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CCLI: Evaluation of a Cost Effective Program for Augmenting Calculus with Engineering Content

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Abstract

Engineering educators have been working to increase student persistence by improving the calculus experience. This has primarily taken the form of augmenting calculus with engineering content. Data indicates that these programs have a real and positive impact on student learning and persistence in engineering. Despite the success of such programs, institutional obstacles have slowed their export. An alternative method for augmenting calculus with engineering content utilizes modules and mentors to limit obstacles to adoption. This paper presents data collected on the impact of the modules and mentors on student learning, self-efficacy, and connectedness to engineering. The data collected through surveys, focus groups, and a structured record review show that the program positively impacts students in each area of interest.

Introduction

Despite significant improvements made in engineering education, student persistence remains an issue[1]. The most significant barriers are a lack of quantitative skills (both perceived and real), poor study habits, and a lack of commitment to engineering as an academic major[2,3,4,5]. Students who leave engineering to pursue a different degree most often cite struggling with mathematics, specifically calculus, as the most influential factor in their decision[5,6]. In an effort to increase student retention, researchers work to improve the overall student experience in calculus. Much of this work has focused on augmenting calculus problems with engineering content[5,7,8,9].

The difficulty with augmenting calculus with engineering content is that Mathematics professors are not comfortable with delivering such content. This situation has led some institutions to create specialized engineering courses team taught by Mathematics and Engineering professors[8] or only by Engineering professors[7]. Both methods have been successfully implemented and have had a positive impact on student retention, but none enjoy widespread adoption. The main obstacle to adoption of such programs is a lack of the institutional mechanisms needed to team teach a course, and a resistance to allowing engineers to teach calculus. While some institutions have had success introducing engineering calculus courses, the inclusion of engineering applications may come at the expense of a general in-depth understanding of calculus topics if care is not taken by instructors.

An alternative approach is to pair calculus courses with a required engineering-based companion course[9,10]. This eliminates the issues raised above, but concerns still remain. First, adding a credit-bearing course to an existing engineering curriculum is difficult because there is little room for additional credits. Second, it is not uncommon for sections of the same calculus course to differ in pace and in the order of concepts covered, making it difficult to align the companion course content with a given calculus course. Lastly, student performance in paired courses is highly correlated; thus, paired courses put students at risk—poor performance in multiple courses will impact students' financial aid and/or academic status.

J. Neubert et al.[11] presented a low-cost, easily implemented method for augmenting Calculus I and II with Engineering content through the use of modules and peer mentors. The program eliminated the need for a significant time commitment from engineering faculty, institutional changes or modifications of existing calculus curriculum. The objective of this paper is to evaluate the impact of the program on student learning, self-efficacy, and student connectedness to engineering. The impact was measured using data gathered through a structured record review, student surveys, and focus groups. Presentation of the collected data is followed with a discussion of its meaning and suggestions for improving the program.

Augmenting Calculus with Engineering Content

The stated objective of the program presented by J. Neubert et al.[11] was to increase student persistence and improve student learning by augmenting calculus with engineering content in a way that does not require institutional change or significant cost increases. The authors propose accomplishing this by employing a set of 16 modules, eight for Calculus I and eight for Calculus II, that illustrate the importance of calculus concepts in solving real world engineering problems. The engineering content of the modules was delivered by peer mentors. The modules and mentors allow the changes to the existing calculus curriculum to be minimized. This limited change and cost of the program makes it relatively easy to implement at any institution. A brief summary of the program is provided below.

Modules

Each module contains two real world engineering problems that can be solved using concepts from calculus. The problems appeal to a broad, diverse group of students. Specifically, the problems emphasize the ways in which engineers improve society in a direct and observable way. These topics include how engineers are improving living conditions in underdeveloped countries, and creating the technology needed to generate inexpensive, green energy.

The module problems are constructed so that students with no engineering background can solve them. Each begins with a brief description of the problem and the background information needed to solve it, followed by two to five questions that guide students though the problem solving process. It is important to note that the questions not only help the students find the mathematical solution to the problem, but also often ask them to think more deeply about the solution. For example, students may find that a structure is not designed correctly and are then asked how it could be changed to meet the desired design specifications. This process requires them to not only solve the equation, but they must also understand its meaning and know how to manipulate it. An example problem from one of the modules is provided in Fig. 1; the module problem sets can be obtained via the project website[12].

Search and Rescue Unmanned Aerial Vehicle

Unmanned aerial vehicles (UAVs), such as the one shown in Figure 3(a), are becoming less expensive and easier to use. This makes them ideal for search and rescue operations. The ACME company makes a UAV that can be deployed by hand that automatically flies a spiral search pattern like the one depicted in Figure 1(b). This pattern maintains a half-mile distance between passes to guarantee the plane will pass within a quarter mile of any person in the search area.

The path of the plane is described by the equations

$$x(s) = 0.5s\cos(2\pi s)$$

and

$$y(s) = 0.5s\sin(2\pi s),$$

where x and y represent the coordinates of the UAV and are expressed in miles. The parameter s has no physical meaning, but is used to delineate where the plane is on the curve.

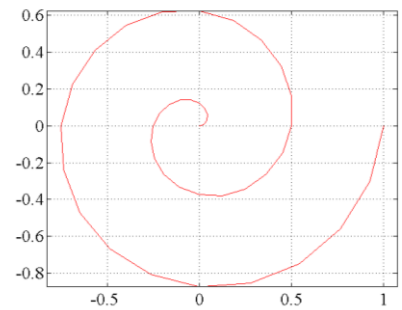
The plane can fly 15 miles of the spiral before it must return to refuel.

The distance travelled by the UAV for any given value of t is given as

$$L = \int_0^t \sqrt{\left(\frac{dx}{ds}\right)^2 + \left(\frac{dy}{ds}\right)^2}\, ds$$

1) *Find the equation of the distance travelled by the UAV at any point t.*
2) *What is the value of s when the plane has gone 15 miles?*
3) *Assuming the total range of the plane is 17.5 miles. Can the plane make it back to the landing strip at the origin of the spiral? Neglect the radius of the plane's turns. Only the straight line distance needs to be considered.*

(a)



(b)

Figure 1: Unmanned Aerial Vehicles, such as the one shown in (a), are playing an increasing role in search and rescue. The desired search path is shown in (b).

Figure 1: An example module problem.

Mentors

Peer mentors delivered the engineering content used to connect students to engineering, and provided general guidance to students on how to successfully navigate the engineering curriculum. The mentors were a diverse group of junior and senior level engineering students who received grades of "B" or better in each class in their calculus sequence. In addition, the mentors displayed high levels of social skills and involvement in engineering student groups.

Prior to meeting with students enrolled in calculus courses, the mentors received 3-4 hours of training. The training session prepared mentors to interact with students in a positive manner and provided them with the necessary tools to facilitate discussions on the modules.

Program participants were placed in groups of 3 to 5 individuals. Each group met with a mentor biweekly. At each meeting the students took turns presenting their solutions to the problems contained in the modules while the mentor facilitated discussions on important points. The meetings encouraged deeper learning by providing an opportunity for the students to discuss calculus topics and their application. Students were also given a better idea of their own levels of self-efficacy by observing their peers' solution processes and struggles.

In addition to discussing the modules, the mentors were asked to talk with students about getting involved in engineering student groups and successfully navigating the engineering curriculum. Peer mentors are a great mechanism for making students aware of resources available inside the engineering departments such as the Society of Women Engineers and the Society of Automotive Engineers Formula One Car team. Moreover, peer mentors provided guidance as to how to be successful in engineering by advising students about the best study habits and alerting them about common obstacles that they may encounter[13,14].

Method

For the purposes of this study, students were recruited into the program during the fall 2011 and the spring 2012 semesters. The recruiting process involved a ten-minute presentation by an engineering faculty member in approximately five Calculus I classrooms and three Calculus II classrooms at the beginning each semester. The presentation provided a brief description of the program and emphasized that it was voluntary. Participation was encouraged through the offer of up to five percent extra credit in the calculus course. To receive full credit, students needed to attempt the modules and attend seven of the eight discussion sessions. The amount of extra credit was scaled down proportionally based on their participation.

Both online and paper surveys were used to gather data on students' experiences in the program. Completing the surveys was optional and had no effect on the amount of extra credit a student was awarded. The *Modules and Mentors (MM) Survey*, was administered to Calculus I and Calculus II students that participated in the discussion at the end of the fall 2011 and spring 2012 semesters, after all the mentor-led study sessions were completed (n=51). Within this population, 28 Calculus I students participated in the program, and 23 Calculus II students participated in the program. This survey was designed to learn about students' experiences in their calculus classes related to the engineering concept problems and working with their engineering peer mentors. There were 18 total questions on the survey, nine of which concerned students' feedback on working with the peer mentors and their interactions with other students in the peer-led study sessions. In addition, participants responded to questions that focused on their self-reported comfort and confidence levels with calculus, as well as on connecting calculus knowledge to the study of engineering.

Results

Approximately 86.5% of the students who responded to the survey attended all of the mentor-led study sessions. The majority of students (88.2%) were motivated to attend by the opportunity to "earn extra homework points" for class. Many respondents (62.7%) indicated that they attended to "learn how calculus is used to solve engineering problems". Nine students (17.6%) students noted that they preferred to learn in a group setting; only three students indicated their reason for attending was to "get to know [their] classmates better".

The results of the content-based questions on the *Modules and Mentors Survey* are organized into sections that correspond to stated objectives of the study: to evaluate the impact of our program on learning, self-efficacy, and connectedness to engineering for students who participated in the engineering peer mentor-led calculus study sessions.

Student Learning

There are two separate categories in which perceptions of impact on student learning were measured: 1) working with the peer mentor and 2) using the module problems to learn calculus. As previously stated, the peer mentor led each study session and facilitated group work toward exploring and finding solutions to the engineering-related calculus problems. Participating students felt that working with the engineering peer mentor was "helpful" (37.3%), "very helpful" (25.5%), or "extremely helpful" (17.6%) in learning calculus (see Table 1).

Table 1
Student Perceptions of Helpfulness of Working with an Engineering Peer Mentor to Learning Calculus

	%
Not at all helpful	2.0
Somewhat helpful	17.6
Helpful	37.3
Very helpful	25.5
Extremely helpful	17.6

The subject matter of the module problems varied from Calculus I to Calculus II. Thus, two separate versions of the Modules and Mentors survey section pertaining to the module problems were used. In Calculus I, students preferred the module problems that focused on rocket acceleration (60.7%), low orbit satellites (57.1%), wind turbines (50.0%), and green energy (50.0%) (see Table 2). In Calculus II, students slightly preferred the module problems that focused on unmanned aerial vehicles (56.5%), wind turbines (52.2%), and aircraft systems composites (52.2%) (see Table 3). In combination, Calculus I and Calculus II students reported that they felt that the engineering problems were "somewhat helpful" (23.5%), "helpful" (45.1%), "very helpful" (19.6%), and "extremely helpful" (7.8%) in learning calculus (see Table 4).

Table 2
Calculus I Student Preference for Module Problems

	Did not prefer % (n)	Neutral % (n)	Preferred % (n)
Flood control	3.6(1)	50.0(14)	46.4(13)
Plastic production (making chairs)	7.1(2)	71.4(20)	21.4(6)
Shuttle arm motion	7.1(2)	46.4(13)	46.4(13)
Wind turbine: Angle of attack	3.6(1)	46.4(13)	50.0(14)
The Haitian crisis (clean drinking water)	7.1(2)	57.1(16)	35.7(10)
Saturn V rocket acceleration	3.6(1)	35.7(10)	60.7(17)
Low orbit satellites	7.1(2)	35.7(10)	57.1(16)
Diffusion bonding	17.9(5)	53.6(15)	28.6(8)
DARPA challenge and autonomous vehicles	7.1(2)	46.4(13)	46.4(14)
Electromagnets	14.3(4)	53.6(15)	32.1(9)
Gel electromorphesis image analysis	14.3(4)	53.6(15)	32.1(9)
Portable devices: Resistors	7.1(2)	64.3(18)	28.6(8)
Diabetes and foot ulcers	17.9(5)	53.6(15)	25.0(7)
Green energy: Greenhouse gas emissions	0.0(0)	50.0(14)	50.0(14)
Wind energy	3.6(1)	53.6(15)	39.3(11)
Aircraft and rivets	17.9(5)	35.7(10)	46.4(13)

Table 3
Calculus II Student Preference for Module Problems

	Did not prefer % (n)	Neutral % (n)	Preferred % (n)
Tumor growth	13.0(3)	65.2(15)	21.7(5)
Aircraft systems composites	0.0(0)	47.7(11)	52.2(12)
Pacemakers	4.3(1)	69.6(16)	26.1(6)
Renewable power investment	0.0(0)	60.9(14)	39.1(9)
Prosthetic arm	13.0(3)	60.9(14)	26.1(6)
Wind turbines	0.0(0)	47.8(11)	52.2(12)
Collision avoidance and smart vehicles	0.0(0)	65.2(15)	34.8(8)
Water for Malawi	8.7(2)	56.5(13)	34.8(8)
River flooding	13.0(3)	56.5(13)	30.4(7)
Unmanned aerial vehicles (UAVs)	4.3(1)	39.1(9)	56.5(13)
Robots for rehabilitation	4.3(1)	52.2(12)	43.5(10)
UAV parameterization	4.3(1)	52.2(12)	43.5(10)
Microscope design	0.0(0)	69.6(16)	30.4(7)
Collision avoidance model	8.7(2)	65.2(15)	26.1(6)

Table 4
Student Perceptions of Helpfulness of Module Problems in Learning Calculus

	%
Not at all helpful	3.9
Somewhat helpful	23.5
Helpful	45.1
Very helpful	19.6
Extremely helpful	7.8

Self-Efficacy

Approximately half of the students were “confident” (56.9%) in their mathematical abilities following completion of their participation in the mentor-led study sessions (see Table 5). Concerning their confidence in engineering subject matter, 31.4% of students felt confident in their ability to succeed in engineering (see Table 6). Table 7 further illustrates students’ comfort and confidence levels in using calculus to solve engineering problems. Table 8 highlights perceptions of using calculus to solve engineering problems, specifically concerning the frequency with which students felt calculus was necessary to solve engineering problems. Responses to this question indicate that the majority of participants felt that calculus was “sometimes” (54.9%) or “always” (43.1%) required to solve engineering problems.

Table 5
Self-reported Student Confidence Levels in Mathematical Abilities

	%
Not at all confident	0.0
Somewhat confident	15.7
Confident	56.9
Very confident	17.6
Extremely confident	9.8

Table 6
Self-reported Student Confidence Levels in Engineering

	%
Not at all confident	7.9
Somewhat confident	17.6
Confident	31.4
Very confident	27.5
Extremely confident	11.8

Note: There were two nonresponses to this question

Table 7
Student Comfort Levels in Using Calculus to Solve Engineering Problems

	%
Not at all comfortable	0.0
Somewhat comfortable	31.4
Comfortable	49.0
Very comfortable	15.7
Extremely comfortable	3.9

Table 8
Student Perceptions of Using Calculus to Solve Engineering Problems

	%
I do not see the connection between calculus and engineering	2.0
Calculus is sometimes used to solve engineering problems	54.9
Calculus is always used to solve engineering problems	43.1

Student Connectedness to Engineering

In the fall 2011 and spring 2012 semesters combined, participating students felt "somewhat connected" (52.9%) or "connected" (33.3%) to other students in math and engineering after taking Calculus I or Calculus II and participating in the mentor-led study sessions (see Table 9).

Table 9
Student Perceptions of Connectedness to Other Students in Math and Engineering

	%
Not at all connected	5.9
Somewhat connected	52.9
Connected	33.3
Very connected	3.9
Extremely connected	3.9

Discussion

Overall, preliminary results indicate that modules were an effective method for augmenting calculus with engineering content and that students benefit from participating in the program. The use of modules and mentors increased student interest in calculus without having to modify existing calculus courses. Moreover, students enjoyed the modules and were better prepared for success in calculus after participating in the discussion sessions. Students also felt that the discussions with their peers were beneficial and helped them feel connected to engineering.

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