AC 2008-1697: MATHEMATICS SKILLS ASSESSMENT AND TRAINING IN FRESHMAN ENGINEERING COURSES

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Abstract

In recent years, the professors who have taught freshman engineering courses at Northern Arizona University have expressed some disappointment regarding the level of students' abilities and their rates of academic success. A major cause, we believe, is the inadequately developed mathematical intuition and skills that students possess when they begin college. To address this issue, we have developed and deployed a pilot program called TIMES: Training Intuition in Math for Engineering Success. Once students are assessed to determine their skill levels in six chosen numeracy areas, guided practice and training is provided to each student who has exhibited difficulty. All students are required to reach a level of mastery as measured by a post-test instrument. The goals have been to increase retention and academic success for these engineering students and to measure the effectiveness of the TIMES approach. Three semesters have been completed and more than 850 students have participated. The majority of the students have shown weakness in one or more of the targeted skill areas. In this paper, we present both quantitative and qualitative results of the first three semesters of this ongoing project.

Introduction

Many students in our entry-level engineering courses at Northern Arizona University have difficulty adjusting to the expectations, fully understanding the material, and achieving good grades. Too many students either change their majors away from engineering or experience a frustrating period of time before establishing a successful academic path. We believe a major cause is often students' inadequately developed mathematical intuition and skills set. Success in engineering studies requires students to have a good facility and comfort level with numerical concepts. To address this need, we have created and are pilot testing a structure that provides training in targeted mathematical skill areas that are applicable across several engineering disciplines.

Background

To succeed in an engineering major, it is very important that students have a positive experience in the courses that introduce them to their chosen engineering field. Professors who teach these introductory courses at our university frequently observe that many students are not nearly as well prepared as they should be when it comes to key mathematical skills and concepts. The common opinion among these professors is this lack of math preparation, a poor intuitive "feel for numbers", is very often primarily responsible for students achieving poor grades, becoming frustrated or discouraged, and deciding to change majors or leave the university.

The inadequate numeracy skills manifest themselves in a variety of ways:

- Inability to properly carry units through calculations
- Heavy reliance on calculators and computers for even very simple computations
- Blind trust in the correctness of answers that emerge from a calculator

- Inability to make rough numerical estimates
- Inability to detect nonsense answers
- Inability to visualize or plot common functions
- Inability to decompose a task into a logical series of detailed steps

These problems are common across disciplines and departments and are not directly addressed in the normal engineering curricular path. Even our existing tutoring program through our Learning Assistance Center does not directly focus on difficulties of the above types.

Others have addressed the issue of mathematics preparedness and how it correlates with student retention and success in engineering programs of study. Gardner[3] observed that student performance in their first college math course was significantly correlated with their persistence in college. Many, including Blat[1], Bottomley[2], Gardner[4], Heinze[6], Mathias[7], and Stewardson[8], have stressed the importance of good math preparation in engineering studies and suggest a variety of approaches for addressing the apparent shortfalls.

Strategy

We believe significant improvements in student success and retention in engineering may be achieved through a dedicated effort to identify students possessing relatively poor math intuitive abilities and provide them specific training and practice until a targeted level of mastery is measured. This is the basis of our TIMES project: Training Intuition in Math for Engineering Success. Measurement of the improvements in student mathematical abilities as well as rates of retention and academic success are very important goals of the project.

The TIMES project is a significant pilot effort that has potential for broader implementation in fields beyond engineering. TIMES consists of several different types of activities, all focused upon improving targeted math and conceptual reasoning skills in the students. The overall strategy is to give the students the guidance, help, and training on an individual basis as much as possible. The focus lies upon the individual student's needs and how he or she can achieve the best gains in the topic skills. The realization of this strategy has been accomplished in a manner congruent with the principles and characteristics of learner-centered education: active learning, student engagement, adaptivity focused upon individual student needs, practice until mastery, prompt feedback, and general avoidance of the traditional lecture format.

TIMES consists of two main components. The first is the use of an assessment instrument, a pre-test, designed to identify freshman-level engineering students who possess relatively poor mathematics skills in several targeted areas. The second is a guided set of training and practice exercises designed to improve students' abilities in the areas in which they have exhibited weakness. The goal has been to attain a certain level of comfort and mastery as demonstrated by post-training skills assessment. Six specific mathematics skill areas have been targeted because of their commonality across engineering disciplines as areas of weakness and their relative importance as stumbling blocks to good academic progress.

Since our research has involved human subjects, we obtained the approval of our university's institutional review board. All student participants whose data appears here have signed consent forms.

Implementation

We targeted the following entry-level engineering courses: EE 110 – Introduction to Digital Logic, EE 188 – Electrical Engineering I, EGR 186 – Introduction to Engineering Design, and CENE 150 – Introduction to Environmental Engineering. In each course, a pre-test was administered during the first two weeks of the semester to all students in the course. The pre-test covered the mathematical skills that the engineering faculty judged most useful for success in the engineering courses. These were: (1) fractions, (2) unit conversions, (3) graphing of basic polynomial functions, (4) systems of equations, (5) exponentials and logarithms, and (6) estimation and problem solving. Based on the student's performance on the questions covering these topics, they were deemed to have either satisfactory knowledge in the area or a need for improvement.

Students and their instructors were given notification of the results of the pre-test. Because the test covered the six areas mentioned above, in relaying the results to the students they were told whether or not they had passed a specific area. Thus a student may have been successful in answering the questions on fractions, unit conversions, and problem solving, but not successful with the questions on graphing, systems of equations, and exponentials and logarithms.

If a student showed a deficiency in a topic area, then they were asked to attend sessions that would help them solidify their understanding and improve their skills. These help sessions were scheduled at various time periods throughout the week and were held in both the engineering and mathematics buildings. They were staffed and managed by two mathematics GTA's. The students could walk into any of the scheduled sessions to work on the modules they had not passed. They were given various materials to help improve their skills in the needed area along with very individualized tutoring. Once a student had worked through various problems and felt that they now understood the material, they were given a post-test over the specific module. If they successfully completed the post-test, they were deemed to have passed that module and their instructor would be notified of this event. If the post-test revealed that the student did not have a firm grasp of the material, they then were given more materials and practice problems and the chance to attempt the post-test again at a later time.

Throughout the semester, we continued to update the instructors of the participating courses regarding their students' progress in completing the various modules. Some instructors were very proactive in encouraging their students to attend the help sessions to improve their mathematics skills while other instructors were not.

During the first semester of the pilot (Fall 2006), participation in the program was entirely optional. Consequently, very few students took advantage of this opportunity to improve their mathematical skills. Hence, we worked with the engineering faculty who taught the targeted courses during the Spring 2007 semester and encouraged them to make the TIMES project an actual part of their course grade. That is, a small percentage of the course grade was dependent on the student passing all 6 modules. If the student performed well on the pre-test, then they automatically received these course points; if they did not, then they needed to attend the TIMES sessions and complete the post-test in their deficient areas. If they successfully completed the necessary post-tests, they also received the course points. If students completed some modules but not others, the grade was adjusted accordingly. The result of this 'required' aspect of the program meant that many more students participated in the program in the Spring 2007 semester than did in the Fall 2006 semester. During the Fall 2007 semester, some instructors made the TIMES program a required portion of the course and others did not; thus we had mixed participation. Based on this, we again encouraged the instructors for Spring 2008 to make it a required component of their course. Participation rates can be found in the next section.

Results

Overall, we tested a total of 872 students over the course of three complete semesters. An additional 231 students are currently being tested during the Spring 2008 semester. The breakdown with regard to each class is represented in Table 1.

Table 1. Breakdown of Students by Course

	Fall 2006	Spring 2007	Fall 2007	Spring 2008	Overall
EE 110	54	0	69	0	123
EE 188	88	56	87	78	309
EGR 186	122	77	167	108	474
CENE 150	51	26	75	45	197
Total Students	315	159	398	231	1103

As mentioned in the previous section, the participation levels varied from semester to semester somewhat depending on whether or not the TIMES program was a required component of the student's engineering course. This data is represented in Table 2.

Table 2. Participation of Students

	Fall 2006	Spring 2007	Fall 2007	Overall
Number of students that needed help and participated	4 (1.3%)	44 (27.7%)	69 (17.3%)	117 (13.4%)
Number of students that needed help and did not participate	251 (79.7%)	64 (40.3%)	208 (52.3%)	523 (60.0%)
Number of students that did not need help	60 (19.0%)	51 (32.1%)	121 (30.4%)	232 (26.6%)
Total number of students	315	159	398	872

We also looked at how many students needed help in each specific area. This data can be found in Table 3.

Table 3. Number and Percentage of Students Needing Help in Specific Areas

	Fall 2006	Spr 2007	Fall 2007	Spr 2008	Overall
Fractions	72 (22.9%)	23 (14.5%)	98 (24.6%)	66 (28.6%)	187(17.0%)
Unit Conversion	78 (24.8%)	43 (27.0%)	125 (31.4%)	92 (39.8%)	338 (30.6%)
Graphing	77 (24.4%)	24 (15.1%)	35 (8.8%)	36 (15.6%)	172 (15.6%)
Systems of Eqs.	161 (51.1%)	45 (28.3%)	108 (27.1%)	72 (31.2%)	386 (35.0%)
Exponentials / Logs	67 (21.3%)	21 (13.2%)	104 (26.1%)	68 (29.4%)	260 (23.6%)
Estimation / Problem Solving	140 (44.4%)	66 (41.5%)	82 (20.6%)	83 (35.9%)	371 (33.6%)
Total Students	315	159	398	231	1103

We were interested in how students performed in their engineering course given that they did or did not need help to improve their skills and they did or did not participate in the program. These results are in Table 4.

Table 4. D, F, and Withdrawal Grades as Related to Need and Participation

	Fall 2006	Spring 2007	Fall 2007	Overall
Students who received a D/F, given they needed help and participated	0.0% *0/4*	20.45% *9/44*	4.35% *3/69*	10.26% *12/117*
Students who received a D/F, given they needed help and did not participate	15.54% *39/251*	21.88% *14/64*	41.25% *35/208*	16.83% *88/523*
Students who received a D/F/W, given they needed help	23.92% *61/255*	31.48% *34/108*	21.66% *60/277*	24.22% *155/640*
Students who received a D/F/W, given they did not need help	8.33% *5/60*	15.69% *8/51*	12.40% *15/121*	12.07% *28/232*

Table 5. 95% Confidence Intervals for Course Grade Points vs. Category

Category	Category Abbreviation	Lower 95% Limit in Course Grade Points	Upper 95% Limit in Course Grade Points
Students Who *Did Not Need* Help	DNN	2.882	3.157
Students Who *Needed* Help and *Participated*	NP	2.667	3.054
Students Who *Needed* Help and Did *Not Participate*	NNP	2.406	2.657
Overall		2.657	2.829

An analysis of the data from the three completed semesters of the TIMES project has produced several important results. First, we have statistical significance that the pre-test results are a good predictor of the course grade. Table 5 provides the 95% confidence intervals of average grade points (on a 4.0 scale) that the students achieved in their sponsoring freshman engineering course for the various categories of our study. The confidence limits were determined by first computing the mean of the students' course grade points for each category. The ***t*** distribution for the 95% confidence level was then applied using the standard deviation of the category grade points and the sample size for that category.

The most striking result from the Table 5 data is the lack of overlap between the NNP and both the NP and DNN categories. This strongly supports the conclusion that students who showed weakness in the targeted math skills and did not improve these skills have much more difficulty succeeding in their freshman engineering courses compared to either those students who demonstrated improvement or those who showed no weakness. The Table 4 data adds further weight in the form of significantly higher D/F/W rates among students who needed help and did not participate in TIMES training compared to either those who did or those who needed no help. Comparing the NP category with the DNN category, there is a good deal of overlap in their ranges. This is good because it indicates that those students who worked at improving their weak skills ultimately performed at nearly the same level as those who did not show weakness.

The three semesters of data can be examined another way by computing the confidence intervals for grade point differences among the DNN, NP, and NNP categories and testing for statistical significance. This approach yields statistically significant differences at the 99% confidence level between the following categories: NNP compared to NP and NNP compared to DNN. These results reinforce the conclusion that TIMES participation has demonstrated a measurable and statistically significant improvement in student performance in their sponsoring engineering courses.

The students who participated in the TIMES modules have provided some subjective feedback through a survey given at the end of the semester. Some representative comments are:

- "The modules were very well written and explained the material very clearly."
- "The material was confusing."
- "I learned new things. I can solve problems that I couldn't before."
- "I would have passed if I could use my calculator."

Other feedback from students who needed help in one or more module areas but did not participate:

- "I only needed a few minutes of self review to remember how to do the math."
- "I knew what to do. I just was caught by surprise and made stupid mistakes."
- "Too busy / forgot / not very good information."
- "My schedule was extremely busy."
- "The schedule for the meetings did not fit my schedule."
- "My math level is far beyond this TIMES test. I felt this was a blatant waste of my time."

Conclusions

Our experience with the TIMES pilot project has taught us several things. First, the percentage of freshman students who exhibit difficulty with one or more of the six target topics is quite high. This provides some validation to the professors' subjective impressions of poor mathematics skills among many of the incoming freshmen. Second, the pre-test has proven to be a good predictor of student success in the course even though the material tested is not explicitly a course component. Third, students are very unlikely to follow through with the training modules unless this activity is a required part of their course; voluntary or suggested participation has produced low participation rates. Fourth, and most importantly, TIMES participation produces a measurable and significant improvement of student performance in freshman engineering courses. Examination of the effect of TIMES on student retention rates in our engineering majors is planned as one of the next steps of our study.

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