AC 2011-586: USING UNDERGRADUATE MENTORS TO DELIVER ENGINEERING CONTENT TO CALCULUS FOR INCREASED PERSISTENCE IN ENGINEERING

J. Neubert, University of North Dakota

Jeremiah Neubert is Assistant Professor in the Department of Mechanical Engineering at the University of North Dakota. He conducted research and taught at Cambridge University. Prior to that Dr. Neubert attended the University of Wisconsin and obtained a Ph.D. in Mechanical Engineering as well as Masters of Science degrees in Computer Science and Mechanical Engineering. During his time at the University of Wisconsin he served as a National Science GK12 fellow where he worked with a team of high school teachers and colleagues at the University of Wisconsin-Madison to develop modules for secondary school educators.

Deborah Worley, University of North Dakota
Naima Kaabouch, Electrical Engineering Department, University of North Dakota

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Abstract

The objective of this work is to increase student retention in engineering by providing a better calculus experience with a minimal amount of institutional change and cost. This will be accomplished by augmenting calculus with *real world* engineering problems. Moreover, the program aims to strengthen students' commitment to their chosen academic department and help them to feel as if they belong to a community. The presented program uses a novel method to deliver the engineering content without the need for significant institutional change. This will allow it to be easily adopted by other institutions.

This paper describes a plan to use modules and mentors as a vehicle to deliver engineering content to engineering students in calculus. The modules will be composed of a series of self contained engineering problems that highlight important calculus concepts. Students will meet in small groups to discuss the modules. The group discussion will be facilitated by upper level engineering students in an effort to facilitate social engagement. Lastly, by using a diverse set of mentors the program will provide a role model for students from underrepresented groups.

The evaluation plan for this project will incorporate a mixed-methods approach to data collection in determining if there is a correlation between engineering retention rates and student success in calculus classes that use problem-based learning modules with peer mentors.

1. Introduction

Despite significant improvements made in engineering education, persistence rates remain less than desirable[1,2]. Some of the most significant factors to persistence in engineering is a student's quantitative skills, both perceived and real, and commitment to engineering[3]. Students that leave engineering to pursue another degree most often cite math/calculus as the most influential factors in their decision[4]. Thus, it should be no surprise that an engineering student's probability of persistence and success is highly correlated to their performance in calculus[5]. In fact, improving student performance in calculus has improved retention and graduations rates[6]. This is particularly true among underrepresented groups who may already lack confidence in their mathematical abilities[7]. Engineering student interest in calculus is increased by augmenting it with *real world* engineering problems[6]. A two pronged approach will be used to deliver this content to the students in the context of this project.

First, we will develop a series of modules to be paired with course content in Calculus I and Calculus II. The modules will demonstrate to students how calculus is applied to solve real world engineering problems. It is important, as educators, to realize that "the mind is not a vessel to be filled, but a fire to be kindled"--Plutarch. So, while engineering students may not be interested in math, they are intrigued by the application of math to problem solving in the field. In this context, emphasizing the importance of calculus to engineers will encourage deeper student learning.

Second, the project fosters student persistence in engineering by developing a mentorship program that will aid in the delivery of the engineering modules. The mentors will be junior and senior engineering students that participate in a workshop on effective mentoring. The mentors

will meet with calculus students in a small group setting on a weekly basis to work through the modules. These meetings will provide the students with real time feedback on their problem solving techniques as well as a glimpse at the methods used by others. The mentors, as peers, will provide contemporary, institution-specific advice on succeeding in calculus that faculty cannot. The mentor relationships will also be used to facilitate early involvement in professional engineering activities, such as those accessed through membership in the American Society of Mechanical Engineers (ASME) and the Institute of Electrical and Electronics Engineers (IEEE). This will strengthen the students ties to engineering making the transition to another major unattractive.

The evaluation plan for this project component centers on implementing an assessment model for evaluating the effectiveness of instructional tools. Additional impact areas for the comprehensive project include student learning and engineering retention rates. Concomitant with existing literature on the evaluation of student learning[8], college student retention[9, 10] and outcomes-based instruction[11, 12], it is important to adopt a multidimensional approach to evaluation and assessment. Thus, the evaluation plan for this project is formative and summative; it also incorporates a mixed-methods approach to data collection and answers the guiding questions as follows: Is there a correlation between student success in calculus classes that use problem-based learning modules with peer mentors? Does the use of peer mentors increase the use and effectiveness of the problem-based learning modules as an instructional tool?

2. Background

There has been a great deal of research focusing on determining the reasons that students choose to leave or fail to thrive in their first year of engineering[3,13]. The most frequently cited obstacles to success is both the real and perceived quantitative skills of incoming students[7,13,14]. This is highlighted by the fact that the most cited reason for leaving engineering is calculus[15]. Student struggles in calculus has lead to a diversity of work on how to improve engineering student persistence and learning in calculus.

A commonly researched method is the creation of a calculus course with significant engineering content used to underscore the applicability of topics covered to solving engineering problems. This can be accomplished through the creation of a separate, specialized calculus course taught by engineers[16], a engineering course that must be taken in conjunction with calculus[6], or a course shared by engineering and mathmatics[17]. Teaching such courses is difficult because many institutions subscribe to the philosophy that only the mathematics department should teach calculus and a lack of policies regarding course sharing. Also, engineering departments, typically, have just enough teaching resources to meet current offerings. An alternative is to produce problem sheets or stand alone modules that the instructor delivers to the students[18,19]. Anecdotal evidence has shown that math professors are adamantly opposed to delivering such content. In a meeting at University of North Dakota only one of fifteen mathematics professors would even consider such a program.

Another method for improving student persistence in calculus includes intervening when poor student performance is observed. The intervention programs have produced reasonable results, but requires the calculus instructor to assess students early and often[4,5]. One program allows students failing at midterm to drop the course and participate in a calculus preparatory course.

This course prepares students for a second attempt at Calculus I[4]. These programs increase the burden on the instructor so implementation requires buy-in from calculus professors.

One of the more effective methods for improving first year student persistence is the use of mentors[20,21]. Mentors are the students' peers and can provide institution specific information about succeeding in engineering that faculty advisors cannot. Moreover, mentors, if selected properly, can be role models for students from underrepresented groups[20]. Additionally, having students meet mentors in small peer groups will allow the students to obtain a better idea of their own levels of self efficacy. A lack of self confidence is a significant factor among students from underrepresented groups[7]. The problem with mentors is getting those most in need to commit to meeting. That is why in this work the mentoring program is tied directly to the calculus course. Student will receive a small amount of course credit for being adequately prepared and attending the small group meetings with the mentors.

3. Our Method

The project will involve augmenting the existing Calculus I and Calculus II courses at the University of North Dakota with engineering content. The courses themselves will remain unchanged. That is, the lecture portion of the course will not be altered. Each week a module will be handed out to engineering students which requires them to use concepts from lecture to solve engineering problems. Each module will be assigned a small amount of points. This could be extra credit or homework points based on the instructor's preference. Students will receive the points for arriving at the mentoring session prepared and participating in the discussion, not the "correctness" of their solutions. The students will be given one week to complete the modules and arrange a group meeting with their mentor.

3.1 Modules

There has been a great deal of evidence that points to augmenting calculus with engineering as being beneficial for engineering students[16,17,18,19]. To deliver this content we propose the development of standalone modules that students can complete with little if any outside help. There will be a total of 30 modules created. This is one module per week for the duration of both Calculus I and Calculus II. Because the modules are self contained they can be easily adopted by other institutions.

The modules will be constructed so that the average student could complete it in one to two hours. They will be composed of one to two pages of background material and approximately one page of problems related to the background. The problems will be inspired by real problems encountered in research or industry. The problems will be taken from all the various engineering disciplines. Utilizing problems selected from each of the engineering disciplines is important because first year engineering students often do not understand the difference between civil, mechanical, electrical and chemical engineering. These problems will help delineate the differences. The modules will emphasize the societal benefits engineers provides to the world. It has been shown that such problems appeal to a diverse group of students[22]. An example problem can be found below.

Example Problem: The objective of this problem is to expose students to one of the applications of integration and trigonometric functions in the energy field.

Rising pollution levels and worrying changes in climate, arising in most part from energy processes, demand the reduction of ever-increasing environmentally damaging emissions. Generating electricity by making use of renewable sources allows the attainment of significant reductions of the pollution levels. Therefore, solar and wind energy assume great importance. A wind energy system, wind turbines, transforms the kinetic (moving) energy of the wind into electrical energy that can be harnessed for practical use. The wind blows through the wind turbines' blades (Fig. 1), which converts the wind's energy into rotational energy to spin magnets in the generator and convert that energy into electrical current. In areas with an excellent wind resource, it can sometimes be more affordable to get new power by building a wind farm than by building a coal, natural gas, or other type of power plant.

Figure 1: Wind Turbines

Calculating the power available from the wind relies on knowledge of basic geometry and physics behind kinetic energy. This power is given as

$$Power = \tfrac{1}{2}\,\rho S V^3$$

Where, ρ represents the density of the air, *S* represents the area swept by the blades, and V represents the velocity of the wind.

If we divide this *Power* by the section S, then

$$Power / S = \tfrac{1}{2}\,\rho V^3$$

depends only on the velocity of the wind and the density of the air. This last expression, Power/S, is called Wind Power Density (WPD) and has units of watts/m^2.

The energy generated from the wind during the interval [0, t] is given by

$$Energy = \int_0^t Power\ dt$$

a) Assuming ρ= 1.225 kg/m^3 and a wind blowing with a constant velocity **V** of 10 m/s through the blades, calculate the Wind Power Density.

b) How does the WPD change if the velocity of the wind is 5 times higher?

c) Assuming the blades have a radius of 7m and the velocity of wind is $v(t) = 5.5 + 2.7\sin(0.01t)$ m/s, calculate the power and derive the energy generated from the wind for one hour.

3.2 Discussion Groups

The most significant obstacle to augmenting calculus with engineering content is having sufficient support for both the mathematics and engineering. As stated above the lecture portion of the calculus will remain unchanged and will be taught by a mathematics professor. The engineering content will be supported using mentor led discussion groups. Junior or senior level engineering students will be hired as mentors. This eliminates the need to alter departmental responsibilities or negotiate a complex course sharing agreement.

The main objective of the discussion groups is to provide students with real-time feedback in a risk free environment. Typically, students complete homework assignments, often alone, and turn them in only to receive feedback days later. The feedback may not even provide insight into process errors and has a cost with respect to the student's grade. An alternative that will be used in this work is based on the system used at Cambridge University in the United Kingdom. The system supports students discussing their homework in small groups with a mentor. Students are only penalized if they fail to attend the mentoring sessions or are not prepared.

For each exercise contained in the modules a student is selected by the mentor to share the process for solving it. The other students are encouraged to comment in a positive manner and ask questions as they go through the process. The discussion, guided by the mentor, will lead to students finding the most efficient, correct method for solving the problem. Also by sharing their work and discussing it with others they achieve a deeper understanding of the material and learn about technical communication. Students also obtain a better estimate of their quantitative abilities with respect to their peers. This is especially important for underrepresented groups in engineering who may lack confidence in their quantitative abilities.

Mentors: The objective of the mentors will be providing support for the engineering content, facilitating group discussions, aiding students in being successful during their first year in engineering, and making students aware of opportunities inside of engineering such as the student chapters of the Institute of Electrical and Electronics Engineers and American Society of Mechanical Engineers. Mentor selection will be done to ensure a diverse group of mentors. This is important as matching underrepresented students to appropriate mentors is beneficial to retention and alleviating feelings of isolation[20,21].

Mentors will attend a one day training session. In this session they will learn about what resources are available to students on campus. This will include student groups for various underrepresented groups and engineering organizations. They will also be provided with some training on how to facilitate active learning, recognize learning difficulties, and connect students with learning problems to the appropriate resources. The training will also cover how to facilitate a positive discussion and deal with common issues that may arise in group discussions.

Group Formation: The discussion groups will consist of three-to-four students and a mentor. The groups will be selected using Team Maker[23]. This software allows student groups to be matched using a variety of criteria. Effort will be made to ensure that students from underrepresented groups are not outnumbered in their discussion group by traditional engineering students. Additionally, student schedules and majors will be matched. It is hoped that by creating groups of students with similar backgrounds and schedules will increase the likelihood they meet outside of the mentoring sessions. This will allow the study groups to

become a support system for students that will carry them through their remaining years in engineering.

4. Evaluation

The plan for evaluation concerns the adoption of two specific instructional tools, modules and mentors, into the course itself. In doing so, it is expected that changes in course curriculum and delivery may result. Project evaluation efforts will rely on observation from internal and external reviewers, student satisfaction surveys and focus groups, and structured record review of student success in the module lessons (mentor session performance indicators as a formative assessment vehicle) as well as in the overall course (course performance indicators as a summative assessment vehicle). Table 1 outlines the plan for evaluating these instructional tools, and aligns the evaluation goals, outcomes, assessment vehicles, and performance indicators.

Table 1: *Evaluating Instructional Tools*

	Evaluation Goals	**Outcomes**	**Assessment Vehicles**	**Performance Indicators**
Instructional Tools	Implement modules and mentor-led discussion	Changes in course curriculum and delivery	1. Structured record review of student success artifacts 2. Observation 3. Satisfaction survey 4. Focus groups	1. Mentor session progress reports (formative) 2. Course grades (summative) 3. Recommendations to use modules and mentors

This project component seeks to determine if 1) there is a correlation between student success in calculus classes that use problem-based learning modules with peer mentors and 2) the use of peer mentors increases the use and effectiveness of problem-based learning modules as an instructional tool. Responding to this question will aid in meeting four overarching project evaluation goals: (1) assess student learning of engineering-specific calculus concepts; (2) assess student comfort levels with engineering-specific calculus concepts; (3) compare engineering retention rates of students enrolled in the engineering-specific calculus course and those who were not enrolled; (4) implement problem-based learning (PBL) modules and mentor-led discussion as teaching tools. Table 2 illustrates the alignment between evaluation goals, outcomes, assessment vehicles, and performance indicators for all project components, highlighting how the evaluation of using mentors completes the comprehensive project evaluation plan.

Table 2: ***Comprehensive Project Evaluation Plan***

	Evaluation Goals	Outcomes	Assessment Vehicles	Performance Indicators
Student Learning	1. Assess student learning	1. Changes in students' knowledge levels	1.1. Surveys 1.2. Pre-post module quizzes	1.1 Calculus knowledge 1.2 Growth on pre-post module quizzes
Engineering Retention Rates	2. Assess student comfort levels 3. Compare engineering retention rates	2. Changes in students' comfort levels 3. Differences in engineering retention rates and enrollment	2.1. Survey 2.2. Pre-post module student focus groups and interviews 3. Structured record review	2.1. Calculus comfort 2.2 Growth expressed through focus groups and interviews 3.1. Improved engineering retention rates (continued student enrollment)
Instructional Tools	4. Implement modules and mentor-led discussion	4. Changes in course curriculum and delivery	4.1. Structured record review of student success artifacts 4.2. Observation 4.3. Satisfaction survey 4.4. Focus groups	4.1. Mentor session progress reports (formative) 4.2. Course grades (summative) 4.3. Recommendations to use modules and mentors

5. Conclusion

Addressing engineering student success in calculus is not a trivial issue. This paper presents a method aimed at fostering deeper learning in calculus among engineering students without requiring changes in the current calculus curriculum. In addition, the alterations presented are engineered to be easily implemented at any institution and can be used by any science, technology, engineering, and mathematics (STEM) department that positions calculus as a prerequisite to specific disciplinary content.

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