Design of an International Bridge Program for Engineering Calculus

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Abstract. A large university in the southwest U.S. established a bridge program for incoming freshmen to increase success in engineering calculus and retention in engineering majors. The program was initially grant-funded but became institutionalized because of continued success. Participants in the program who were at high risk of failure in mathematics, based on the mathematics placement exam (MPE), performed as well in their first semester as their peers who had scored higher on the (MPE). The program was fully online, consisting of practice problems, quizzes, example videos, textbook, and required time with a live tutor (online). The original program spread the 36 hours of tutoring over six weeks, and the revised program compressed it into three weeks. The content of the program was used as a basis of a face-to-face bridge program at an engineering school in the western Asia. The same MPE and cut score were used at both campuses. However, the program was adapted from a fully online to a fully face-to-face program. In addition, different educational experiences for the students in the western Asia were taken into account in the teaching strategies implemented. Students in the western Asia campus were somewhat stronger in symbolic manipulation and use of formulas to solve standard problems. However, they had little experience with problems in a real-life context. The instruction on the same mathematics content involved hands-on activities designed to deepen understanding of mathematics concepts, laying a stronger foundation on which to build calculus knowledge and skills. Students were presented with real-life data and asked to work collaboratively to analyze and find a function to model the data. They learned how to utilize a graphing calculator to aid their understanding of the relationship between graphs and their equations and find solutions to problems that did not lend themselves to traditional algebraic manipulation. In the second year of the program, additional time was allotted to the program, making room to add another small component. Because spatial visualization is so important in engineering, activities were added to support improvement in this area. Students explored spatial relationships of 3-D objects through a drawing task, paper models, and computer simulations. Through the development of these two bridge programs that addressed primarily the same mathematics content to support engineering calculus concepts and skills, we can see the possibilities to adapt a program to different groups of students to achieve greater success. This paper describes the design, similarities, and differences of these programs along with quantitative data results.

Introduction

Struggles in mathematics knowledge and skills remain an issue for students in engineering everywhere [1]. One of the supports that many colleges have provided is a summer bridge program. There are many variations on those programs [2] and reports of success [3], [4], [5], but relatively little strong quantitative results [6]. Successful bridge programs generally utilize a lot of money, time, and effort [7], but they can especially help address inequities for subpopulations such as first generation college students and low socio-economic students [8], [9].

At the main campus of a large university in the southwest U.S., in about 2000, the mathematics department began administering the (MPE) for incoming freshmen to determine their placement in Precalculus or Calculus I. Previously high school GPR and SAT scores were used to advise students on the most appropriate course. The MPE was a paper-based, multiple-choice exam, and the exam scores were subsequently compared with final grades in the two courses. With encouragement from the College of Engineering, the MPE was instituted as a placement exam, and it was placed online in 2007. Questions on the MPE were grouped into the following subscales (number of questions): Exponential (4), Polynomial (6), Graphing (5), Functions (5), Trigonometry (5), Power Rules (4), and Problem Solving (4). Before students attend the New Student Conference, they are expected to take the MPE online so that they could register for classes when they arrive. The MPE continues to be required for all entering STEM majors for placement into precalculus or calculus. There are 33 questions on the MPE, and students are required to correctly answer 22 questions to enroll in Engineering Calculus I. Each of the 33 problems has multiple iterations, creating the possibility of hundreds of different exams as one of each is chosen randomly. The total number and types of problems have remained constant, but in 2014 changes were made to a few of the problems. Two examples are given:

1) Original problem: Consider the line passing through the points (5, 10) and (8, 19). Which of the following points also lies on the line?
   Revised problem: Find the equation of the line passing through the point (-4, 2) that is perpendicular to the line $3x + 5y = 6$.
2) Original problem: Soap powder is paced in cube-shaped cartons. One such carton measures 8 cm on each side. The company manufacturing these cartons decides to increase the length of each edge of the carton by 15 percent. How much does the volume increase?
   Revised problem: A closed box has a square based with side length l feet and height h feet. Given that the volume of the box is 36 cubic feet, express the surface area of the box in terms of l only.

Utilizing funding from the National Science Foundation (NSF), a bridge program to strengthen precalculus skills, the Personalized Precalculus Program (PPP), was created [10]. The purpose of the PPP was to increase retention in engineering majors by strengthening mathematics skills before students began their university studies. The program was completely online, with practice problems, quizzes, videos, PowerPoint documents, and a textbook. However, an additional, critical component was live, online tutoring sessions that were required of all participants [11]. For the first three years of the program, incoming freshmen participants worked through the PPP and met with tutors 36 hours over a six-week period. Then the program was concentrated into three weeks, with the same number of online tutoring hours [12], [13]. The main topics covered, based on deficiencies identified from MPE scores over about 10 years were Graphs and Functions; Factoring and Solving Equations and Inequalities; Algebraic Fractions, Exponents, and Radicals; and Trigonometry.

The PPP components consisted of online videos, textbook, practice problems, and quizzes. The videos were about 5-8 minutes long, each addressing concepts or example problems from the main topics listed above. The online venue, WebAssign®, contained a personalized study program (PSP), which was utilized. The PSP had a bar to indicate progress, and the bar turned from yellow to green when the student reached the passing level on the practice problems, which were algorithmic problems so that they could be practiced repeatedly for mastery. The videos and textbook were available but not required for use by the students. However, they were required to participate in live, online sessions with a tutor. For these sessions, each tutor had a group of no more than 20 students. The tutor explained problems on which students asked for help. She/he put the students into breakout rooms individually or in pairs to work problems she assigned. She could then rotate throughout the rooms to see how they were progressing in working the problems on the whiteboard, to listen to the discussion, and to ask or answer questions to help students understand the problems. The tutor met with the group for 36 hours during the summer PPP. At the end of the PPP, students retook the MPE to see whether they could meet the score required to register for engineering calculus I.

Methodology

The university in the U.S. has a branch campus in western Asia. This campus also wanted to strengthen precalculus skills for incoming engineering majors to prepare them for engineering calculus I. The same MPE is used to place students, and the same content is covered in Precalculus and Calculus I. It was determined that a face-to-face program would better serve the students at the branch campus in the Asian country. Students on the main campus were spread over a much larger geographical area and worked in the summer. The online program allowed them to work in their hometowns and still participate in the summer program. However, the students in Asia came from a very small geographical area, and few needed to work summer jobs. The classes on that campus were also taught in English, but the students' first language was not English. For these reasons, the face-to-face program was more appropriate.

Because the content in both locations was the same for the courses into which students would be placed, the topics would likely be the same because the challenging topics in mathematics seem to be somewhat similar across various institutions. To verify this, the MPE results were examined to determine what students missed most. Thus, the same topics were covered at the Asian campus. The face-to-face format lent itself to a more hands-on, inquiry approach to facilitate deeper understanding of the mathematics concepts. The same practice problem sets were used, but they were in paper format rather than online. Class time was spent on real life examples, hands-on activities, direct instruction, practice problem sets, and students presenting their work and explaining to their fellow students using an electronic whiteboard.

As was true for many of the students in the U.S., the students in Asia had been primarily taught by learning rules and applying them to the problem sets they solved. They sometimes confused the memorized rules, and class time included opportunities to discuss and make sense of those rules as well as the hands-on activities to explore how the rules worked. Unlike many students on the main campus, the students in Asia had not solved problems in a real life context. They were asked to work in groups on some problems. One problem was to find a quadratic function to model the famous Gateway Arch in St. Louis, Missouri. They were given the width of the arch at the ground level, and the height of the arch at its tallest point. The students had no idea how to start the problem even though they had been working on quadratic functions and equations. It was suggested to them that they might want to put it on a grid. The students still struggled for quite some time before figuring out how to do it. When they figured out how they wanted to approach the problem, they applied their skills very well. Different groups placed the parabola and different places on the grid. The difference in the equations were compared to see that they represented the same arch with simple horizontal and/or vertical transformations.

Results

In the original PPP in the U.S., for the pilot year (2010) and first two years, 2011-2012, more than 375 students participated and increased their MPE scores an average of 5-6 points (total is 33). Their performance in Calculus I was slightly better than their peers who had the same range of scores (16-21 out of 33) [10]. Materials continued to be developed after the pilot year in 2010. After the PPP was compressed into a 3-week program, the results from the 6-week program from 2011-2013 and the 3-week program from 2014-2015 were compared. Table 1 gives the means and standard deviations for those years.

Table 1. PPP Means and Standard Deviations.

	Mean of Pre-MPE (S.D.)	Mean of Post- MPE (S.D.)
2011-2013 6-week program (N = 305)	18.25 (2.79)	22.61 (5.06)
2014-2015 3-week program (N = 141)	18.03 (2.95)	24.02 (5.24)

Hedge's *g* effect size for the MPE score difference for the 6-week program was statistically significant at 1.067 ($p < .01$), confidence interval [0.90, 1.24]. For the 3-weeek program, Hedge's $g = 1.405$ ($p < .01$), confidence interval [1.15, 1.67]. (See Figure 1.)

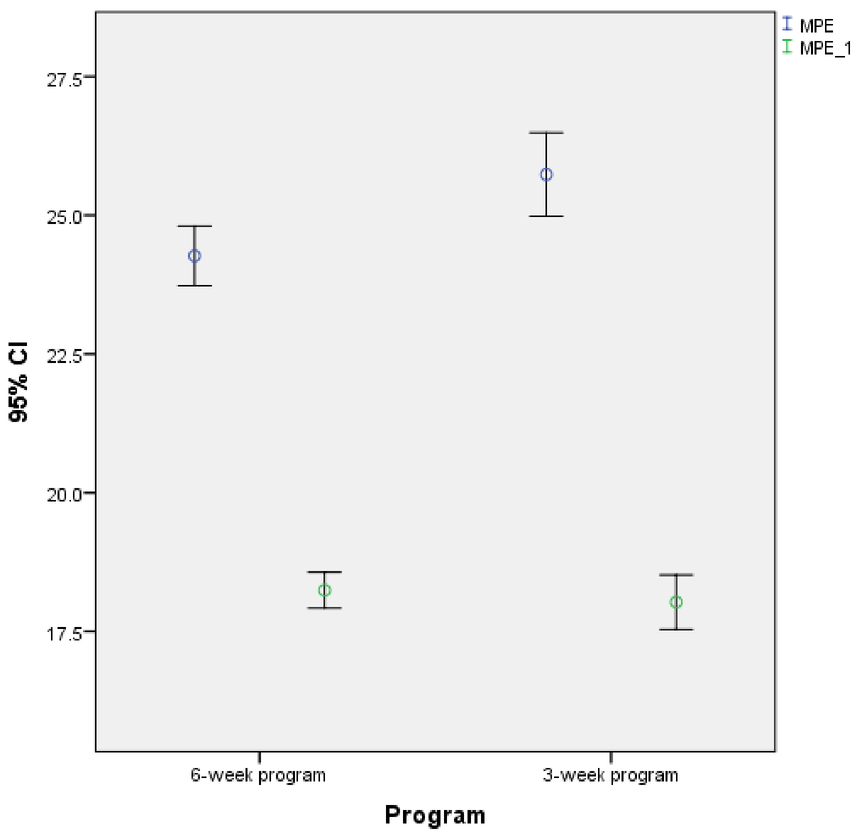

Figure 1. Confidence Interval for students' MPE* and MPE-1** test scores.
*score after PPP participation
**original score

The Engineering Calculus I grades for the two programs were compared through a *t*-test, and there was a statistically significant difference ($p < .01$) between students in the two programs. The Hedge's *g* effect size for the difference was 0.610, confidence interval [0.40, 0.83]. (See Figure 2.) Thus students in the 3-week program increased their MPE scores more, but students in the 6-week program fared better in Calculus I [13].

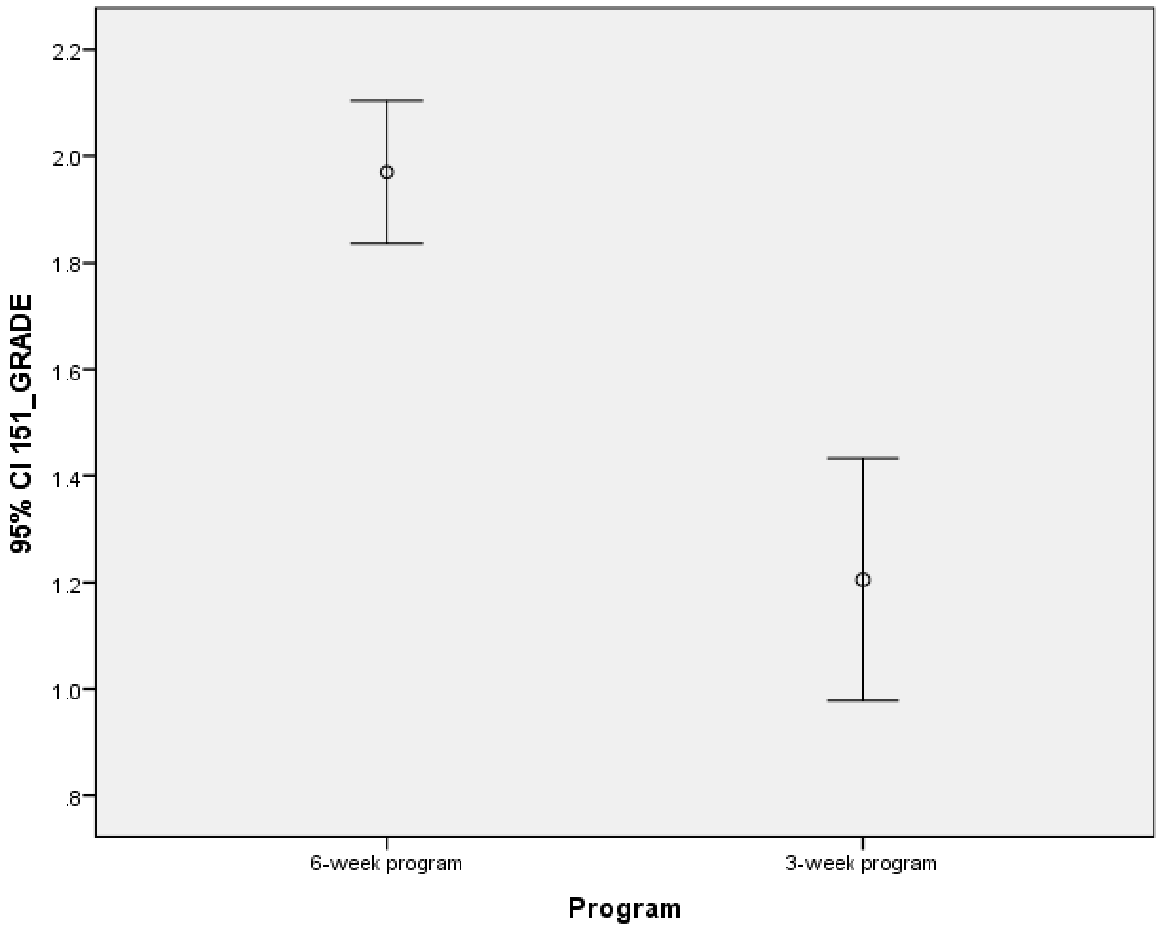

Figure 2. Confidence interval for students' Calculus I grades.

Overall, in the PPP from the pilot in 2010 through 2014, students who participated in the PPP did not fare as well in engineering calculus I as those who did not participate. However, they would only be expected to fare as well as others who had similar initial MPE scores. Students who did not meet the cut score on the MPE were required to take precalculus in the fall rather than engineering calculus. Table 2 shows the means and standard deviations for the PPP and non-PPP groups for precalculus and engineering calculus I. Note that the large number of participants increases the probability of finding statistical significance in the score differences.

Table 2. Means and Standard Deviations for PPP and non-PPP students.

	Mean Precalculus Grade (S.D.)	Mean Engineering Calculus I Grade (S.D.)
PPP	1.82 (1.32) N = 119	1.65 (1.29) N = 297
Non-PPP	1.88 (1.39) N = 3,801	2.00 (1.49) N = 15,543

The program in Asia has less detailed data available at this point. The program was developed in 2016 and revised slightly in 2017. The Pathways for Retention in Engineering Programs (PREP) began as a 2-week face-to-face program. The same topics were covered as in the PPP, but they were taught in a less traditional way, with the instructor acting more as a facilitator of learning and the students working in groups to explore mathematical concepts and solve problems. They collected real life data and analyzed it numerically and graphically to find a functional model to represent the data. They used graphing calculators to create scatter plots and graph curves. They worked in groups of two or three to create graphs by hand on large grid paper and solve problems, which they explained to their classmates, justifying their procedures and solutions. In the second year of the program, it was extended to three weeks, allowing time to address additional topics. Students explored spatial relationships of 3-D objects through a drawing task, by creating paper models of polygons, and with computer simulations. Initially many students struggled with the spatial visualization. Over the 3-week period, observations were that the students became much more adept at solving real-life problems and increased their spatial abilities. Overall, students increased their MPE scores by 40% after participation in PREP in 2016 and more than 20% in 2017.

Discussion

Both bridge programs to strengthen precalculus knowledge and skills in preparation for engineering calculus were successful in raising students' MPE scores. The 2016 PREP program had a huge increase. Without further analysis, we cannot be sure of the reason. Perhaps it was the particular group of students. It was a smaller group the first year than the 2017 program, and this likely contributed to the difference. In 2017 students who had already met the cut score on the MPE were invited. The ceiling effect came into play at that point [15]. The PREP program increased MPE scores by a larger percentage than the PPP. Although there is not sufficient data to determine the cause, researchers theorize that the human element was a factor. The PREP students had more time with an instructor than the PPP students.

One of the challenges in analyzing the results of the grades in the engineering calculus courses is that the course grades are not fine-grained. Course grades are assigned on a four-point scale: 4 points for A (90-100); 3 points for B (80-89); 2 points for C (70-79); 1 point for D (60-69); and 0 points for F (below 60). A grade of B may represent 80%, which a grade of C may represent 79%. Although these grades are quite similar, they differ by points allotted the same as a grade of B representing 89% and a grade of C representing 70%.

Students who did not meet the cut score on the MPE were required to take precalculus in the fall rather than engineering calculus. Many reasons for participating or not participating in the summer program play an important role in the results. For example, some students preferred to take precalculus, even though their scores were very close to the cutoff. Some students increased their MPE scores through the PPP but still chose to take precalculus before taking engineering calculus I. All of these choices affect the results, making it impossible to fully analyze the effects of the PPP. See [14] for more detail on some of the varied paths students took, based on MPE scores and personal choices.

The content of a bridge program to strengthen mathematics knowledge and skills may be developed at different levels, but there appear to be some common characteristics of successful programs. Significant personnel time is one of those characteristics. Early programs that tried to use exclusively asynchronous online venues were abandoned because they were largely unsuccessful or did not enjoy the success of a similar face-to-face program. More recent online programs have enjoyed somewhat better success, but it appears that there is no substitute for personal instruction or tutoring, whether by peers or faculty, online or face-to-face. Secondly, although the mathematical content may be similar, depending on the level, the teaching strategies may vary with the culture and educational experiences of the students. There is a certain amount of mathematical knowledge that must be memorized in order to use that knowledge effectively. However, students must have a deep enough understanding of the mathematical principles and ability to engage in problem solving that enables them to transfer knowledge to different situations. Knowledge of common deficiencies in mathematics for the regional or cultural environment can help to adapt a bridge program. For example, some studies have claimed the U.S. students are weaker in mathematical knowledge overall but are better at problem solving than students in other countries. In one author's experience, for the same content, U.S. students often need more focus on deeper understanding and practice with mathematical principles and theorems while students from some other countries may need more focus on applying their knowledge to applications and problem-solving skills. Bridge programs can be successful in giving more students the mathematical knowledge and skills needed for STEM or non-STEM majors, especially if they are adapted for the particular mathematical deficiencies of that population or culture.

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