AC 2009-1431: TUTORIALS AND IN-CLASS ACTIVITY FOR IMPROVING STUDENT PERFORMANCE IN A FIRST-YEAR ENGINEERING COURSE

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Tutorials and In-Class Activity for Improving Student Performance in a First Year Engineering Course

Abstract

An important factor in student satisfaction and retention in engineering courses is their pre-requisite knowledge. We seek to address the needs of these students who are not calculus-ready upon entering our first year engineering program by introducing self-paced video tutorial modules that deliver background in basic engineering mathematics, and an in-class activity applying those mathematical concepts. We are focusing on logarithms and trigonometric functions, as they are used ubiquitously in engineering, and have been identified as particularly problematic for students in our classes. Because future engineering classes will demand frequent recall of these mathematical concepts, the modules and demonstration focused on tying these concepts to prior knowledge in hopes of reducing cognitive load. The objective of this study is to examine the effects of having first year engineering students use these resources in terms of student performance and their perception of their own learning gains.

We based the design of the resources on social constructivist theory, allowing students to build on what they already know. The video modules on trigonometric functions take students from very basic definitions and relationships to solving equations using these terms. Through an in-class activity using sine functions, students observe real objects in cyclic motion, collect data from them, manipulate the data, interpret it, and make predictions about how related systems will behave. This essentially moves students through the levels of Bloom's taxonomy from knowledge to synthesis. The experimental design consisted of comparisons between three main groups: 1) controls, 2) those who viewed the tutorials, and 3) those who viewed the tutorials and participated in the in-class activity. Student performance on pre- and post- content tests, and self-assessments of learning gains were compared. We report on results of these assessments, and their implications for affecting change in student success, especially for students with weak pre-requisite skills.

Introduction

Students entering our first year engineering course arrive with different levels of mathematics preparation, which is of critical importance to their academic success. In our program, students scoring below a proficiency level on an institution-wide mathematics placement test are enrolled in a first semester course with an additional one-hour session ("recitation") for content review and practice. However, even with this support, 53% of these students earned a D or F, or withdrew from the course (DFW rate). This is over twice the DFW rate of 20% for all other first year engineering students.

The US is one of the few industrialized nations that do not have national mathematics standards[1]. Seventy-two percent of the states require three or less mathematics courses for a high school diploma, while twenty two percent require four mathematics credits. Consistent across states is the college preparatory coursework offerings of Algebra I, Geometry, Algebra II, Pre-Calculus, and Calculus.

To assure that students in our program have achieved a mastery level in basic mathematics skills necessary to move on to more complex topics in engineering, they are required to pass a mathematics mastery test. The test draws from high school mathematics content (60% Pre-Calculus, 10% Algebra I, and 30 % Algebra II). Sample test questions are listed in the Appendix. Students are given three attempts to pass the test with a passing grade of 80% or higher on a ten-item test. We have administered this test for six years, and have observed a high failure rate in spite of the fact that nearly all incoming engineering students have taken Pre-Calculus and Algebra I/II in high school. For the students entering our program in Fall 2008, 83 % had taken Calculus (and in some cases, Calculus II) in high school, yet only 40 % of all students passed the mathematics mastery test on the first attempt. A summary of high school mathematics preparation is shown in Table 1.

Students who were not calculus-ready based on a university-wide mathematics placement test are particularly prone to high failure rates on this test. Engineering students scoring below a certain level on this test are placed in Pre-Calculus. All other students taking Calculus during their first semester enrolled in a two-credit introductory engineering course (CES 102). Students taking Pre-Calculus enroll in a similar course, with an additional credit hour of "recitation" for reviewing basic skills and practicing engineering problem-solving (CES 101). In order to help students in these courses master the required basic mathematics, we have developed supplemental course materials that they can access at a self-regulated pace outside of class.

Table 1. Summary of mathematics courses for which students in the first year engineering courses earned high school credit. Students taking Pre-Calculus during their first semester in college were enrolled in CES 101; those taking Calculus were enrolled in CES 102.

First Year Engr Course Section	Algebra 1, Geometry	Algebra 1, Geometry Algebra 2	Algebra 1, Geometry Algebra 2, Statistics	Algebra 1, Geometry Algebra 2, Pre-Calculus	Algebra 1, Geometry Algebra 2, Pre-Calculus, Statistics	Algebra 1, Geometry Algebra 2, Pre-Calculus, Calculus (+)	All
CES 101	1	0	1	25	12	56	95
CES 102	0	2	0	49	7	440	498
All	1	2	1	74	19	496	593

Theoretical Framework and Activity Design

Self-Paced Tutorial Video Modules

In an effort to increase the retention rate of engineering students, several universities have used mathematics placement tests to assure proper placement in freshman engineering and mathematics courses.[2] Research has shown that students often do not have the proper background in algebra, trigonometry, and calculus to succeed in their engineering program, even if they completed these courses in high school.[3] One engineering program that attempted to rectify the disparity between mathematics courses taken in high school and mathematical readiness delayed student placement into engineering courses until successful completion of pre-calculus. This same program also reported lower retention rates of their freshman engineering students.[4] In order to sustain students' interest in their engineering major, we created a program that works in parallel with their first year engineering course and their mathematical readiness for upper level engineering courses. The theoretical perspective of intrinsic cognitive load was used to guide the production of video materials, which were created to help students improve specific weak mathematical skills.

Intrinsic cognitive load occurs in the learning of mathematics because of the many connections that exists in mathematics. These connections are referred to as element interactivity. Higher element interactivity indicates higher cognitive load, which results in limited learning for retention and transfer.[5] There are several approaches to lower intrinsic cognitive load. The two approaches that we used were pre-training and simple to complex sequencing. In pre-training learners initially develop specific prior knowledge needed for understanding before the desired content is presented. Simple to complex is a type of procedural teaching that has been shown as an effective strategy to reduce intrinsic cognitive load.

Short video modules were created to assist the students in recalling mathematical material needed in their first year engineering course. A National Board Certified secondary mathematics teacher created the videos using a Tablet PC and recording software (LectureScribe, www.cs.clemson.edu/~bcdean/lscribe). Students accessed the videos online and could watch them in their entirety or in individual segments, as often as needed. Each module of the video review included problems for the students to solve which allowed them to analyze their own understanding of the material.

The videos connected material comprised a comprehensive review of logarithmic and trigonometric functions. The review for logarithms spanned from exponents to the common and natural logarithmic functions. The review for trigonometry spanned from the unit circle to the sine and cosine functions (graphs and equations). The videos placed trigonometric functions on a Cartesian coordinate plane, an important fact when considering their connection to a lab activity, which will be discussed later in this paper.

The element interactivity for logarithms is high because understanding requires recall of exponent rules and their specific algorithms. Logarithm problem solving requires schema recall into working memory. With high element interactivity between the content of exponents (taught in algebra I) and logarithms (taught in pre-calculus) it was important to produce the logarithm modules with the goal of reducing intrinsic cognitive load.

The element interactivity for trigonometric graphing and problem solving is also high. A comprehensive review of the unit circle was provided since understanding the connections between the circle and trigonometric wave functions are important to schema creation. Once a basic review was provided of graphing the sine and cosine functions, a lesson incorporating these skills into sketching graphs with amplitude, period, and phase shifts followed.

In-Class Demonstration and Activity

To demonstrate the importance of these mathematical concepts, an activity emphasizing the use of trigonometric graphs was created using a bicycle on a stationary trainer in which the students would participate in angle measurements using electronic goniometers. This demonstration served the purposes of tying the new mathematical concepts to familiar repeatable human motion. Students sat on the bike and varied their sitting position at a fixed pedaling speed (cadence), or varied their cadence at a fixed sitting position. One electronic goniometer was placed between the student's trunk and thigh, and another was strapped between the thigh and calf, allowing measurement of hip and knee angles. The data was plotted in real time on screens around the room so that students could observe the sine wave pattern from the measurements and to see the influence of the changes in sitting position and cadence on hip and knee angles. From the data, students created a mathematical model to predict hip and knee angles using the trigonometric concepts they had been reviewing. They were prompted to verbally describe the features of the signals as a group activity, writing down as many descriptive terms as possible. Using a worksheet, students then transformed their descriptions into sine function parameters (amplitude, period, phase shift and vertical offset). Students predicted how the parameters would change for different types of bike riders, different speeds, or different bike features.

The theoretical framework for this was based on situated cognition theory. Situated cognition theory suggests that knowledge is a matter of competence related to a valued enterprise and that knowing is a matter of participating in the pursuit of such enterprises[6]. Meaning therefore is the ability to experience the world and have a meaningful engagement into it. Ultimately, this is what learning is to produce. The purpose of this in-class activity was for the students to have a meaningful engagement of their prior learning toward a real world experience. Two main attributes of this theory were used in the design of the in class demonstration: anchored instruction and authentic activities.

Anchored instruction has been used as a means of implementing the conditions of situated learning. A situated context based on an objective question is provided for a more complex and realistic problem. The objective question posed to the students was "Create a model (mathematical equation) to describe knee angles for a cyclist and apply this model to predict the corresponding hip angle". The students must rely on their prior knowledge to lead them through the problem solving process, leading them to answer the objective question. The students pose questions to decide what information they already know, what information they will need to find, and how to group this information together[7]. Considering the classroom as a learning community, the emphasis is on distributed expertise[8,9] in which the students come to the learning task with different interests and experiences. As a learning community, students offer their experiences as a way of sharing meaning and understanding of the activity as a means to answering the objective question.

To distinguish between an authentic activity and a school activity, an authentic activity is most simply defined as the ordinary practices of the culture of interest[10]. The culture of interest in this case was the biomechanics associated with professional cycling. Because this activity took place within the classroom, contextual features were needed to most closely resemble this culture such as the bicycle, stationary trainer, and electronic goniometers. Students participated in the experiment to collect data as they would in the approximated culture. Observers took on the role of scientists, analyzing and discussing what methods could be invoked to correctly model the observations. In this way, the demonstration more closely resembled the actions of participants in that culture. The student takes on a role of participant or observer and then communicates back to the learning community in the interest of answering the objective question.

Experimental Design

Five groups of students participated in this study; groups were in different sections of the same introductory course. Groups 1 – 3 were taught by two of the authors (Benson and Bowman).

1. Controls –Students in sections of the first year engineering course without additional recitation sessions (CES 102) who did not view video modules or in-class demonstration. These students had access to the video modules, but were not required to view them. Only those students who did not view the video modules were included in the control group (n=347).
2. Group 1 – Recitation students (CES 101) who did not view video modules, and who did not participate in the in-class demonstration prior to taking the Math Mastery test (n=92).
3. Group 2 – Recitation students (CES 101) who were assigned viewing the video modules as homework but did not participate in the in-class demonstration prior to taking the Math Mastery test (n=45).
4. Group 3 – Recitation students (CES 101) who were assigned viewing the video modules as homework and participated in the in-class demonstration prior to taking the Math Mastery test (n=44).

5. Group 4 –Students in sections of the first year engineering course without additional recitation sessions (CES 102) who viewed video modules, even though they were not required to view them (n=186).

A pre-test was given in all class sections of CES 101 and 102 prior to release of the video modules and the in-class demonstration, and consisted of three questions (one each on logarithms, exponents and trigonometric functions). Student mastery of basic engineering mathematics was assessed on a ten-question Math Mastery Test. Scores on individual questions related to logarithms, exponents and trig functions were recorded.

Assessments of the effectiveness of the supplemental materials for each of the five groups of students were as follows:

a. Pre- and Post- test scores. Comparison of scores on relevant questions on the pre-test and Math Mastery Test (1 question per topic on the pre-test, 3 questions per topic on the Math Mastery Test).

b. Quiz scores. Scores on topical quizzes given after each self-paced tutorial (3 questions per segment for 6 module segments). These scores verified that students viewed the materials, identified which students viewed them, and indicated whether or not the students understood the material.

c. Self-Assessment of Learning Gains (SALG). Through an online survey (www.salgsite.org), students self-reported their perceived learning gains, which aspects of the course helped them make those gains, and what mathematics courses they received credit for in high school. Students also reported which section of the course they were in so we could identify which treatment group they were in.

Results

Video modules on exponents, logarithms and trigonometry were viewed by both students who were required to watch them and those who were not. Groups 2 and 3 were required to view the videos; Group 4 was not, but students in this group chose to view the videos on their own. For students in Group 4, who do not participate in the recitation sessions, the videos were mentioned once in lecture as an additional resource for preparing for the post-test. The number of views was about evenly divided between the exponent/logarithm modules and the trigonometry modules. The most frequently viewed module was Trigonometry 1 (27% of all views), in which students were didactically guided through the concept of the unit circle to the basic definition of trigonometric functions. The least frequently viewed module was Trigonometry 3 (95 of all views), in which an example trigonometry problem was worked out.

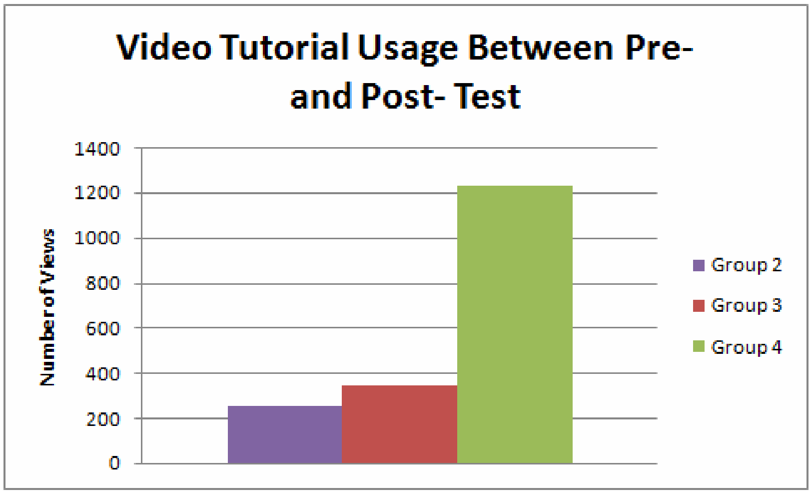

Figure 1. Summary of viewing statistics of video modules by experimental group prior to taking the Math Mastery test. (Group 2: n=45; Group 3: n=44; Group 4: n=186; Groups 1 and 5 did not view the modules.)

All students scored higher on post-tests than pre-tests for questions pertaining to exponents and logarithms. (See Table 2.) Students in Control and Group 4 (not in recitation) did not improve pre- to post- on trigonometry related questions; Students in Groups 1 – 3 (those in recitation) did show increased pre- to post-scores on trigonometry problems, but the difference in gains between these gains was not significant.

Table 2. Change in the average pre- to post- scores (0 = incorrect; 1 = correct) on test questions related to logarithms, exponents or trigonometry for students in the experimental groups.

	Control	Group 1	Group 2	Group 3	Group 4
Exp Ave	0.647	0.304	0.346	0.402	0.685
Log Ave	0.144	0.203	0.238	0.318	0.262
Trig Ave	-0.064	0.045	0.141	0.086	-0.046

The SALG was completed by 613 students. Results showed that on average, students did not find the supplemental materials particularly helpful to their learning. Responses on the Likert-scale question, "How much did each of the following aspects of the class help your learning?" were rated on a scale of 1 to 5, where 1 = no help and 5 = great help. Thus, with scores below 3 indicating minimal help, students' responses were as follows:

- Bicycle Demo of Trig functions: 2.5
- Logarithm Video Modules: 2.8
- Trigonometric Video Modules: 2.8

However, in response to an open-ended question, a small number of the students (6%) specifically identified the video modules as helpful to their learning.

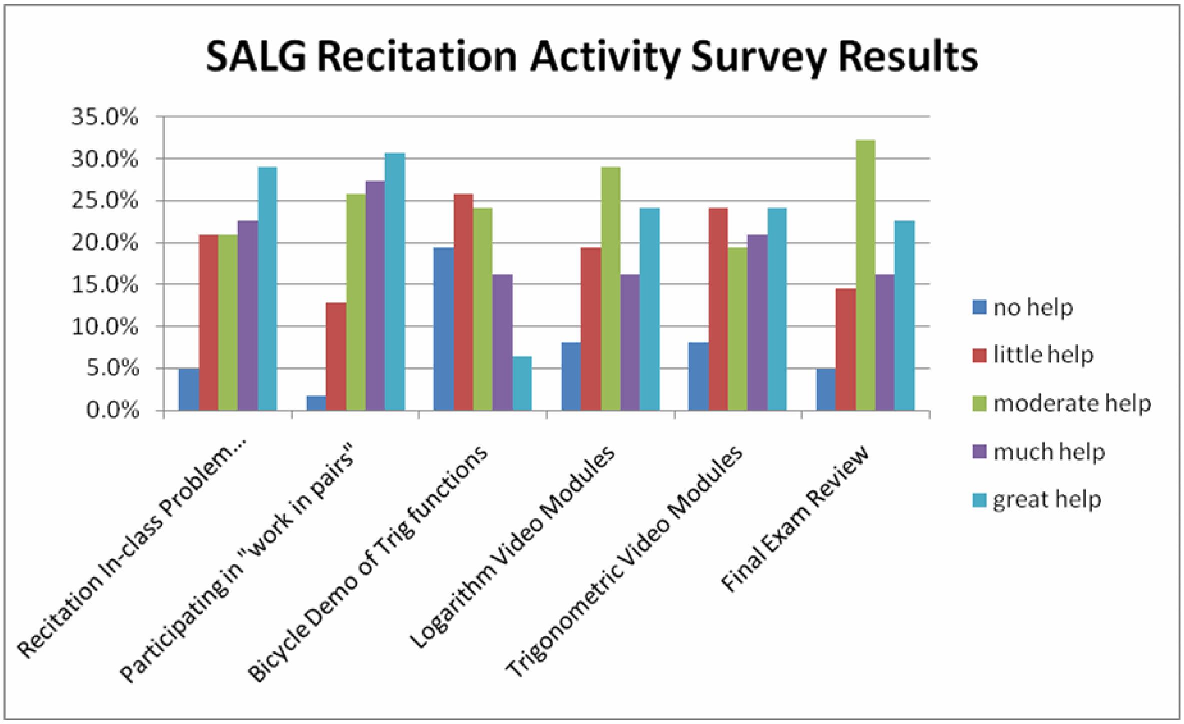

Figure 2. Results from Self-Assessment of Learning Gains (SALG) in response to the Likert-scale question, “How much did each of the following aspects of the class help your learning?” (n=613).

Students also had the following responses to short answer questions on the survey:

1. Please comment on how the RECITATION ACTIVITIES helped your learning.
   - 50% responded that going over tests or reviewing helped their learning in recitation.
   - 46% commented on reinforcement through additional problem solving or going back over concepts helped
   - 27% responded that recitation did not help
   - 13% enjoyed working in pairs or in teams
   - 6% specifically responded that the math videos helped their learning
2. Please comment on HOW OFTEN YOU PARTICIPATED in class discussions and HOW THE ATMOSPHERE IN RECITATION ENCOURAGED OR DISCOURAGED your participation
   - 75% of the students gave “encouraging” comments on some aspect of the recitation

- 50% of the students gave comments that were “discouraging or no encouragement”
- 53% of the students commented that they “participated often”
- 22% “did not participate, but listened”
- 14% of the students stated that they did not participate

Discussion and Conclusions

The fact the trigonometry video modules were created on a Cartesian coordinate plane caused confusion for the students when the bicycle demonstration was plotted using amplitude versus time. In future iterations of these interventions, the trigonometric video lessons will connect the wave functions to the unit circle, but also transfer them to real time graphs as well.

Null results were obtained for the comparisons of gains made in test scores for groups of students who were given different supplemental resources. This may indicate one of several things:

1. Students may not be developmentally ready to relate supplemental materials to basic principles on the mathematics mastery test. Perhaps students in upper level classes who already understood the basic principles quite well might show more significant gains in performance and/or attitude towards the demonstrations. The students in this study were at all different levels of academic preparedness, similar to what Roth refers to as “different discourses”[11]. In his analysis of why demonstrations sometimes are not effective in classrooms, Roth cites the differences between the resources that students draw on as one factor.

2. The supplemental materials were not delivered in a format that was effective for helping students to assimilate the concepts. For example, the video format of the tutorials is a one-way delivery of material, and does not actively engage the students to achieve deeper learning. On the other hand, the in-class demonstration, which actively engaged the students, may have been more sophisticated than the students needed in order to understand the basic concepts being taught.

3. The class structure, in which students who are not calculus-ready are given supplemental classroom instruction (“recitation” for students in CES 101), simply may not be helping our students who are not calculus-ready upon entering college. The null data shows that even if multiple resources and types of resources are given to these students, they still struggle with basic mathematical concepts. This would suggest that the course should be redesigned to better meet the needs of these students.

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Appendix

Sample Mathematics Mastery Test Questions Related to Logarithms, Exponents and Trigonometry

(1) Determine the numerical value of x in the following expression: $B^{x} B^{3} = B^{2}$

(2) Given that log(5) = 0.7, evaluate the expression: log (25)

(3) In domain x=0 to x=360°, list the values of x where the function sin(x / 2) equals zero.

(4) Sketch the function cos(x) + 8.