Improving Success in Engineering Calculus: Design of a Bridge Program

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Structured Abstract

BACKGROUND

Bridge programs to strengthen mathematics skills for students who aspire to be engineers have been instituted at universities for over 20 years. Most of them have faced similar challenges, but at the same time have shown positive results. Generally these programs involved face-to-face instruction, although more recent ones have incorporated mathematics skills software for the purpose of improving test scores for placement into first semester engineering calculus. In addition, some universities have established programs to support students who are struggling during the first semester. Focus of summer programs has been on students whose scores fall below a required cut score for entry into engineering calculus or an engineering program rather than students who have already met the required score. Recruitment and retention in bridge programs has been challenging because very few are mandatory.

PURPOSE

The hypothesis is that a new type of bridge program can be designed based on prior experiences and knowledge to a) attract at-risk students who already placed into Engineering Calculus I as beginning freshmen and b) improve confidence and mathematical knowledge for the students who participate.

DESIGN/METHOD

Results from prior bridge programs at other universities were studied through a literature review. In addition to that knowledge, data from grades and surveys with other bridge programs at our own university were used to design the new program.

RESULTS

A new bridge program was designed, based on prior knowledge and experience. The program attracted 200 students who were placed into Engineering Calculus I as beginning freshmen. Although the surveys are not complete and a number of students did not complete the course, the responses submitted so far show that over 90% of the students feel better prepared for Engineering Calculus I.

CONCLUSIONS

It is expected the new bridge program will continue to be offered. Although it cannot be offered free in the future, it is expected that the fee necessary to sustain it will be small enough that students will continue to enrol.

KEYWORDS

Calculus, bridge program

Introduction

Mathematics success is critical to success in virtually all engineering majors. Ability to provide the expected need for engineers in the United States in the future depends on the ability of universities to improve recruitment and retention of students in engineering fields (Augustine, 2007; PCAST, 2012) Attrition in the engineering degree pipeline is highly correlated to student performance in college calculus courses (Waits & Demana, 1988). Bridge programs to increase engineering success were prevalent in the 1990's, and they continue to be designed and utilized. In 2002, a classification of programs published was compiled, but there was not sufficient data for a meta-analysis (Ohland & Crockett). Several common features were cited, including the following:

- Bridge programs have successfully increased scores on assessment.
- Few programs are compulsory; thus they face challenges in convincing students to take advantage of the opportunities afforded them.
- Training in skills is common, and mathematics is the most common subject addressed by skills training, likely because it is the most commonly cited as the most difficult for students matriculating to college.

A meta-analysis of bridge programs focused on mathematics instruction was conducted some six years later (Papadopoulos & Reisel, 2008). Even at that point in time, only 12 summer bridge programs for new engineering freshmen with mathematics deficiencies were identified and studied. Eight of those programs lasted 4-6 weeks, while only one had a shorter program. Purdue's one-week program was intense, with students spending about 8 hours a day immersed in solving mathematics problems. The total amount of time was comparable to the longer programs (Diefes-Dux, 2002). Although small percentages of eligible students participated in the bridge programs, high percentages of those who completed the program increased their mathematics scores (Diefes-Dux, 2002; Papadopoulos & Reisel, 2008).

At the University of Wisconsin-Milwaukee, a bridge program that began in the summer of 2007, focused on precalculus instruction. The program was free and lasted four weeks, after which students retook the Math Placement Test. This appears to be the first program reported with an online format; others used computer-based instruction with an in-class format. Students were given the choice between an in-class format, four days a week for four hours a day or a distance online format. The online format was discontinued after two years because student completion rates and score increases were low. Students also spent far less time, on average, working on the mathematics (Papadopoulos & Reisel, 2008).

Although bridge programs were generally conducted in the summer, West Virginia University offered a calculus readiness course during the second half of the semester to support students who withdrew from Calculus 1 with failing grades. The intent was to remediate mathematical skills to help students succeed when they retook the course the following semester. Students who participated in the intervention had an approximately equal probability of success on the second attempt at Calculus 1 as the group entering Calculus 1 for the first time. Thus, the program was successful in increasing success in Calculus 1 and retention in engineering majors (Hensel, Sigler, & Lowery, 2008). The advantage of this program was that students who were failing but wanted to remain in an engineering major were more likely to not only realize their need for help but also complete the intervention program.

Bridge programs aimed at increasing retention in engineering by strengthening mathematics skills continue to be introduced because lack of proficiency in mathematics continues to cause roadblocks for students. Later programs used additional technology to individualize mathematics instruction and practice for students (Boykin, Raju, & Bonner, 2010; Reisel, Jablonski, Hosseini, & Munson, 2012). A program that offered students a choice of face-to-face or online mathematics instruction found that the online program was not effective and discontinued that format. However, the design of the program did not involve live interaction with a tutor, and students were not able to receive immediate answers to questions because they had to rely on email for a response from tutors or instructors (Reisel et al., 2012)

Bridge programs have faced several issues in common over the years. One of the greatest challenges was convincing students that they needed to improve their mathematics background. Because most programs were voluntary, they needed to spend considerable time refining their recruiting techniques in order to draw in students who could benefit most from the program. Students with especially low test scores, either ACT or campus-based mathematics tests, often realized the need, but students with borderline passing scores were also at risk. A second challenge was retaining students throughout the program. A related concern was that students would drop out or decrease their efforts as soon as they thought they were able to retake the placement test and score high enough to move one. Again, they did not understand that the risk of failure was still high for them. Typically, less than half students who qualified to participate in the bridge programs did so, and often the completion rate was low (Reisel et al., 2012).

History of Bridge Programs at Texas A&M University

With support from the National Science Foundation (NSF-DUE 0856767), the Department of Mathematics at Texas A&M University created a Personalized Precalculus Program (PPP) to enable students to improve scores on the Mathematics Placement Exam (MPE) so they could meet the score needed to enrol in Engineering Calculus I. Based on the success in the PPP, an additional one-week Bridge to Engineering Calculus II was designed and offered between Fall 2013 and Spring 2014 semesters to students who earned a B or C in Engineering Calculus I. In both bridge programs, one significant difference from most online programs was the use of live online tutoring sessions that students were required to attend.

Precalculus Summer Bridge Program

During the summers of 2010-2013, the 36-hour PPP was a 6-week program, during which students met with tutors three times a week for two hours each meeting. The program focused on four major areas: (1) Graphs and Functions; (2) Factoring and Solving Equations and Inequalities; (3) Algebraic Fractions, Exponents, and Radicals; and (4) Trigonometry. The design of the PPP was very similar to the summer bridge program at University of Wisconsin-Milwaukee (Reisel et al., 2012) with one major difference. Although the PPP was fully online, it contained synchronous sessions with tutors. Students and tutors used headphones to communicate online as they discussed mathematical concepts and worked problems together as a whole, pairs, or in small groups. The online environment and its features are described more fully in the design section about the Bridge to Engineering Calculus I below.

Often students do not realize the importance of fluency in mathematics in preparation for engineering coursework, about 200 of the 600 students eligible for the PPP in summer 2010 took advantage of the opportunity. Challenges to recruitment and retention in the PPP include overcoming students' beliefs of understanding the material because they previously had it in high school. Additionally, they are advised by calculus students who downplay the importance of strengthening the precalculus background. Students also need to recognize that the probability of success in the calculus sequence is very low if they do not earn an A or B in precalculus (Allen, Nite, Pilant, & Whitfield, 2013). Another barrier to student success in college calculus is their lack of experience with appropriate learning strategies. Student surveys from the summer 2013 PPP showed that students overwhelmingly learned to solve mathematics problems in high school by imitating the teacher's solutions to specific types of problems; however, they believed they needed a different approach for college calculus (Nite & Allen, 2014a).

Although recruitment and retention for the PPP were challenging, approximately 500 students have benefited from participation over the years 2010-2013. Average increases in MPE scores were about 7 points on a total of 33 points (Nite, Capraro, Morgan, Peterson, & Capraro, 2014; Allen, Nite, Pilant, & Whitfield, 2013). More importantly, half of the students from the summer 2011 PPP who completed the program and raised MPE scores sufficiently (22 out of 33) to advance to Engineering Calculus I successfully completed the course and stayed on track to enter engineering coursework in the Fall semester (Nite, 2012).

Bridge to Engineering Calculus II

After three years of encouraging results of the PPP, a second bridge program was developed to serve students who struggled in the first engineering calculus course. The one-week Bridge to Engineering Calculus II was offered between Fall 2013 and Spring 2014 semesters to students who earned a B or C in Engineering Calculus I. Topics covered included: derivative rules for various types of functions, including the chain rule; graphing concavity, critical points, and optimization; integration; partial fractions; and simplifying derivative results. Over 100 students registered for the free program, but only 41 completed the coursework and the survey after the second exam. Of the 41 students, 18 had earned a B in Engineering Calculus I, and 23 had earned a C. Less than half of those students reported that they had understood the material in the course, and more than half reported that they never spoke up in class. Reasons for not participating in class discussion or answering questions was because they were not confident, were intimidated by large class sizes, or were afraid they might be ridiculed. However, 86% felt that they were better prepared for Engineering Calculus I after completion of the program. As expected, students who spent more time in the program also felt more strongly that the program improved their preparation for Engineering Calculus II. In addition, there was a positive correlation between feeling of preparedness for Engineering Calculus II and belief that the online learning environment was at least as effective as a face-to-face environment would have been. Midterm course grades for Engineering Calculus II were positively correlated with final course grades for Engineering Calculus I, indicating that students were able to maintain grades throughout the calculus sequence rather than dropping lower (Nite & Allen, 2014b). As shown in Figure 1 the average grade was not statistically significantly different, nevertheless, the grade difference for students who spent more than 820 hours in the bridge program could have resulted in a letter grade difference. Although the number of students in Engineering Calculus I in the spring was much lower than in the fall semester, 77 students registered for the Bridge to Engineering Calculus II course offered at the end of summer 2014. Success rates will be calculated after the completion of the Fall 2014 semester when the students complete Engineering Calculus II.

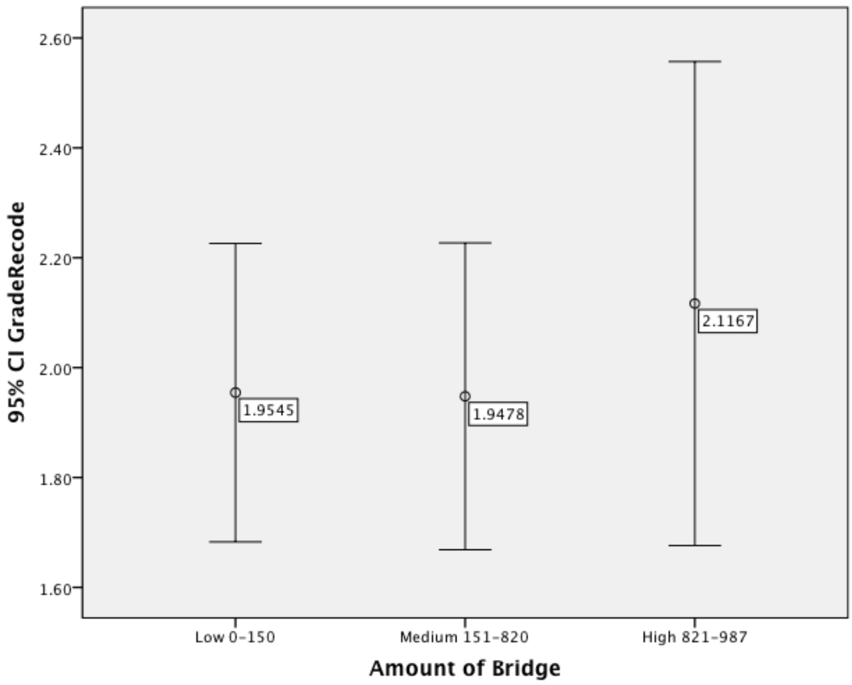

Figure 1: Average Grade Point Versus Time Spent in Engineering Calculus II Bridge

Design of New Bridge to Engineering Calculus I

The PPP was designed to improve mathematics skills for prospective engineering students who did not the meet the cut score on the MPE to qualify for enrolling in Engineering Calculus I during their first semester in college. However, professors of the engineering calculus sequence noted that many students who met the cut score were still deficient, and students whose scores were borderline were especially at high risk of not completing the entire engineering calculus sequence successfully. The subsequently designed Bridge to Engineering Calculus II resulted in 86% of students believing that the program better prepared them for the course in a survey administered after the second exam in Engineering Calculus II. In a continuing effort to improve success in the calculus sequence for engineering majors, the Department of Mathematics designed a one-week Bridge to Engineering Calculus I program to better prepare students who may be deficient in knowledge and skills needed in particular mathematics topics that are important in calculus applications. The program was different from the PPP because it was offered to students who had already qualified to enrol in Engineering Calculus I, based on their MPE scores. As noted with past bridge programs at other universities, there was concern that students who met the cut score were even less likely to take advantage of a bridge program than those who did not score high enough to take the course. It was decided that students were unlikely to take a course that simply reviewed material they believed they already knew. However, instructors of Engineering Calculus I cited trigonometry, parametric equations, and vectors as topics that were difficult for students. Results of surveys in the PPP revealed that students realized their knowledge of trigonometry was deficient, and they were not confident in their abilities to be successful with calculus problems that required knowledge of trigonometry. Parametric equations and vectors were two topics that were expected to be covered in high school precalculus because they were included in the state standards. However, faculty members with ties to the K-12 community realized the topics were often omitted or addressed only briefly. Although many university level first semester calculus courses in the state did not cover those topics, and they were reserved for AP Calculus BC rather than AP Calculus AB, the first semester calculus at Texas A&M did cover those topics. Professors were aware of the situation and treated the topics as new concepts for students. However, it was decided that the exposure to these topics before encountering them in Engineering

Calculus I would decrease the amount of completely new information, increase student confidence and level of success, and perhaps also entice students to participate in the new bridge program. Based on this information, positive student responses to the PPP and the Bridge to Engineering Calculus II, and lessons learned from the first two programs, the third program - a one-week Bridge to Engineering Calculus I was developed. Students who (a) took the PPP earlier in the summer and improved their MPE scores to meet the required score, (b) met the required score but at a lower level, making them still at risk for failing Engineering Calculus I, or (c) successfully completed the precalculus course at Texas A&M but still felt they were deficient in the topic areas listed were eligible to participate in the program.

As a result of experiences described, the Bridge to Calculus I program was designed to run for a period of five days, three hours per day, for a total of 15 hours of instruction. Live online tutors were provided with 15 Power point presentations that included an outline of the instructional points to be addressed, several example problems for the tutor to work and explain, and several problems for the students to work during the session. Three-hour sessions were set up for morning and afternoon, and students were able to make a choice of time frames best fitting their schedules. They were then assigned to a particular tutor. Students received links to their sessions in Blackboard Collaborate each day. The online environment in which the tutors worked with the students had several features that were particularly important for the program:

- Tools to allow tutors to write on the slides in order to
    - highlight and emphasize phrases or formulas in the notes
    - work example problems on the slides
- Voice-over IP (VOIP) so tutors and students could wear headsets and talk online with each other
- Online breakout rooms so tutors could place students in working groups to solve problems
- Recordings of sessions so that students could watch again later or watch missed sessions

In addition to the problems students worked together online, a set of problems with answers was provided to students for additional practice outside sessions. Students could ask tutors about them in session or by email, if needed. Videos developed over the trigonometry topics were made available, and links to freely available videos for vectors and parametric equations were provided to students on a webpage. Over 200 students registered for the program, but many did not complete the entire week. In addition to the retention issues faced by many bridge programs, students who were enrolled in the first semester of calculus for mathematics majors and the first semester of calculus for biology majors were invited to participate The biology major calculus did not require vectors or parametric equations, and students who knew that may have dropped out at the end of the trigonometry review. It is anticipated that students who completed the Bridge to Engineering Calculus I will be more confident in their knowledge and abilities in the mathematics required for Engineering Calculus I. Although not all surveys have been submitted to date, over 90% of those submitted so far indicate that the students felt better prepared for Engineering Calculus I after participating in the bridge program.

Conclusions

Bridge programs are not new, and reported success is mixed for remediating mathematics skills (Papadopoulos & Reisel, 2008; Reisel et al., 2012). Short-term bridge programs with a narrow focus on very specific known deficiencies in mathematics needed for calculus can be very effective in increasing confidence as well as filling gaps in mathematical knowledge. Although the first year of Bridge to Engineering Calculus I was just completed, it is expected that students' knowledge and understanding of the topics addressed will increase. There was no content knowledge pre-test or post-test administered for the new bridge program, however, a survey conducted at the conclusion of the summer and again after students have scores from their first exam includes questions about their knowledge and confidence beliefs in their abilities to successfully complete the course. A similar survey was given to the small group in the Bridge to Engineering Calculus II pilot in January 2014, and results were favourable (Nite & Allen, 2014b). After students received scores from the first test and took the second test, those who completed the survey believed they had increased content knowledge from the bridge program and were more likely to be successful in passing the course with an A, B, or C. Additionally administering a similar survey at the end of the Bridge to Engineering Calculus I and again after the first exam grades are known, results of course grades will be compared with the grades of students with MPE scores in the same range to determine whether participants in the program are more successful. Over time, retention will also be examined. It is expected that the combination of three bridge programs will serve a large number of at-risk students who desire to major in engineering but do not begin their academic career with the requisite mathematics skills. It is believed that mini-bridging type programs may be suitable for many STEM continuation course sequences, such as Chemistry I and II, where underperformance in the first puts students at serious risk in the second. Such bridging interventions are relatively inexpensive to operate and indicate a substantial benefit to participants.

The centrepiece of the bridge program is the required live online tutoring sessions. As with other online programs, students appreciated the ability to watch a recording. As one student stated, “if I ever misunderstood or forgot how to attach a problem, I could always go back to the recording and view class all over again.” However, the success of our online program has much more to do with the live tutoring component. Another student “felt it was able to be much more one-on-one, and much more interactive” than a typical classroom environment. The online tutoring was the most popular component of the program. Although students had access to tutors by email, but they preferred to wait until the tutoring sessions to ask questions about the mathematics. Tutors were described as “awesome,” “excellent,” “very good,” “great,” “patient,” and “encouraging.” “She would work out and explain difficult problems, and she kept it interactive which helped keep everyone involved and learning.” Students commented positively about the features of the online environment that allowed them to work individually or with another student in a separate online room and to discuss solutions of rigorous problems. These are reasons we expect the new bridge program to be successful (Nite, 2012).

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