report)	Excavation and Fill in Highway Construction	Geometry	Approximation
Experiment #3 (Informal Report)	Behavior of Beams	Mathematical Modeling	Data Collection/Analysis
Lecture	Exponential and Logarithm Functions	Exponentials & Logarithms Mathematical Modeling	Time Constants
Experiment #4 (Formal Report)	Capacitance Charging	Exponentials Mathematical Modeling	Multimeters & Breadboards Fitting Empirical Data to Exponential Model
Lecture	Exponential Models Indirect Measurements	Mathematical Modeling of Exponentials	Conversion of Thermistor Resistance to Temperature
Experiment #5 (Formal Report)	Newton's Law of Cooling	Mathematical Modeling	Indirect Measurements Data Conversion
Lecture	Linear Algebra Review	Solution of Simultaneous Linear Equations	Resistive Circuits
Experiment #6 (Informal Report)	Resistive Circuit Experiment	Simultaneous Linear Equations	Resistive Circuits Sensitivity Analysis
Lecture (In-Class)	Variability of Resistors	Mean, Median, Std. Dev. Normal Distribution Confidence Intervals	Variability of Resistor values

Table 1. Overview of Pilot Course Topics

Our primary goals for this course were (1) to improve the long-term retention of these topics amongst the students in this class; (2) to introduce engineering problem solving issues and techniques to students at an early stage; and (3) to foster retention of students in engineering or other technical fields.

Pilot Course Experiments

The classroom was scheduled to be vacant for 30 minutes beforehand to allow for experimental set-up on laboratory days. Two upper-division undergraduate students assisted in experimental preparation and set-up. They also helped with student questions during the experiments. A short description of each of the experiments is provided below.

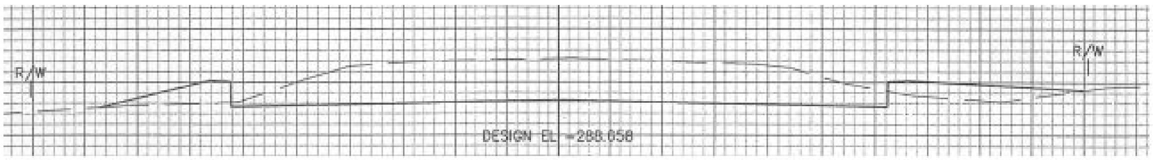
1. **Approximation of building heights**

Students in groups of two were asked to approximate the heights of two buildings on campus. Each group was provided with a clinometer, a 25 ft. measuring tape, and a topographical map of campus. The clinometer was constructed using a protractor, a large soda straw, a piece of fishing line, and a large metal nut[2]. For each building, each student within the group was required to take measurements from two locations (at least one relatively close to the building, and at least one relatively far away from the building). For these measurements, each student needed to take into consideration their own height and the differences in elevation of the point of measurement and the base of the building. The height of a third building on campus with known height was given to the students to allow them to verify the measurement technique prior to taking final measurements. Each student was required to write his or her own formal lab report for this experiment.

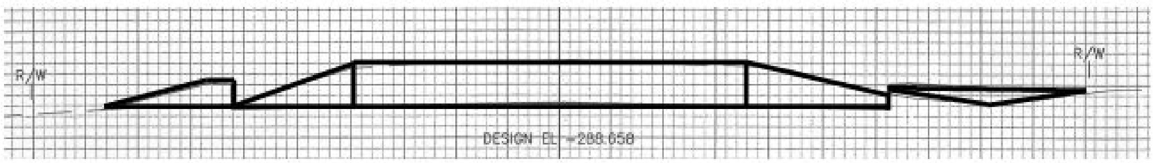
2. **Calculation of volumes of excavation and fill in highway construction**

In the design and construction of roadways the land is surveyed. From this data the volume of land that must either be "excavated" (removed) or "filled" (added) can be calculated. Scale highway cross-section drawings from an actual road recently constructed in Wisconsin were obtained. The students were grouped into pairs; each pair received two successive cross sections, and successive groups received cross-sections that overlapped each other such that all the assigned cross-sections were being evaluated by two groups with the exception of the first and last segments.

Figure 1 shows a typical cross section. Each small square represents 0.2 m x 0.2m. The dashed line shows the original contour of the land, and the solid line indicates the desired contour after construction. Areas for which the dashed line is above the solid line must be excavated; areas for which the dashed line is below the solid line must be filled. The students were asked to calculate the excavation and fill areas for each cross section by two approximate methods: counting squares (Figure 1a) and by subdividing the region into 5 or fewer common shapes (Figure 1b). Using the mean cross-sectional areas between two successive sections located 20 meters apart, the students were asked to approximate the volume of land that needed to be excavated and filled over this stretch of road and to determine how many standard dump truck loads would be required to haul away any excess dirt (students were required to research or estimate the volume capacity of a typical dump truck).



(a)



(b)

Figure 1. Sample Highway Cross-Sectional Drawings [3]. Dashed lines indicate original Cross-Sectional Contour. Solid lines indicate the desired contour. (a) Areas approximated by counting small squares (each small square represents 0.2 m x 0.2m). (b) Areas approximated by using common shapes.

3. **Measuring and predicting the behavior of beams**

Two basic experiments were prepared, each involving three aluminum cantilevered beams. The first experiment tested the effect of varied beam depth (Figure 2a); these beams had common widths and lengths. The second experiment tested the effect of varied beam width (Figure 2b); these beams had common depths and lengths. For each beam, increasing weights were successively hung from the free end. A dial gage was positioned (using a magnetic mounts) to measure the deflection of the free end. Because the gage itself exerts a force on the end of the beam, for each specified applied weight, the effect of the gage was eliminated by manually lifting the gage's probe to be in impending contact with the end of the beam. The students took turns collecting the data, which was posted on the class webpage for all students to access.

(a) Depth Experiment

(b) Width Experiment

Figure 2. Cantilevered beams having variable depths (width and length held constant)

Using this data, students were required to plot the load vs. deflection curve for each beam, and to answer a series of probing questions, such as to identify appropriate trends of beam behavior from a list of given possibilities. For example, given a choice of linear, quadratic, and cubic models, students were asked to determine from their data that as beam depth decreases, deflection increases cubicly. Also, in order to provide the students with an elementary introduction to design, the students were asked extrapolate their data to propose a design of a beam that would carry a load that was significantly greater than any applied in the experiment, and that would not exceed a given deflection.

4. Capacitance charging

This laboratory experiment allowed students to investigate and to model a practical problem (the charging of a capacitor) involving the use of exponential functions. The students constructed first-order circuits of the form shown in Figure 3 involving a super capacitor on a breadboard. A Portable Breadboard with Battery Power Supply (Figure 4) was used for all circuit experiments for this course so that these experiments could be conducted in a normal classroom instead of a designated laboratory. Rechargeable batteries were used to save on long-term battery expenses. Each group measured and recorded the voltage across the capacitor as a function of time for the circuit in Figure 3 with different resistor R values. Students were asked to plot their data for each first order circuit and to obtain mathematical models from their plotted

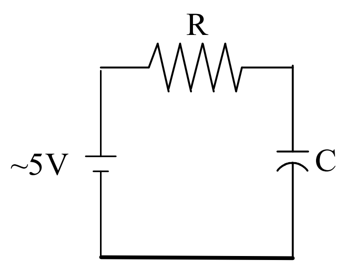


Figure 3. First-Order RC Circuit used in Capacitance Charging Experiment

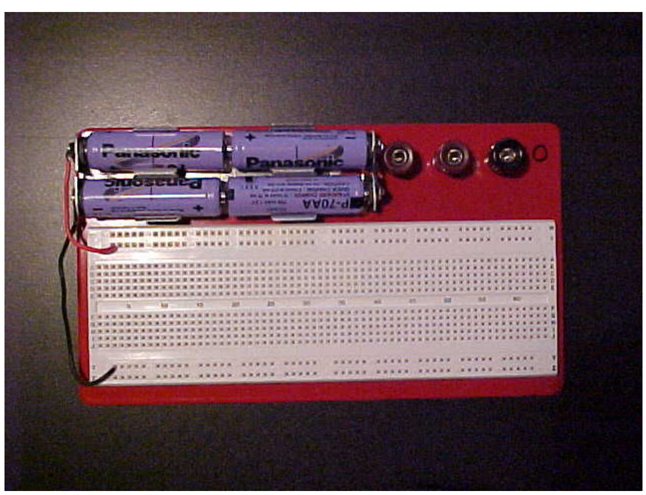


Figure 4. A Portable Breadboard with Rechargeable Battery Power Supply

results using equations of the form $V(t) = C_1 + C_2e^{-t/\tau}$, where τ is the time constant. Each student was required to write his or her own formal lab report for this experiment, including a discussion about the relative accuracy of the results.

5. Newton's law of cooling

Students in groups of two indirectly measured the change in temperature of warm water placed in glass jars as a function of time using a thermistor. They recorded the thermistor resistance R as a function of time for uninsulated and insulated glass jars (using layers of foam insulation). The students were asked to convert their resistance data to temperature data entering the relationship $T(K) = 1/(A_0 + A_1(\ln R) + A_3(\ln R)^3)$ into Microsoft Excel. This data was used to obtain mathematical models for the uninsultated and insulated cases. Each student was required to write his or her own formal lab report for this experiment including a discussion about the relative accuracy of the results.

6. Resistive Circuit Experiment

This laboratory experiment allowed students to investigate a practical application: the determination of the mesh currents in a resistive circuit, which requires the solution of simultaneous equations. Students did hand calculations on both two-mesh and three-mesh circuits (Figure 5 and Figure 6) to determine the expected currents flowing through the resistors using the values indicated on the resistors. Students then constructed the circuits and make voltage and resistive measurements in order to determine the mesh current values and compared these to their calculated values. The experiment was repeated with a 1% resistor replaced by a 10% resistor to allow students to understand the overall effect resistor variation can have on the circuit.

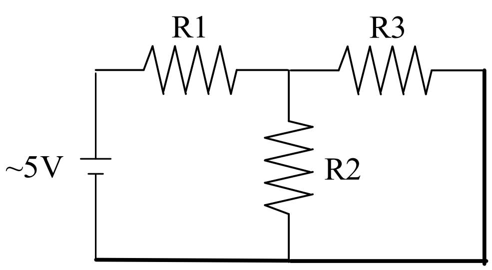


Figure 8. Two-Mesh Resistive Circuit

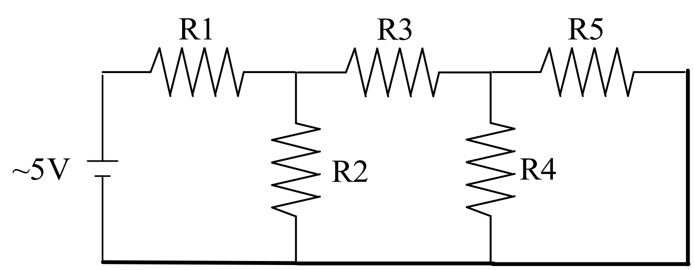


Figure 9. Three-Mesh Resistive Circuit.

Lab Reports and Exercises

Each laboratory experiment had an accompanying document that gave an overview of the experiment, the experimental procedure, tables to record data, and questions to answer. Some experiments only required informal lab reports consisting of the recorded experimental data, required plots and/or figures, and answers to questions. Other laboratory experiments required a typewritten formal report consisting of an introductory paragraph, a methods section, a results section, and a discussion and conclusions section. Table 1 (above) identifies which experiments required formal or informal reports. On days for which a laboratory experiment was not scheduled, a lecture was presented, most of which included an in-class assignment. In-class assignments are designated "In-Class" in Table 1.

Assessment

To assess the success of this course, two primary methods were used: Student Survey Results and Student Grades. The results are presented below.

1. Student Survey Results

On the last day of class, students were given a survey asking for specific feedback on this pilot course. (This was in addition to the normal course evaluation forms). As part of this survey, students were asked to rate each of the experiments in the class. Half the students in the class (six) were present. Table 2 includes feedback on specific experiments. Table 3 includes answers to specific questions.

Experiment	**Rating (std dev)** **1 - excellent** **2 - above avg** **3 - avg** **4 - below avg** **5 - poor**	**Should the experiment be retained? (Yes/No)**	**Comments?**
Building Heights	2.17 (0.75)	5 Yes, 1 No	"More Electrical Engineering" "it was nice to get out of the room"
Road Building	2.67 (0.52)	2 Yes, 4 No	"interesting to see approximations" "too much Civil Engineering" "more Electrical Engineering type experiments"
Beam Bending	2.50 (1.05)	4 Yes, 2 No	"Too repetitive and boring" "More Electrical Engineering"
Capacitor Charging	2.33 (0.82)	6 Yes, 0 No	"I liked working with circuits more" "maybe explain more on capacitors"
Newton's Law of Cooling	2.50 (0.55)	6 Yes, 0 No	"this was interesting"
Determining Current in Resistive Circuits	2.83 (0.98)	5 Yes, 1 No	"equations were too confusing"

Table 2. Student Feedback on Experiments Used In Pilot Course

Would it be helpful to have an introductory section on spreadsheet programs as part of this class?	Has this class been helpful as a supplement to your math and/or science classes?	Any other improvements?
6 Yes, 0 No	"Yes, it shows good real applications"	"Make the course more than a 1 credit class"
"After fighting with excel I found it a great tool and should be taught"	"It did help a little toward my math"	"The experiments should be shrunken a little to ensure enough time to finish"
"At least a refresher course"	"No change really"	"The class need to be at least a little longer so you could finish the experiment because we have to rush to finish at the end of class"
"I struggles with excel!"	"Kind of. It was helpful to see why we were doing what we were doing in math class"	"No, workload was a little heavy, but not too much."
"It would be a great idea"	2 "Yes" responses	"It was a fun class"

Table 3. Other needs to be addressed.

2. Student Grades

The grades in the pilot class were based on assignments and lab reports (80%) and on attendance (20%). In assessing the short-term performance of the twelve students in this pilot course we looked at their grades in this pilot course and grades in math and science courses taken concurrently. Of these twelve students five were enrolled in both college algebra and trigonometry; three were enrolled in only college algebra; two were enrolled in only trigonometry, and two were enrolled in calculus I. Eight of the twelve students received passing grades in the pilot course: Four students received excellent marks; two received very good marks; two received average marks; three received failing marks; and one was administratively dropped from all classes.

Those completing the pilot course did fairly well in the math courses they were taking concurrently. All students who completed the pilot class and were enrolled in trigonometry received a grade above a "C" in trigonometry. Only one of the students who both completed the pilot class and was enrolled in college algebra received less than a "C" in college algebra. Those students concurrently enrolled in calculus I (one of whom was initially placed in college algebra and trigonometry but retested) received excellent marks in both the pilot course and calculus I, as would be expected.

In general, the grade earned in the one-credit pilot course appeared to be an indicator of the overall semester GPA. The two best students in this course had excellent semester GPAs as well. Three others had very good semester GPAs. One had average performance. Three students received failing grades in the pilot class because they stopped attending class; they displayed the same behavior in most of their other classes. The remaining two students had below average semester GPAs due to their performance in college algebra (one stopped attending mid-semester and the other failed the final exam).

Discussion

From the results of the student survey, it appeared that the first time offering of this pilot course was relatively successful. All but one of the students who completed the survey thought that the course had been helpful as a supplement to the math classes they were taking. Overall the students were happy with most of the experiments, although a few students commented that there was too much Civil Engineering content in the course. This type of comment was expected in light of the fact that over half of the students in the class were Electrical Engineering majors. The pilot course was originally developed for all of the engineering majors in the college who were initially placed into college algebra and trigonometry. Shortly after the approval of this pilot course, the mathematics prerequisite level of the freshman courses for mechanical, industrial, and civil engineers was lowered to College Algebra and Trigonometry. As a result, it became more difficult for the college to populate the course with only electrical engineers, material engineers, computer scientists with an engineering minor, undeclared engineering majors, and underrepresented minorities to select from.

The survey did identify some problems as well. The students required more time than anticipated to complete the experiments that we developed for this class. It became clear early on that the weekly one-credit, 50-minute lecture/lab format was too short. We attempted to cut back on the content of some of the latter experiments in order to reduce the time pressure. The survey also indicated that many of the students had very little experience with spreadsheet programs such as Excel prior to this class.

One problem that we did not envision was the lack of maturity of the students in the class. Many of the students were not prepared for class when they arrived. Some did not attend class regularly. Many had problems following written directions. Some failed to turn in assignments in a timely manner and did not complete the work they did turn in. Most did not show their work and very few checked their final answers to see if they made sense. Few students asked questions (either in class or in office hours). Students were informed of the availability of free tutoring for their math and science courses several times during the semester; however, they did not make use of this resource.

In addition, we found that many of the students had poor writing skills. Many of the formal lab reports lacked several key elements, such as how results were obtained, supporting calculations, and discussion about validity of the results and potential sources of error.

If this course is to be offered in the future, it needs to have more contact time. It should meet at least 2 hours per week without expanding course content. The reason for the time expansion is two-fold. First, the experiments would be less rushed and students could complete all the calculations needed for the laboratory report while help is readily available. Second, a part of the course should include a structured meeting time during which students are expected to begin their out of class assignments in the presence of the instructor. The idea here is to address more than just the development of the technical competence of the students; it is for the purpose of helping them to develop the maturity to become engaged learners. A structured meeting time, for example, provides students with the opportunity to discover and answer their own questions with a guiding hand. This might provide a more effective alternative to traditional tutoring.

Finally, it might be advantageous to alter the order of topics in our course to better align with the topics in the concurrent college algebra and trigonometry courses. Preparation is currently being made for this pilot course to become a regular course for pre-calculus engineering freshman.

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Disclaimer

References

1 D.N. Buechler, C.M. Papadopoulos, T.R. Johnson, E.S. Key, "Development of a targeted engineering application course to improve retention," Proceedings of the 2005 ASEE Annual Conference, Portland, OR, June, 2005.

2 University of Texas at Austin and GE Foundation, "Water Rockets: First Derivatives, Building and Using Clinometers," 2004. Located at: www.engr.utexas.edu/aim/curriculum/files/AIM_Calc_2004/Rockets_T_BuildingClinometer.doc

3 Wisconsin Dept. of Transportation