Supporting Engineering Education Through Calculus Success

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CONTEXT
Recruiting and retaining engineering majors in colleges to meet the workforce demand for engineers continues to be challenging. Success in the engineering calculus course sequence is vital to the attainment of this goal. Many universities have seen the need to support students with weak mathematics skills in order to retain a diverse group of prospective engineers. Previous studies have shown that improving precalculus can be effective in improving placement scores for enrolling in the first engineering calculus course.

PURPOSE
The purpose of the study is to compare engineering calculus success, throughout the sequence of three courses, between students who took the PPP and those with similar scores who chose not to participate in the PPP.

APPROACH
The Department of Mathematics at one of the university in central Texas implemented a summer bridge program to strengthen precalculus background for engineering majors, with the goal of increasing success in the three engineering calculus courses sequence. The program was offered for a modest fee to students who did not meet the cut score on the Mathematics Placement Exam (MPE). The program consisted of 36 hours of instruction with an online tutor in addition to online quizzes, practice problems, and book. The summer intervention allowed students to strengthen skills for success on the MPE so that they could take engineering calculus and complete the calculus course sequence for engineers.

RESULTS
It is expected that students who participated in the PPP will fare as well as or better than those with similar MPE scores and chose not to participate. Early results show that the program benefits both genders and all ethnic groups. The PPP is expected to provide students will the start they need to be successful throughout the engineering calculus sequence.

CONCLUSIONS
Bridge programs have most typically involved either face-to-face instruction or asynchronous online instruction. However, an online bridge program with both asynchronous and synchronous components can be successful in strengthening mathematics skills in order to reduce attrition in engineering majors as a result of difficulties in mathematics.

KEYWORDS
Bridge program, engineering calculus, precalculus.

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Introduction

Retention of engineering majors is an important objective supporting the goal for sufficient engineers throughout the world to address world-wide problems in society, including the grand challenges identified by the National Academy of Engineering. Thus institutions of higher education are interested in solutions to the problem of retention in engineering majors (Augustine, 2007; PCAST, 2012). Their efforts include identifying causes of attrition and finding ways to support students in a variety of ways (French, Immekus, & Oakes, 2005; Hieb, Lyle, Ralston, & Chariker, 2015).

Researchers in countries around the world, including the Africa, Australia, Canada, New Zealand, United Kingdom, and the United States have reported similar results about retention in engineering majors. Among the causes of attrition in engineering majors was deficiency in mathematics skills, mathematical problem solving, and lack of conceptual understanding (Beanland, 2010; Fowler, Maxwell, & Froyd, 2003; Gleason, 2010; Miller-Reilly, 2007; Nite & Allen, 2014; Ohland & Crockett, 2002; Parsad & Lewis, 2003; Tolley, Blat, McDaniel, Blackman, & Royster, 2012; Waits and Demana, 1988). Students who were fluent in working with functions (Fisher, 1996) or independent thinkers (van der Hoff & Harding, 2016) have been more successful in calculus. Factors affecting student mathematics preparation for college mathematics included the number of mathematics courses taken at the secondary level (Gleason, 2010) and SAT math scores (Hieb, 2015). Complicating the mathematics issue was the fact that difficulty in mathematics courses tended to decrease motivation to study the subject (Gula, Hoessler, & Maciejewski, 2015; Kinnari-Korpela, 2015). Retention in engineering has been linked to success in the first college mathematics course (Budny, LeBold, & Bjedov, 1998) and the overall grade point average in the first semester (Hieb, 2015). In particular, a strong calculus background was important for success in engineering majors (Hieb, 2015). However, poor achievement in mathematics did not always mean students would not succeed (Hieb, 2015). Many other factors besides mathematics knowledge play important roles in engineering success in retention. Those factors include personality characteristics, study skills, and opportunities to develop a sense of belonging in the field (Gleason, 2010; Hieb, 2015; Miller-Reilly, 2007). Engineering education programs across the globe are implementing programs and strategies to increase recruitment and retention of a diverse population of students. Mathematics is the focus of many bridge programs because of its importance as a foundation and the clear need for improvement in that area. Technology has often been a part of the solution to provide practice problems with immediate feedback (Babaali & Gonzalez, 2015) or video lectures (Kinnari-Korpela, 2015). Some programs were held face-to-face (Miller-Reilly, 2007) and included hands-on experiences (Gleason, 2010; Hieb, 2015; Reisel, Jablonski, Hosseini, & Munson, 2012). Bridge program fight an uphill battle with academically underprepared students, but universities continue to search for methods to support students who desire engineering careers. Some revisions and refinements in bridge programs include more detailed feedback online practice problems (Babaali & Gonzalez, 2015), hands-on learning (van der Hoff, & Harding, 2016), social connections (Gleason, 2010; Miller-Reilly, 2007), learning strategies and motivational factors (Hieb, 2015), and varying the length of the intervention (Nite, Morgan, Allen, Bicer, & Capraro, 2016).

Methodology

Texas A&M University experienced the same challenges as others mentioned in the introduction to the study. In response, a summer bridge program to strengthen precalculus skills, the Personalized Precalculus Program (PPP) was created and offered to students who placed below the cut score of 22 out of 33 on the Mathematics Placement Exam (MPE), required to enroll in the first engineering calculus course. Students who chose not to participate or whose scores on the MPE after the PPP did not meet the cut point were required to take a semester-long precalculus course. The PPP was six weeks long and consisted of asynchronous and synchronous online components. The asynchronous component includes slide presentations, practice problems, and quizzes over topics such as functions and graphs, transformations, composite functions, algebraic fractions, factoring polynomials, solving equations and inequalities, and trigonometry basics. There are many face-to-face and online bridge programs, but the unique characteristic of this bridge program is the synchronous online feature. The synchronous component consists of 36 hours online, in small groups, with a tutor. Participants can be separated into virtual rooms where they work on a whiteboard, individually or in pairs, on problems the tutor assigns. The tutor moves through the rooms, answering questions and providing guiding questions to the participants. Then the tutor can bring the whole group together again and discuss any common problems that arose and correct misconceptions.

Studies reporting the results of the PPP in raising MPE scores to allow incoming freshmen to enroll in the engineering calculus sequence in the fall (Nite, Allen, Sledge, & Whitfield, 2012; Nite & Allen, 2014), improving knowledge and confidence in trigonometry (Nite, Allen, Bicer, & Morgan, 2016), and increasing success in the first engineering calculus course (Nite, 2012; Nite, Capraro, Morgan, Peterson, & Capraro, 2014).

The aim of the Personalized Precalculus Program (PPP) was to increase freshman engineering students' mathematics abilities to enable them to succeed in engineering calculus I. The Mathematics Department at Texas A&M University implemented the PPP program in the three consecutive years during summer of 2011, 2012, and 2013. Participation in the PPP program was optional, and it was strongly suggested to students whose MPE (Mathematics Placement Exam) scores were below 22. This cut score was determined as the minimum score of the MPE for which students have the necessary mathematics knowledge to be successful in engineering calculus. Those who scored below 22 were placed into a precalculus class. The participants enrolled the PPP program in a 6-week long received necessary mathematical knowledge and skills intervention for success in engineering calculus. In order to understand the effects of the PPP program in students' engineering calculus courses, two groups of students were purposefully selected as students with scores below 22 who enrolled in the PPP (N = 45) and students with scores below 22 who did *not* enroll in the PPP (N = 730). The two groups of students' course grades in the three engineering calculus courses were analyzed to see whether their mean scores were statistically significantly different by their groups. Applying the *t-test* was the appropriate analytic technique when the two groups' comparison of researchers' interests. A *t-test* in *SPSS 23* was applied. In addition, gender comparison of mean scores was conducted. Reporting effect sizes are suggested whenever statistical analyses are conducted to show the effects of intervention (Thompson, 2008).

Results

Students who attended the PPP were marginally more successful in Engineering Calculus I (see Table 1 for grade point averages), earning a higher percent of A's, B's, and C's in the course (66.4%) than students who did not participate in the PPP (63.9%). Although D is considered a passing grade, engineering students must earn a C in order to progress to the next course in the sequence. Effects of the PPP on student success, in terms of average grade and number of A's, B's, and C's, in the engineering calculus series seemed to lessen as students moved through the sequence. However, PPP students received more As and Bs (44.4%) in engineering calculus III than students who did not attend the program (42.2%). Cohen's *d* effect size of the mean differences between grades of students in the PPP and students *not* in the PPP, though positive, was small at .05 compared to effects in other bridge program studies.

Table 1 shows the grade point averages, on a 4-point scale, where 4 = A (90-100%), 3 = B (80-89%), 2 = C (70-79%), 1 = D (60-69%), 0 = F (<60%). Also counted as F were those who dropped the course or withdrew from the university during the semester. In this grading system, there were no grades between these, such as A+ and A-. This could be a reason it was not possible to see more differences in the averages grades.

The results indicated that there was not a statistically significant difference ($p > .5$) between students who attended PPP and students who did not attend PPP on their mathematics mean scores in the third engineering calculus course (See Figure 1).

Table 1: Grade Point Averages for Engineering Calculus Courses

	Mean	Standard Deviation	N
Engineering Calculus I - PPP	1.83	1.272	134
Engineering Calculus I – non PPP	1.79	1.317	1811
Engineering Calculus II – PPP	1.63	1.331	57
Engineering Calculus II – non PPP	1.79	1.232	1090
Engineering Calculus III – PPP	2.04	1.224	45
Engineering Calculus III – non PPP	2.16	1.163	730

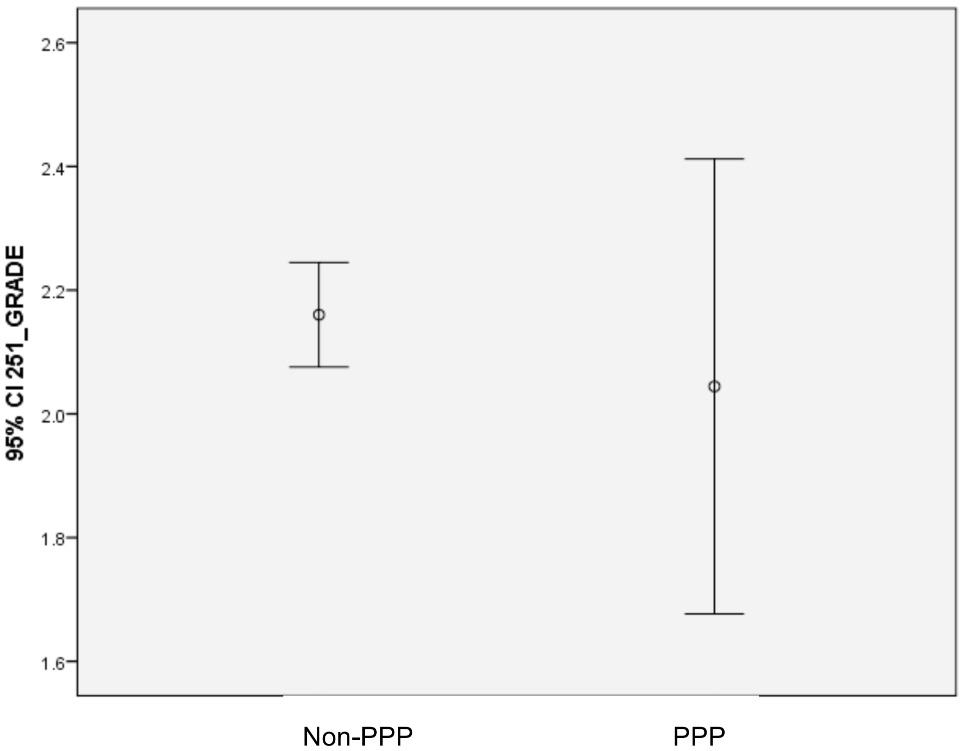

Figure 1: Engineering Calculus III Grades

Then, another focus of the present study was the investigation of the effects of the PPP program by gender. The results showed that the effects of participating or not participating in the PPP were not statistically significantly different from each other for males and females ($p > .05$) (See Figure 2).

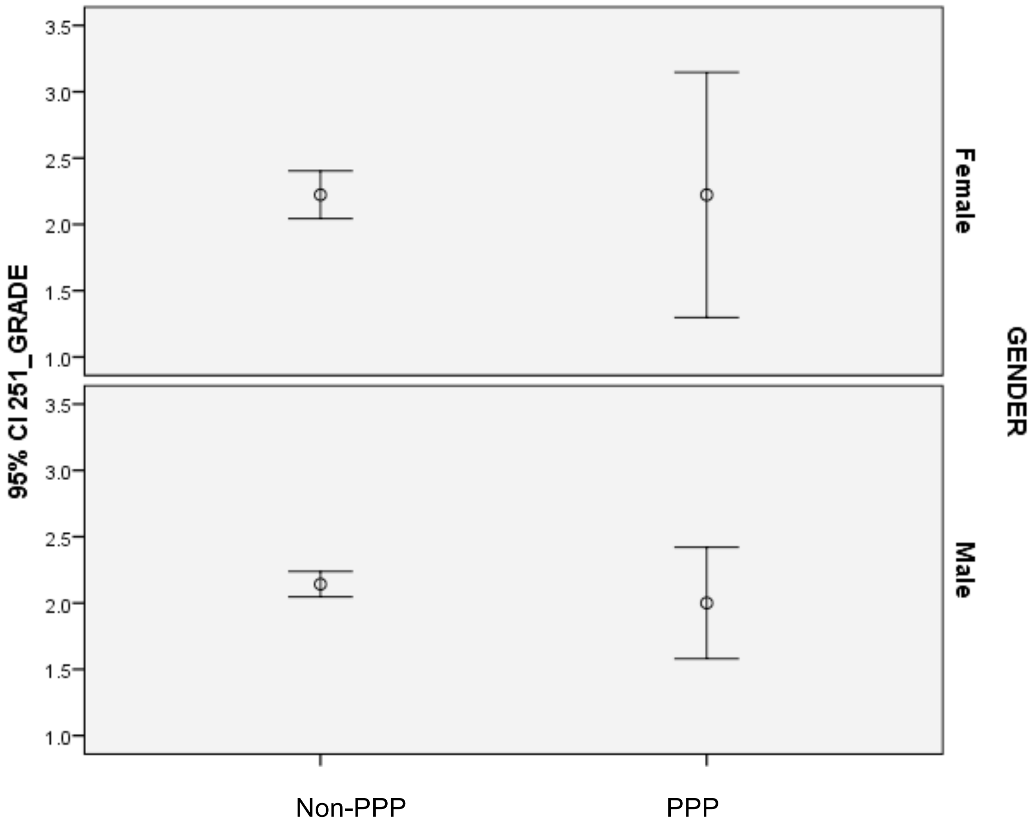

Figure 2: Engineering Calculus III Grades by Gender

Conclusion

The main effects of the present study were to reveal the long-term effects of the PPP program on engineering students' college mathematics success. Although our results showed no statistically significant difference ($p > .05$) between students who attended PPP and students who did not participate in the PPP, the results should be evaluated cautiously. The most distinct difference between the two groups was the length of the program students received. While students who attended the PPP received 6-weeks intervention, students who did not attend the PPP received a semester-long instruction. Students take the Mathematics Placement Exam (MPE) before entering as a freshman. If they score below 22 out of 33, they are placed into a precalculus course. They are offered the opportunity to take the PPP and retake the MPE. If their scores increase to meet the cut score, they may register for Engineering Calculus I. Otherwise, they must take the precalculus course. Participating in the shorter program, the summer PPP, but receiving the same scores may be important because of the time and money saved. The cost for participating in the PPP was much less than the cost of taking a college course. In addition, students who were not placed in the first engineering calculus course could not begin the engineering course sequence, delaying graduation for at least one semester. Thus, bridge programs can be very beneficial to engineering students to prepare them to begin on target for graduation and enter the engineering calculus course sequence at the same level as similar students who do not participate in bridge programs. As the need for engineers throughout the world continues to exist, programs to increase recruitment and retention of a diverse group of students remains a challenge. Mathematics bridge programs are one important part of that initiative.

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