Session 2793

Improving Retention of Calculus by Engineering Students in Small Programs

David L. Silverstein, John R. Baker
University of Kentucky

Abstract

Students in engineering and the sciences often complete their studies in mathematics before they have an opportunity to develop an appreciation for the application of mathematical concepts in their major field. All of the required topics are covered in the math courses students successfully complete, but when asked to apply the concepts learned in courses taken a year or more prior to application, they are often surprised to discover that they actually needed to know how to apply seemingly abstract techniques to real science and engineering problems. This shortfall in retention leads to additional work on the student's behalf and often a slowdown in the progress of a class to ensure adequate time is spent on a topic. While the responsibility to learn this material lies with the student, it nonetheless impacts the quality of the student's education.

This project is designed to address the problem by modifying student attitudes towards learning calculus by presenting examples in the context of engineering and science problems. The examples would be adapted from the actual sorts of problems engineers and scientists will encounter later in their course of study, but presented with all the emphasis on applying concepts currently being covered in the student's calculus class. The implementation is not intended to make the course "Calculus for Engineers", but instead will augment the general theoretical approach with relevant source material for examples.

The results of this project would be applied initially to calculus courses being taught to support the University of Kentucky (UK) College of Engineering Extended Campus in Paducah. Mathematics instructors with Paducah Community College (PCC) will adapt in-class examples from material provided by UK chemical and mechanical engineering faculty, distribute additional materials, and make use of web-based materials developed as a part of this project.

The primary expected outcome is that students taking courses requiring application of calculus concepts would enter the course expecting to use calculus and better prepared to apply advanced mathematics to engineering problems. The success of the project will be assessed over a period of 3-5 years using examinations designed to assess preparedness in

mathematics at the beginning of engineering courses. Results will be compared between current students who will not have seen the materials developed in this project, and later students who will.

Introduction

Engineering is at its core mathematics applied to physics. It can be argued that without a solid foundation in mathematics at the calculus level, an engineering student will find difficulty in understanding and applying the knowledge involved in upper level engineering classes.

Even with this impetus, students often fail to apply themselves to their calculus courses with an intensity and dedication that they apply to their engineering courses. The result is an ability to pass exams in calculus courses, but a failure to retain key elements of knowledge.

This study is intended to evaluate whether incorporating discipline-specific examples of how calculus is applied to mechanical and chemical engineering will result in improved retention of calculus topics in later engineering courses. It is a multi-year project conducted in cooperation with Paducah Community College (PCC), the institution providing calculus instruction for the University of Kentucky (UK) College of Engineering Extended Campus Programs in Paducah, Kentucky.[1]

The Paducah programs are four-year engineering programs which provide Kentucky citizens the opportunity to earn B.S. degrees in mechanical or chemical engineering in a local setting. Students receive on-site instruction from UK engineering faculty on a site provided by PCC and supported by courses offered by PCC faculty (lower level courses) and Murray State University (upper level math, science, general engineering).

This potential for UK and PCC faculty to improve mathematics retention in students is high due to the level of interaction with the PCC mathematics faculty. All PCC calculus instructors have agreed to integrate the materials developed as part of this project into their courses.

Background

For lower levels of math, an emphasis on "story problems" is common. A somewhat realistic scenario is created, and students are asked to apply mathematical concepts to formulate the problem and obtain a solution. As the mathematics become more complex, fewer and fewer applied problems tend to be presented to students, and still fewer become part of their homework or self-study. One result of the often repetitive nature of mathematical problem solving without application is that students fail to move beyond the levels of learning at the lowest rungs of Bloom's Taxonomy.

In larger institutions with large enrollments in calculus courses, the option to specialize instruction is often applied. Some schools offer "Engineering Calculus," which emphasizes applications, and provides solid evidence that students will later apply calculus concepts to their engineering studies. However, many schools, especially smaller institutions, such as community colleges, do not have the enrollment to justify separate offerings in calculus for engineering students, mathematics majors, and any other field of study which applies calculus within its curriculum.

A curriculum must be more than the sum of the courses a student takes to earn a degree. Students must integrate a wide range of knowledge to maximize the value of an education. In engineering, integrating mathematics with science and engineering courses is key to producing top quality graduates. There are an increasing number of integrated curricula, where instruction in chemistry and physics is tied to instruction in calculus (La. Tech, Texas A&M, others).[2] Other faculty have developed multimedia modules to tie engineering to topics in calculus (N.C. A&T, Dartmouth, N.C. State, others).[3] The effectiveness of these approaches is still under study, but expectations are high that the increased motivation of students will improve student performance and knowledge retention in calculus.

Reworking the structure of mathematics and science courses requires significant resources, due to course redevelopment, administrative restructuring, and creation of course sections devoted to engineering students. The project described will examine whether some simpler, lower cost efforts to improve student motivation will bring about the desired changes in knowledge retention.

This project will investigate the benefit of integrating engineering examples into the general calculus course offered to pre-engineering students and others. It is a three year proof-of-concept study involving three phases: development of materials for use by calculus instructors; integration of those materials into all four semesters of calculus courses; and evaluation of student retention of relevant calculus topics in later engineering courses with and without the aforementioned supplements. During the course of this project, these applications and examples will be introduced to area high school calculus instructors in a workshop format as part of a larger cooperative effort to encourage students to pursue careers in STEM disciplines.

Goals and Objectives

This project intends to answer the following questions:

- What calculus topics are in need of improvement in retention and understanding by students in the mechanical and chemical engineering programs at the University of Kentucky?
- Will supplementing calculus courses with engineering oriented examples improve retention of subject matter?

- Can these supplements be implemented without modifying the existing structure of the calculus courses?
- Is there a difference in outcomes for topics supported by examples designed for different learning styles?

The outcomes from this study will be used to determine whether additional supplementary materials from engineering and other academic majors would promote better student learning. The results from this study should be useful to faculty in all science and engineering disciplines. While our materials will focus on the needs of our mechanical and chemical engineering students, the same approaches to motivating students will apply to other science and engineering fields in general. The proposed methods used do not require significant capital investment. An additional consideration, the effectiveness of incorporating learning style into design of educational materials, will be useful to the educational community as a whole.

Implementation

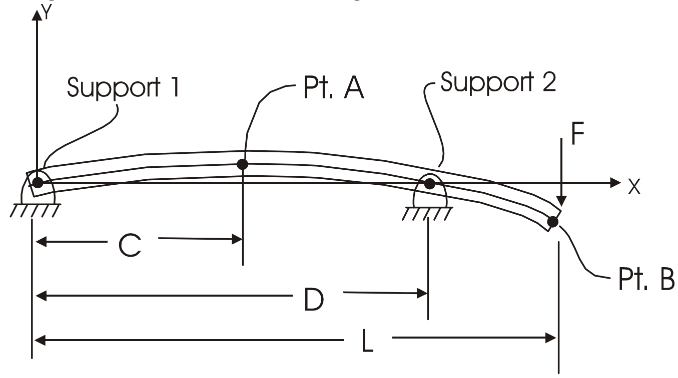
The first phase of the project requires engineering faculty meet with mathematics faculty to determine the specific coverage of the calculus courses as taught locally. Engineering faculty will then take this information and develop a list of topics to address for this project, based on their collective experience of student recall of calculus concepts when first applied in engineering classes. These topics will cover the full range of calculus courses, from differential and integral single variable calculus, through multivariable calculus and elementary differential equations. Some studies have already considered the essential topics in certain engineering fields.[4]

The second phase will involve assigning faculty to develop prototypical material to address the topics identified in the previous phase, and developing a plan to address these topics using a variety of learning styles. The two learning style models primarily used in engineering education studies are the Kolb[5] and Felder/Silverman[6] models. It is still not clear whether addressing specific learning styles with instructional materials improves student learning. However, since learning styles are particularly diverse early in a college student's career, suggestions from "Teaching through the Cycle" will be used to generate a diverse range of approaches in the design of materials produced in this project.[7]

The materials developed through this project will take several forms, including highly formatted handouts for students; worked examples for instructors to adapt to their classes; and web based materials in both interactive and static forms. A brief example of how an engineering topic would be developed into a calculus problem suitable for in-class use in a mathematics class is given in Figure 1. The majority of the development of interactive web-based materials would likely be part of a follow-up project due to the substantial increase in resources required.

FIGURE 1-- Example Problem:

Engineers, in particular mechanical and civil engineers, are often concerned with the way beams bend when a force is applied. The illustration below depicts a beam, of length, L, being used to support a weight, F, at its free end. The beam is supported at two points as indicated. Support 1 is at the end opposite the weight, F, and Support 2 is at a distance, D, from Support 1. Point A is the location of the maximum vertical deflection (+y direction) of the beam, which we are interested in describing. Point A is a distance, C, from Support 1. You might think of this as a diving board, with a diver standing at Point B.



Using beam theory, which is studied by mechanical and civil engineers in solid mechanics courses, it can be shown for this case that the vertical deflection, *y*, at any *x*-location along the beam is given by the equation:

$$y(x)=\frac{FD(L-D)}{6EI}\left[x-\frac{x^3}{D^2}\right]$$

where E is a material property, known as the Young's Modulus, and I is the moment of inertia. I depends on the shape of the beam. After substituting values for the constants (Assume F=6000 N, L=1.1 m, D=1 m, $I=10^{-7}$ m^4, and $E=10^{11}$ N/m^2), the equation for y(x) becomes:

$$y(x)=0.01\left[x-x^3\right]$$

Find the distance, C, and the vertical deflection (*y*) at Point A.

This translates into a local optimization problem in calculus. The slope, *dy/dx*, is zero at Point A since it is a local maximum. Differentiating *y(x)*, and setting *dy/dx* to zero:

$$\frac{dy}{dx}=0.01\left[1-3x^2\right]=0$$

Solving for x, we get:

$$x=C=\frac{1}{\sqrt{3}}=0.5774 \text{ m}$$

Substituting this value for x back into the equation for y(x), we find the vertical deflection at Point A to be 0.00385 m.

It is critical that these materials are developed in consultation and cooperation with the mathematics instructors who have agreed to use them. The integrity of the general calculus course must not be compromised by use of engineering-specific examples. In additional to engineering specific examples, other examples useful to engineers from business and general science will also be developed. For example, economics examples would be relevant to engineering students as well as a wider audience including business majors. Mathematics instructors are not expected to deviate substantially from their normal practices in the course—for example, when a second example of a procedure is to be presented in class, the real-world basis for the applicable equations will be presented and the calculus procedure then performed on those equations.

The third component of this project is the development of continuing education workshops for local high school mathematics teachers. During the second year of this project, a workshop will be held for advanced mathematics instructors from area school systems. They will be given the opportunity to learn why their students are learning calculus, seen in the contexts of science, engineering, economics, and business. Several area high school teachers have indicated a lack of experience with applied calculus and an interest in motivating their students through practical example. It is expected that new calculus instructors would participate in these workshops to better prepare them to be effective teachers by making the course material relevant to their students.

The primary expected outcome is that students taking courses requiring application of calculus concepts would enter the course expecting to use calculus and thus be better prepared to apply advanced mathematics to engineering problems. The success of the project will be assessed using examinations designed to assess preparedness in mathematics at the beginning of courses, and comparing results between current students who have not seen the materials developed in this project and later students who will take the enhanced courses.

Evaluation

The primary means of evaluating the effectiveness of the project will be through examinations administered at the beginning of engineering courses. Twelve engineering courses across two engineering majors have been selected for these evaluations. The courses were selected to obtain a representative sample throughout the student's post-calculus course of study. Exams will be administered starting Spring 2003, prior to integration of the materials produced through this project in the calculus courses, thereby establishing a baseline for comparison with students who will later experience the benefits of this project. The exams will include both in-class and take-home components, designed to examine both conceptual recall and the ability to apply concepts with the aid of reference material. Project success will be indicated by a statistically significant improvement in student performance on exams by students who have taken the enhanced calculus courses compared with those who have not.

Students will be individually tracked, with results correlated with course records indicating what materials from this project were used. This individual tracking will allow for variations in the implementation of the enhanced courses and for examining the role of learning styles on retention.

Summary

This project is intended as a proof-of-concept study with the intent of developing a cost effective means of improving retention of calculus concepts for science and engineering students. The project team intends to continue improvements on this project as part of their routine instructional activities, and to expand the scope of the project as resources permit. Adaptation of new technologies is expected as additional support is obtained to allow for the substantial time commitment required to produce such materials. The vision of the project team includes publishing material for national adaptation, and hosting workshops to assist mathematics instructors at both the high school and college level to motivate students by real-world example without compromising the theoretical basis of the course. Additionally, the role of learning styles is examined in hopes of developing a larger scale experiment to establish the benefit of learning-style centric curriculum design.

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DAVID L. SILVERSTEIN
David L. Silverstein is currently an Assistant Professor of Chemical and Materials Engineering at the University of Kentucky College of Engineering Extended Campus Programs in Paducah. He received his B.S.Ch.E. from the University of Alabama in Tuscaloosa, Alabama; and his M.S. and Ph.D in Chemical Engineering from Vanderbilt University in Nashville, Tennessee, and has been a registered P.E. since 2002. He has over twenty years experience in microcomputer programming, most recently in development of a prototype automatic custom videotape editing and production device. In addition to teaching and research in interfacial phenomena, Dr. Silverstein is developing a computer framework for applying teaching styles to a multimedia computer based supplement to engineering courses.

JOHN R. BAKER
John R. Baker is an Assistant Professor of Mechanical Engineering at the University of Kentucky Extended Campus Program in Paducah, KY. He received his B.S., M.S., and Ph.D. in Mechanical Engineering from the University of Kentucky in Lexington, KY. After obtaining his B.S., he spent three years working in the Plastics Division of Eastman Chemical Products, Inc. He entered his current position in July 2000