AC 2005-630: DEVELOPMENT OF A TARGETED ENGINEERING APPLICATION COURSE TO IMPROVE RETENTION

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Development of a targeted engineering application course to improve retention

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Abstract – At our institution not quite a quarter of our entering freshmen who plan to study engineering are calculus ready. As a result, the entry of some of these students into core engineering courses is being delayed by over a year. This delay is a contributing factor in the poor retention of freshman engineering students at our school. Another difficulty we face is that many students entering their core engineering classes are not retaining important mathematical concepts from their prior algebra and trigonometry coursework. To address both of these issues, we propose a one-semester pilot course involving engineering applications and experiments to be offered concurrently with college algebra and trigonometry at our institution. The purpose of this course is to have these potential engineering students use the mathematical skills they are currently learning and apply them to engineering problems. This paper will discuss the development of this course in conjunction with our mathematics department. Ultimately it is anticipated that this course will allow us to retain capable engineering students who may otherwise become disenchanted with their delayed access to engineering courses plus will give them better skills for their upper division classes.

Introduction

Engineering education over the next decade provides numerous challenges. One of the biggest of these is the retention of engineering students. Our Programs at the College of Engineering and Applied Science (CEAS) at the University of Wisconsin-Milwaukee (UWM), like so many others throughout the country, are based on the assumption that incoming freshman students are calculus ready upon arrival. Unfortunately, this has become the exception instead of the rule. As a result, a majority of our students must complete the prerequisite mathematics courses prior to entering into the traditional first-year engineering curriculum. Since so many of the engineering courses have calculus prerequisites, these students often find that they will reach a point at which they cannot take any other classes until they complete the calculus series. Some of these students, who were initially excited about engineering upon arrival, become disenchanted and give up their dreams of becoming engineers. Many of those who do persevere obtain only a superficial understanding of the material; they look at each exam and each class as a hurdle that they have to clear to move on. It has been our experience that engineering students are more attentive in mathematically challenging engineering classes if we give them practical applications. When this approach is used, students tend to grasp the concepts more deeply, and retain the material longer. We hypothesize that the same results would be true if this approach were applied to the teaching of key mathematical concepts in the preparatory pre-calculus courses. In this paper we describe a one-semester pilot course involving engineering applications and experiments to be offered concurrently with college algebra and trigonometry in order to increase student retention of key mathematical concepts and methods, as well as the retention of students in the College.

Background Information

UWM is located in the city of Milwaukee and has 21,000 undergraduate students, over 1500 of whom are in the College of Engineering and Applied Science (CEAS). Due to its urban location, UWM also attracts a large number of nontraditional students. Most of our students work part-time and 30% of our students work full time. Like many other urban-13 schools, our admission standards are fairly low (top half of graduating class or ACT score of at least 21) in order to provide initial access to disadvantaged students. As a result, many of the incoming freshman engineering students do not have the background of traditional engineering students. This lack of background is demonstrated by the poor performance of incoming freshman engineering students on our Math Placement Test. The initial math placement of freshman students at UWM (2001-2004) who intend to major in engineering is provided in Table 1. Not quite a quarter of incoming freshman engineering students are ready for the traditional three-semester calculus series. The majority of our students (42%) test either into college algebra and/or trigonometry or the four-semester calculus series (college algebra, trigonometry, and the first semester of calculus are covered in two semesters, followed by the final two semesters of the traditional calculus series). Just under a third of our students begin at the intermediate algebra level and 5% begin at levels below intermediate algebra.

Calculus (3 Semester)	Calculus (4 Semester) or College Algebra + Trigonometry	Intermediate Algebra	< Intermediate Algebra
23%	42%	30%	5%

Table 1. Initial Math Placement CEAS freshman at UWM (Fall 2001- Fall 2004) [1]

One of the problems associated with having low admission standards is poor student retention. Table 2 gives the retention of freshman CEAS students over a seven-year period as a function of high school ranking. It also tracks the retention of underrepresented minority students. It should be noted that while high school ranking is a major predictor in determining which students reach junior status, it does not appear to be a predictor of their graduation rate once junior status is reached (~ 50% graduation rate for Top 25%, 2nd 25%, and Underrepresented Minorities). Table 3 presents the one-year retention rates of our students. We currently lose approximately a quarter of our students during the first year and almost another fifth by the time the students reach junior status.

In a recent study of the mathematical background of 287 of our CEAS graduates during the two-year period (Summer 02 – Spring 04), we found a strong correlation between performance in intermediate algebra, college algebra, and trigonometry, and final engineering degree GPA, as shown in Table 4 [2]. Students' performance in the first calculus class and in differential equations was found to be much a better indicator of future success of engineering students than performance in the second and third semesters of calculus [2]. Similar trends were seen in a previous four-year study involving only electrical engineering majors [3]. Table 5 provides a look at the graduation rate of students who began at UWM as freshmen as a function of initial mathematics placement. It should be noted that although 14.1% of those starting in intermediate algebra graduated, only two students who began at a level prior to that graduated (both were CS majors).

Group	Entering Students	Achieved Jr. Status	Graduated (CEAS)	Graduated (Other)	Still Enrolled Jr/Sr(CEAS)	Still Enrolled Jr/Sr (Other)
Top 25% H.S.	141	100 (70.9%)	47 (33.3%)	33 (23.4%)	3 (2.7%)	1 (0.7%)
2nd 25% H.S.	155	80 (51.6%)	41 (26.5%)	23 (14.8%)	3 (1.9%)	1 (0.6%)
Bot. 50% H.S.	84	34 (40.5%)	10 (11.9%)	9 (10.7%)	5 (6.0%)	2 (2.4%)
Unknown	29	17 (58.6%)	7 (24.1%)	6 (20.7%)	0	2 (6.9%)
Total	409	231 (56.5%)	105 (25.7%)	71 (17.4%)	11 (2.7%)	6 (1.5%)
Underrep. Minority	49	18 (36.7%)	9 (18.4%)	3 (6.1%)	0	1 (2.0%)

Table 2. Seven-year Retention of UWM Freshman Engineering Students entering Fall 1996 and Fall 1997 [1])

	Top 25% H.S.	2nd 25% H.S.	Bot. 50% H.S.	Unknown	Total(561)	Underrep. Minority
Initial	166	222	117	56	561	65
After 1 yr.	135 (81.3%)	173 (77.9%)	75 (64.1%)	39 (69.6%)	422 (75.2%)	48 (73.8%)

Table 3. One-year Retention of UWM Freshman Engineering Students entering Fall 2002 and Fall 2003 [1])

Retention Issues

Like many schools, we have been looking for ways to improve retention of our freshman engineering students. Unfortunately, a majority of students are not calculus-ready upon admission. Many top programs in the country simply do not admit these students. This type of admissions policy adversely affects underrepresented minority groups. The numbers in Table 2 suggest that if a student reaches junior status, the probability of graduating with an engineering degree is approximately the same for underrepresented minorities as for those who graduated in the top 25% or the second 25% of their high-school graduating class. Since the biggest academic obstacle in obtaining junior status in engineering is the successful completion of the entire mathematics sequence, strengthening mathematics preparation appears to be a logical step in the overall improvement of student retention.

Course (Overall # Students)	Criteria	Mean GPA if Criteria met	Mean GPA Criteria not met (# students)
Intermediate algebra	Grade of B or better before advancing	3.017	2.600 (10)
College algebra	Grade of B- or better before advancing	3.078	2.685 (40)
Trigonometry	Grade of B- or better before advancing	3.071	2.612 (30)
Calculus I	C or better	2.998	2.631 (13)
Calculus II	C or better	3.007	2.972 (11)
Calculus III	C or better	3.029	2.768 (27)
Analytical Methods in Engineering	C or better	3.067	2.695 (20)

Table 4. Relative importance of specific math courses to engineering graduates [2].

Calculus (3 Semester)	Calculus (4 Semester) or College Algebra + Trigonometry	Intermediate Algebra	Before Intermediate Algebra*
38.3%	46.1%	14.1%	1.5%

Table 5. Graduation Rate of graduates as a function of initial math placement who began at UWM as freshman (Summer 2002- Spring 2004) [2] (* CS Majors)

Comparing the numbers in Table 5 and Table 1, students entering the College calculus-ready graduate at a greater rate than those who do not (23% freshman class, 38% of graduates). Students entering the College who took college algebra and trigonometry prior to calculus, or who took the four-semester calculus series which contains college algebra and trigonometry, graduated at a rate consistent with the size of their constituency (42% freshman class, 46% of graduates). Students in the intermediate algebra group did not fare as well (30% freshman class, 14% of graduates). We found that these students did much better if they took college algebra and trigonometry *separately,* followed by the traditional three-semester calculus series; rather than taking the four-semester calculus series. As a result, engineering students are no longer being advised to take the 4-semester calculus series at our institution unless they have very minor algebra/trigonometry deficiencies.

Another problem we are seeing relates to long-term learning. The first two years of the engineering curriculum is made up of a series of math and science classes which provide the foundation for the upper division classes that follow. Here, important concepts and techniques are learned which will be needed in future classes. Unfortunately, many students arrive at the university with poor study skills. These students equate studying to memorizing, and they attempt to survive the engineering curriculum by memorizing the appropriate "formula in the blue box" that is given in the text book, or they try to mimic examples provided. These habits have the detrimental effect of allowing students to just get by in their classes without truly understanding the underlying concepts. Although this may get them through a particular class, their understanding is very superficial and they do not retain the information in the long term. As a result, these students often have difficulty in their upper division engineering classes.

Pilot Course

As an initial attempt to improve student retention of information, as well as the retention of students at our institution, we are proposing a one credit pilot course to begin in Fall 2005 for students who have an intended major in engineering and who are concurrently enrolled in college algebra and trigonometry. This will help those students who are initially placed in these classes, as well as those who successfully complete intermediate algebra. Placing the pilot course at this level will allow us to reach most of the underrepresented minority engineering students as well.

The pilot course will introduce these students to engineering problems which use the mathematical techniques that they are learning in their college algebra and trigonometry classes. This will allow students to understand the importance of the mathematical techniques and concepts that they are learning in their other classes, and will provide an important introduction to solving practical engineering applications. The goals of this course will be:

1. Give students entering calculus a much better level of understanding of prerequisite material
2. Give students practical hands-on engineering examples that directly correspond to what they are currently learning in college algebra and trigonometry, providing a *reason* for really learning the material they are currently covering.
3. Allow students to make a connection between areas of math and science and engineering
4. Emphasize the importance of long-term learning instead of memorization
5. Emphasize Mathematical concepts and Skills important for engineers
6. Introduce engineering problem solving techniques at an early stage, including elementary design problems
7. Introduce students to the concepts of using approximation and making reasonable assumptions

Enrollment in this initial pilot course will be limited to the first 30 students who must concurrently enroll in both college algebra and trigonometry. The control for this pilot study will be the remaining students who are enrolled in both college algebra and trigonometry, but who are not in this pilot course. The relative performance of these initial 30 students will also be followed as they complete the calculus series.

Each topic that is covered in the pilot class will attempt to emphasize the mathematical concepts introduced in their college algebra and trigonometry classes. The topics in the pilot class will run in parallel with the material taught in college algebra and trigonometry. Most of the topics will include a practical engineering problem which will help improve student comprehension and emphasize the importance of the topic [4], including elements of design, when possible. Associated with each problem will be a lab experiment or demonstration. Students will be expected to complete a lab report or written assignment for each of these activities. Part of the following class will be devoted to class discussion to reiterate the main points from the previous week's experiment or demonstration.

Planned Experiments

We propose the following outline of engineering applications in the pilot course to complement the syllabi in college algebra and trigonometry. We will use a combination of demonstrations and experiments to engage students in the applications as listed in Table 6.

Math Topic	**Application in Pilot Course**
Trigonometry	Determination of the height of buildings, antennae, and trees. Determination of slope of hills and roads.
Analytic Geometry	Properties of Parabolic Mirrors. Approximation of the quantity of materials in regions of arbitrary shape, such as the excavation and fill required to grade a site.
Polar Coordinates	Kinematics of a Slider-Crank Mechanism. Determination of the length of cable drawn through belt and pulley systems, including cases with non-uniform radii of rollers.
Exponential Functions	Newton's Law of Cooling. Battery Charging.
Systems of Linear Equations	Determination of Current in Simple Circuits. Determination of Forces in Simple Structures.

Table 6. Outline of Engineering applications in pilot course

As an example, we elaborate on the experiment that involves Newton's Law of Cooling, which corresponds to the study of exponential functions. Students will be given several cups filled with hot water, varying in insulating properties and sizes. In small groups, students will be asked to:

1. Record and plot the water temperature as a function of time
2. Obtain an appropriate mathematical model (exponential) representing their data
3. Determine the time constant associated with their data
4. Obtain additional information from the data (steady-state temperature, etc.)
5. Design a water heater for a home that will cool no more than 3 ^{o}C in 1 hour if turned off.

As exemplified by the Newton's Law of Cooling Experiment, each exercise will include a large component of data collection and reasonably straight-forward analysis. This will allow students to master the essentials of the related mathematical topics without the distraction of open-ended questions. However, a key feature that characterizes engineering is the imperative to *design,* in which the questions *are* open-ended. An introductory course that exposes students to actual *engineering* problems should therefore introduce students to solving design problems that require creativity and independent investigation beyond the rote application of mathematical calculation. For example, in the Newton's Law of Cooling Experiment, students must first discover and answer some unstated questions, such as "how large should a home water heater be in the first place?" In addition, they will have to make reasonable assumptions and estimates that will allow them to extrapolate information from the empirical data that they collected with the smaller cups. While we understand that design is increasingly being incorporated in elementary engineering courses, we believe that design is still typically excluded from elementary courses, especially for students at the pre-calculus level. The incorporation of design in the pilot course definitely represents an innovation in engineering education at our campus.

We also note that a general theme in the pilot course, independent of particular topic, will be developing mathematical literacy through learning the grammar of mathematical statements and equations. We have discovered that in addition to having trouble with specific calculation techniques, students often have difficulty conceiving of a well-defined mathematical statement that will then allow them to properly execute calculations. For example, students often ignore the physical units in their problem-solving. Even most textbooks typically neglect to emphasize the importance dimensional balance. Yet paying true and repeated attention to physical units will enable students to absorb the meaning of the underlying physics in the problems that they solve, and will have the practical use of assisting students in identifying errors in calculations by examining whether their statements (e.g. equations and expressions) are dimensionally balanced. The determination of the time constant in the Newton's Law of Cooling Experiment is an excellent example that will engage students in the concept of dimensional balance. Further discussion of the incorporation of teaching elementary dimensional balance is found in [5].

Another general area that causes trouble to students is the understanding of how to use sign conventions, and why they are necessary. Students typically try to 'see' the direction of a force or current before doing any calculations. They do not immediately grasp that a consistent formulation will inherently account for and identify the direction of the force or current, and they are often concerned that the use of differing conventions may lead to different physical answers. This tendency in student work is documented and further discussed in [5].

Discussion

We are currently looking at developing a zero-year curriculum for entering engineering freshman students who are not calculus-ready. This pilot course, if successful, may become a mandatory freshman class for students ready for college geometry and trigonometry. For other students, it would be available as an elective class.

This pilot course mainly addresses retention problems of students who have poor mathematical skills or who do not understand the important connections between math, science and engineering. Other educators have had success in integrating math and science classes [6, 7], but these attempts have typically waited until the students are calculus-ready. The approach in our pilot study – working with students at the pre-calculus level – is being used since most of our students are not calculus-ready when they arrive. This pilot course is not designed to replace existing freshman year design experiences, but to complement them. Freshman design courses at most institutions typically require a student to be calculus ready. There are many other sources of retention problems, many of which are nonacademic, as have been pointed out in the literature [8, 9].

If this pilot course is successful in Fall 2005 semester, adjustments will be made to this course as needed. Multiple sections of the 1 credit course will be offered as a recommended elective for entering engineering freshman students who are not calculus-ready, prior to the establishment and approval of the zeroth year curriculum.

References

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