Engineering Math Based Bridge Program for Student Preparation

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ABSTRACT

University of Alabama (UA) retention statistics showed less than 33% of engineering freshmen were retained through graduation. This is 23% lower than the national average of 52% for similar programs. Analyses indicate the primary reason for low retention is an inability of incoming freshmen to perform well in first-year calculus classes. Low performance in calculus was found to impact upper-level engineering classes. To combat this deficit, UA developed a unique informal, interactive, and interdisciplinary summer residence class called the Engineering Math Advancement Program (E-MAP) sponsored by the National Science Foundation. The program aims to increase prepare students to 1) do well in calculus and 2) to excite them about engineering, introducing students to hands-on "Living-Lab" experiences, industry trips and a community service project led by professional engineers.

Math Placement Test (MPT) data show that 84% of participants skipped one math course and 41% 2-3 courses. Post-program grades (GPA 79.7) are greater than pre-program grades (GPA 56.6). Approximately 30% of participants have been minority and women students. Female scores were higher compared to male scores, the first year showing a significant difference (up to 10 points) in math scores. LASSI, Math Science Inventory and Meyer-Briggs studies are used along with pre- and post- MPT and ALEKs (Artificially Intelligent Assessment and Learning System) assessment providing both qualitative and quantitative data. The program's goal is to determine the best set of teaching methods and materials providing greatest impact on student performance.

Keywords: Engineering Retention, Summer Bridge Programs

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I Introduction

During the 1980s and 1990s, the number of undergraduates in engineering programs was in a significant decline [5],[7] as can be seen in Figure 1. Because of this decline, a large portion of the engineering workforce is nearing retirement age. Since the number of engineering jobs has remained stable during recent years (as can be seen in Figure 2), a large number of individuals with engineering degrees is necessary in the near future. While the engineering enrollment numbers have increased in the past few years [5],[7], increased recruitment and retention of undergraduate students in the field of engineering is critical.

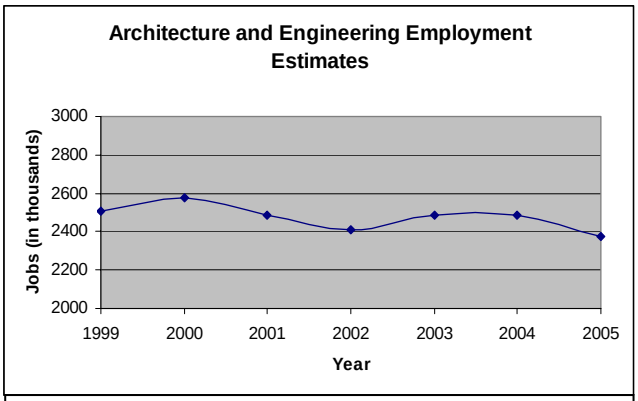

Figure 1: Architecture &Engineering Employment Estimates [1]

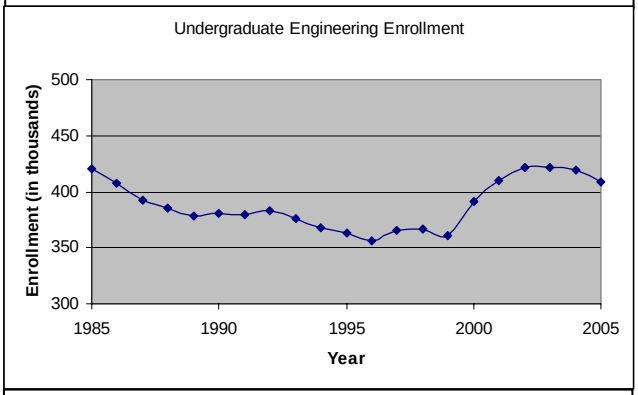

Figure 2: Undergraduate Engineering Enrollment [5], [7]

In an effort to increase the engineering workforce, the National Science Foundation has funded programs designed to improve the recruitment and retention of undergraduate engineering students through the Science, Technology, Engineering, and Mathematics Talent Expansion Program (STEP). At The University of Alabama (UA), these funds are used to focus on the retention of incoming freshmen who have declared engineering as their major.

Since the mathematics requirements of the engineering majors is an area that causes many students to drop out of engineering, the core of the program focuses on mathematics preparation. This mathematical preparation involves non-traditional classes in pre-calculus and calculus concepts designed to take incoming students who place in a pre-calculus class and improve their mathematical knowledge so that they are able to start their calculus sequence in the fall. In addition to the core mathematics content of the program, the students also participate in physics and chemistry classes as well as hands-on engineering activities and fieldtrips to introduce the students to various engineering fields.

II Literature Review

Importance of Mathematics to Success in Engineering

Math is one of the primary tools of engineering. The earlier the student learns to master the tool, the better he/she can manage the tool and apply it to problem solving. Lack of preparation in math is one of the main factors contributing to student dropout in Engineering at UA. The UA student retention statistics showed that less than 33% of incoming engineering freshmen were retained through graduation. This is 19 points lower than the national average of 52% for similar programs. Analyses indicate the primary reason for low retention is an inability of incoming freshmen to perform well in first-year calculus classes.

Current Status of the Mathematical Background if Incoming Freshmen

Studies at UA have established that around 60-70% of entering freshman engineering students are not calculus ready [6],[14]. Since the engineering program of study at UA assumes calculus ready students, 70% of entering freshman engineering students are under-prepared for the program due to deficiency in mathematics. The main results of this are poor performance in math related engineering classes, longer time to graduation and low graduation rates from engineering.

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Calculus courses are fundamental to the engineering curriculum as they provide a strong base for future engineering courses. Therefore success in calculus is important to success in engineering [9]**Error! Reference source not found.**. Many research studies support the fact that freshman students entering engineering program lack the ability to progress through the calculus sequence [3]. [15], [16]. Furthermore research indicates that students entering into current engineering programs do not have the ability to solve multistep problems, and lack higher order thinking skills necessary to solve engineering problems. They have also not developed a questioning attitude necessary for the fundamental understanding of the meaning behind many concepts presented. These important skills are required at all levels of the curriculum to enhance success in engineering [16]**Error! Reference source not found.**.

Programs Designed to Improve the Situation

A study on the effects of mathematics courses taken by students at the junior and high school level showed that the number of mathematics courses plays a prominent role in higher level mathematics achievement [15]**Error! Reference source not found.**. A number of successful programs address the deficiencies in entering freshmen preparedness for the engineering curriculum.

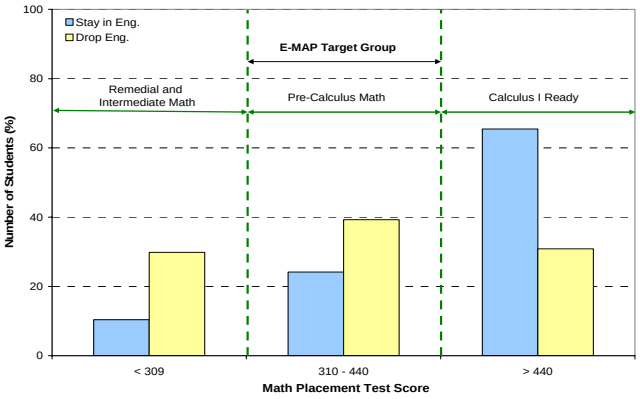
The Emerging Scholars Program (ESP), one of the oldest intervention program developed in the 1970's, has been adapted in mathematics courses at several major universities. These programs offer workshops which help freshman students build necessary mathematics background and develop the skills required to be successful in engineering [2]. Students who attended a "summer bridge program" on calculus performance among engineering freshmen at the University of Missouri in Rolla showed significantly higher performance than their counterparts who did not attend the program [9]**Error! Reference source not found.**. A similar engineering mathematics retention program at Wright State University included a freshman level engineering mathematics course replacing traditional math prerequisite requirements. This program improved overall success in student grades and motivation and helped improve student retention [10]**Error! Reference source not found.**. In another study, at-risk freshman engineering students who participated in a supplemental program received higher course grades and had higher retention rates.

The one week mathematics bridge program at Purdue allows students to discover strengths and weaknesses and improve preparation in mathematics. This program was one of the most effective pre-college retention programs offered by the schools of engineering [8]. Other bridge programs were 10 weeks long and the participants received course credits for participation. Many of the programs offered were free of charge and included scholarships.

Another engineering retention program at the University of Maryland tried to "bridge" the gap between high school preparation and expected standards of engineering freshman majors. This program focused on improving academic success and included life-skills, with social and motivational components. The students who attended this program benefited largely in terms of settling down and dealing with first semester [8].

Program Description

When students first arrive at The University of Alabama (UA), they take a mathematics placement exam, designed by the Department of Mathematics, which determines the mathematics course in which they may enroll. This initial placement has a strong correlation with student engineering retention rates. Historically, students scoring below 310 on the Math Placement Test do not have the math skills needed to pursue a career in engineering and either do not enter into engineering or leave the



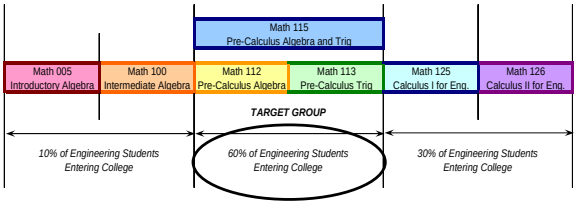
3: Retention as a Function of Math Placement Test Score, [6]

college soon after starting the program (see **Error! Reference source not found.**). For students with math placement scores below 440, retention is also low due to their math skills not being at the level that allow them to succeed in engineering math based courses. Although not as significant, retention is a problem in the higher scoring group, with the main reasons being unchallenging initial mathematics courses and lack of motivation to continue in the pursuit of a career in engineering [6].

To combat this deficit, UA developed a unique, informal, interactive, and interdisciplinary five-week summer residence program called the Engineering Math Advancement Program (E-MAP) to prepare incoming freshmen for calculus. The program aims to increase retention by preparing students to be successful in calculus and excited about engineering. In addition to a non traditional math class, the program includes hands-on "Living-Lab" experiences, field trips and a community service project led by professional engineers. The non-math aspects of the program were developed to strengthen mathematical skills indirectly through engagement of the students in laboratory and real world engineering problems, in the idea that solving skills are best nurtured through hands-on experiences [9], [10].

E-MAP is tuition-free, the only cost being food and on-campus accommodation. Scholarships are available for up to 10% of the participants based on need. Although freshmen students are not required to participate in E-MAP, they are strongly encouraged to do so. Recruitment involves an intensive mailing campaign and high school advising. Promotional material includes program flyers, poster presentations, a web site, and advertise-ments on the university and College of Engineering websites.

E-MAP specifically targets the 60% of students entering the College of Engineering who have math skills which place them into the pre-calculus range. Normally, these students would enroll in Math 112 (Pre-Calculus Algebra) and 113 (Pre-Calculus Trigonometry), or Math 115 (Pre-Calculus Algebra and Trigonometry), placing them in either case a year behind the remaining 30% entering at the Engineering Calculus 125 level. Up to an additional year is required to get back on track with the core engineering courses. Because the lower 10% in incoming students only have a 10% chance of graduating with an engineering degree (**Error! Reference source not found.**), these students do not create a large enough pool to justify a program targeted toward them. The upper 30% consist of engineering students ready for calculus and are therefore also outside the scope of the E-MAP program (4).



4: E-MAP Target Group Related to Math Placement Score

E-MAP Structure

The program includes a variety of experiences to enhance math skills and student engagement in engineering. Engineering related activities include hands-on "Living-Lab" experiences, field trips and a community service project led by professional engineers. The incorporated fun learning experiences, teambuilding and social activities help avoid summer burn-out and encourage participation and bonding. The mathematics classes are primarily in the mornings with the afternoons allocated by rotation to Living-Labs, Calculus Lab, and Community Service Project. One day per week is reserved for the learning experience through the field trips. Social activities and/or math tutoring are available in the evenings.

Math Class

The E-MAP program offers an alternative curriculum for pre-calculus math building upon the principal that students are individuals with different learning styles. The structure of the E-MAP math program provides time for individualized mentoring experiences that could not take place in the traditional lecture classroom because it involves all three forms of learning through the use of multi-media introduction of new material, one-on-one tutoring, and hands-on experience with applications. The classroom model is based on a small student/teacher ratio with a lead instructor assisted by two teaching assistants (TAs). Students are taught pre-calculus algebra and trigonometry for two hours per day. The math class incorporates relevant math concepts from engineering labs and service projects that the students are participating in. Additionally, tutoring sessions are available in the afternoon and evening. Classroom TA interacts within the groups to explain and reinforce concepts. In class testing including a final exam determines if E-MAP students are calculus ready.

Living Laboratory

The Living Laboratories are based on the eight areas of engineering at UA and they are taught in multiple blocks to keep student-instructor ratios low and to allow flexibility in scheduling. Each student is required to take four three-hour labs. Students may select three out of nine offered laboratories, the fourth one being assigned by the program coordinators based on student interest and lab availability. The two primary objectives of the laboratories are: the use of math skills in an engineering setting, and student exposure to the practical side of each engineering discipline. The application of math skills in engineering is experienced, for example, by exposing students to "data-gathering" experiments in each laboratory, data is then used to examine, explain, or derive basic engineering theory. The second objective is achieved by giving "broad-picture" engineering problems to illustrate the thought process behind each step of engineering analysis, and to design and teaching students how to break large, complicated projects down into small manageable pieces. This is an opportunity for the departments to immerse the students in the "hands-on" work within each field and assists the student in career selection and development.

Engineering Site Visits

One day per week is dedicated to exposing students to off-campus engineering practice such as plant and project tours. The field trips, ranging from a half-a-day to day long, are designed to focus on one or more engineering career fields. The field trips facilitate student exposure to basic engineering processes, career choices, and potential employers by providing introductions and promoting interactions between students, key industry, government representatives and decision makers. An effort has been made to line up effective speakers, demonstrations and interactive exhibits at functional plant sites so that students are engaged rather than just observers. Engineering, mathematical, and physical concepts key to operations at the plants are explained. An example used for civil and mechanical engineering students include visualization of superelevation, curve design, and torque by tracking vehicle speed on the Barber Motor Sports track and examining race car

engine operation. Aerospace engineering students worked with Boeing scientists at the United Launch Alliance facility on rocket launching projectile motion problem sets. While electrical engineering students experimented with sound vibration devices at Southern Company's Holt Hydroelectric Generation plant. Sponsorship of site visits may change from year to year, however, the project team works to keep consistency where possible. Sometimes this involves working with the companies to tweak concepts to keep things fresh for the professionals as well as E-MAP staff.

Community Service Themed Project

The societal benefit component introduces students to participate as "team engineers" on real-world projects sponsored by the West Alabama Chamber of Commerce's Environmental Task Force. The "Chamber Project" addresses how to research a project, how to work as part of an engineering team, and the thought process in tackling a large engineering problem. Chamber members have been extremely impressed with the student's presentations and their interaction with local engineers. They asked for continued sponsorship of E-MAP as a Chamber outreach program and have helped to advertise activities with the local press. Year two incorporated a real world societal benefit project for the creation of a "theme park" in the Lake Tuscaloosa area (Figure 5). Problems related to the various design aspects were reiterated and reinforced in various program components. A final presentation consists of a student competition judged by Chamber leaders, local engineers, and other community representatives involved. E-MAP staff attempts to keep the project "low-key" as a reinforcement tool where students work during class time, but keep their focus and priority on the program's math skill development components.

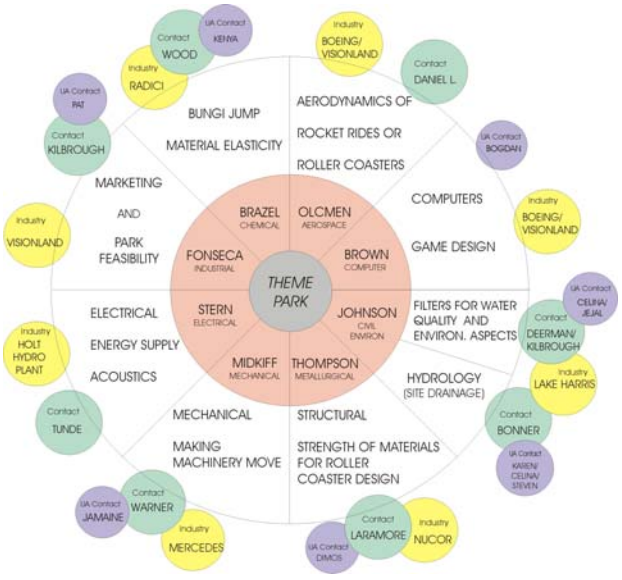


Figure 5: Community Service Themed Project- Water Park

For 2007, the themed project focused on Sustainability, working with the Hale County Empowerment and Revitalization Organization (HERO), a foundation dedicated to helping build low-income housing in rural West Alabama. Students were teamed and asked to work in their engineering discipline areas then tasked with developing ideas related to what an engineer in their field might do in designing a sustainable house. Students were teamed with professional and academic engineers and scientists. Ideas developed included fluid flow for wind maximization through an aerodynamically designed house, a low-cost construction material made from recycled glass and plastic the students called "Glastic"™, and electrical engineering designed wood combustion fueled lighting system. Although they were not required, most student groups built models. All teams are required to learn basic engineering principles and theory that related to their work.

RESULTS

Improved Mathematical Knowledge-

To measure the effectiveness of the E-MAP program at improving the students' mathematical knowledge, the mathematics placement exam was given to the students before arriving for the summer program and at the conclusion of the program during year 2 and 3. The E-MAP students showed an increase (M=54, SD=50.8) in their math placement score. This increase was statistically significant, $t(46)=7.30$, $p<0.01$, one-tailed. The majority (58%) of the participants who were eligible to improve their mathematics placement did so with some of the participants moving two or three classes ahead of their original placement.

Therefore, E-MAP is successful at improving the participants' mathematical knowledge and allowing the participants to begin their college education at a higher level within the mathematics curriculum. This leads to the question of if this increased initial placement within the curriculum reflects a shortening of their undergraduate program by removing one or two mathematics courses.

Success in First Mathematics Course

Although this was not a goal of E-MAP, as a way of measuring the goal of increasing the E-MAP participants' ability to succeed in mathematics courses, the success rate of the E-MAP students was compared to the overall success rate of incoming engineering students with similar mathematics placement exam scores in their mathematics courses during their first semester at the university.

The series of graphs to follow compare E-MAP student's grades with non-E-MAP student's grades from their first college math class again seem to indicate that E-MAP students placing in Calculus 1 (Math 125) after the course seemed to do better than the general population as a whole. E-MAP Students placing in lower math courses seemed to have an elevated withdrawal or incomplete rate over the general population. No direct relationships were observed in the data sets showing good correlations between withdrawal, incomplete, or failing rates except that all these students (for both populations), scored between 200 and 300 on the math placement test (not all students scoring within this range did poorly). Based on this outcome, future work is targeting this sub-population for additional help to change this issue, specifically including use of the ALEKS program, developed by the University of California System with the National Science Foundation.

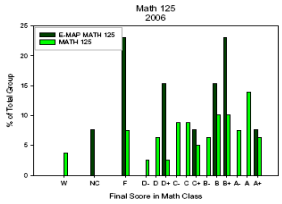


Figure 6: 2006 Math 125 score comparison.

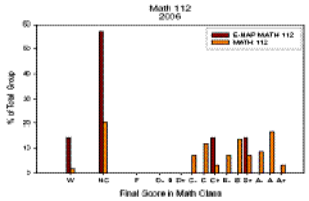


Figure 7: 2006 Math 112 score comparison

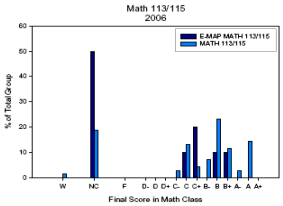


Figure 8: 2006 Math 113/115 score comparison

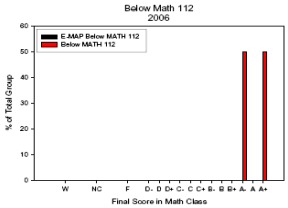


Figure 9: 2006 blow Math 112 score comparison

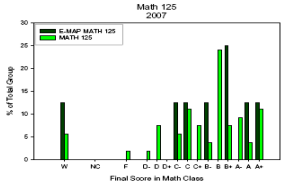


Figure 10: 2007 Math 125 score comparison

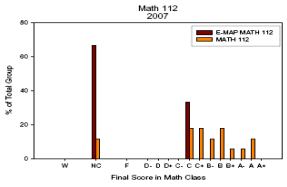


Figure 11: 2007 Math 112 score comparison

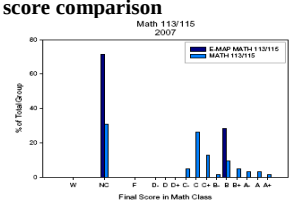


Figure 12: 2007 Math 113/115 score comparison

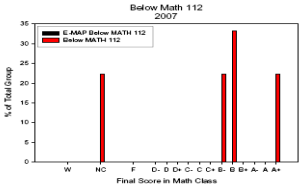


Figure 13: 2007 blow Math 112 score comparison

The data was parsed by ACT score and the E-MAP group and non-E-MAP group was compared. The figures below suggest that within each population there are two subgroups: those that score below 25 on their ACT and those that score above 24. At 25 and above, a correlation exists between the Pre-Math Placement Test and the ACT score grouping. Below 25, there is no strong correlation, suggesting that students in this range of the ACT will probably score within the same distribution.

Interestingly enough, by comparison between Figure 14 and 15, the E-MAP student Pre-Math Placement Test distribution was generally about 100 points lower than the non-E-MAP group. This is due to policy adjustments were by students scoring below 310 were allowed into the program. In 2008, original attendance requirements for scoring pre-calculus level or above was reinstated. Initial examination of student performance for 2008 as measured by the ALEX software is promising.

Subdividing the two populations into two groups each above and below an ACT Math score of 25 gave four distinct distributions. These are plotted on the probability plot on the following page.

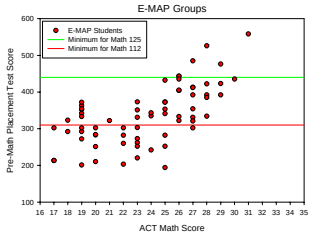


Figure 14: Correlation between ACT Math Score and UA Pre-Math placement test scores in E-MAP groups.

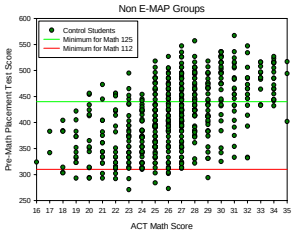


Figure 15: Correlation between ACT Math Score and UA Pre-Math placement test scores in non E-MAP groups.

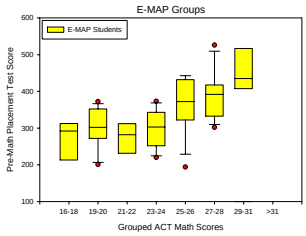


Figure 16: Box plots summarizing correlations between E-MAP student ACT Math Scores and UA Pre-Math placement test scores.

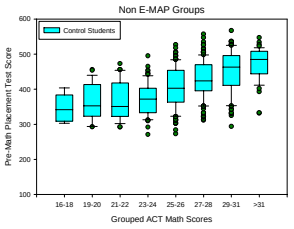


Figure 17: Box plots summarizing correlations between non E-MAP student ACT Math Scores and UA Pre-Math placement test scores.

Figure 18 shows the probability plot of the four data sub-sets. An ANOVA analysis was conducted to ensure statistical appropriateness and significance. The ANOVA confirmed that the subsets are from statistically different populations. This may explain observations from Figures 6 through 13 and answer why

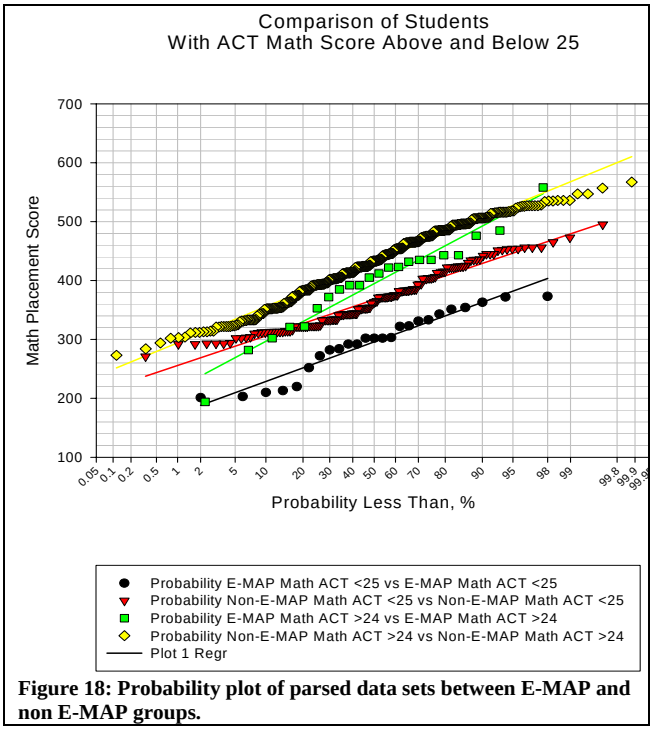


Figure 18: Probability plot of parsed data sets between E-MAP and non E-MAP groups.

a higher portion of the E-MAP students than the control group withdrew from the math classes, while those that stayed performed equally as well as the control. This would indicate that future iterations or similar programs should consider students scoring between 200 and 300 on the Pre-Math Placement test *and* with an ACT Math score less than 24 should be considered a higher risk and given additional instruction.

Retention

One focus of the program goals is to enhance student retention within STEM fields. The data suggests that the program is accomplishing this objective. Below are tables comparing the individual data sets with the data parsed by program year.

The pilot program of 2005 was tracked for retention over the past three years along with the programs for 2006 and 2007. The first subgrouping shows a comparison between those E-MAP students scoring between 310 and 440 (the program target group) on the math placement test and those non-E-MAP students in the same range. Student third-year retention in STEM areas of E-MAP students was 100% for this subgroup compared with only 63.2% of the general STEM students. Examining the entire 2005 E-MAP class, student retention was just over 78% in STEM fields at the end of the third year compared to just over 66% for the control group. First year retention in all cases with E-MAP students was 100% compared to upper 90's for outside students. E-MAP improved retention of students in STEM fields overall by approximately 12%. Note that student status was broken down into those (1) remaining in engineering, (2) leaving engineering and STEM areas, and those (2) leaving engineering but remaining in other STEM areas. This was determined by (A) UA enrollment or (B) direct survey of student if they left the University. A small portion of the students, less than five, who had left the university and were no longer at known addresses were assumed to have left engineering based on their GPA upon leaving.

Conclusions

Based on the 2006 and 2007 data analysis it appears that:

1. The E-MAP program is successful in elevating math placement test scores allowing students to enter college at a higher math level.
2. E-MAP is the most successful with students scoring in the range of 310 to 440 on the math placement test.
3. Students scoring between 200 and 300 on the math placement test have an elevated risk of dropping out of math or failing over other students.
4. E-MAP students outperformed non-E-MAP students in Math 125.
5. 100% of E-MAP students within the 310 to 440 subgroup (the target group) were retained in STEM fields while only 63% of non-E-MAP students at the end of three years.
6. E-MAP improved retention of students in STEM fields overall by approximately 12%.

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