Strengthening Math Skills of Incoming Engineering Freshmen through a Bridge Program

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Dr. Sonia Garcia is the Senior Director for the Access and Inclusion Program in the College of Engineering at Texas A&M University. She joined the college in 2014. In this role, Garcia is responsible for the initiation, development, management, evaluation, and promotion of research informed and strategic comprehensive activities and programs for the recruitment and success of historically underrepresented minority students and under-served communities in engineering at the undergraduate and graduate levels. Through pre-college efforts, in collaboration with the Women in Engineering Program, the Office of Admissions at Texas A&M University, and high school partners, Garcia has provided hundreds of students attending partner Texas' high schools, the opportunity to participate in hands-on engineering activities as well as experiencing life in a college campus. Many of these students have since decided to pursue a degree in engineering at Texas A&M, and Garcia continues to work with them to ensure their success. In fact, her efforts over the last two years alongside other engineering programs have resulted in an increase

of African American and Hispanic students in engineering. Garcia also directs community-building and peer-mentorship programs for undergraduate and graduate students, giving underrepresented students the opportunity to build confidence and camaraderie. These programs include the Engineering Success Program, established to provide academic support to first-generation underrepresented college students, and the Engineering Learning Community Introduction to Research Program, a high impact learning and research opportunity called ELCIR Program that offers freshmen underrepresented engineering students a chance to participate in a one-credit class and research project while gaining global experience with a research trip to Merida, Yucatan, Mexico. Garcia also leads efforts coordinating and directing the Engineering Summer Bridge Program, which gives first-generation underrepresented students a head start on engineering and math courses before their first semester begins. Access and Inclusion has received grants and endowments to support these programs, totaling nearly $1 million. Before joining the College of Engineering, Garcia served as program coordinator then promoted to assistant director of outreach and diversity at Mays Business School at Texas A&M. She later served as director of recruitment in the College of Geosciences at Texas A&M. In both capacities, she created, managed and developed projects and programs to enhance the presence of underserved underrepresented students in science and in business. During her tenure at Mays Business School and the College of Geosciences, Garcia developed instrumental programs to ensure the retention of first time in college underrepresented minority students. Garcia also served as a lecturer at both colleges introductory freshman seminars focusing on culture and diversity. She has received many awards throughout her professional career, including an Outstanding Staff award from the Mays Business School in 2005, the 2008 President's Award for Academic Advising, the 2011 Latino American Who's Who for her achievements in advancing the culture of the Latino American business community, and the 2012 Dean's Distinguished Achievement Award in the College of Geosciences for her work on increasing diversity in STEM. Garcia received her B.S. in Political Science from the University of Massachusetts at Boston, her M.S. in Human Development from the University of Rhode Island, and her Ph.D. in Higher, Adult, and Lifelong Education from Michigan State University. She speaks Spanish, English and Italian fluently, and is well-versed in French.

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Introduction

Since 2016, the College of Engineering at Texas A&M University has offered a four-week summer residential bridge program to enhance the success of first-generation, incoming freshmen engineering students. It is recognized that first-generation students may lack capital (i.e., ability to obtain advice and guidance from family members with experience completing college) important to succeed [6,7]. The goal of the Engineering Summer Bridge Program (ESBP) is to provide student participants with needed capital, while providing an opportunity to increase math proficiency, a key component to complete an engineering curriculum, as well as, academic skills necessary to be successful in their college experience. The importance of this program is to support students from groups historically underrepresented in engineering who may also be retained at lower rates than the overall engineering student population. Thus, expected program outcomes include enhanced math preparation and an increase in first year success of first-generation college students majoring in engineering, with a special focus on women and students from groups historically underrepresented in STEM.

During the four-week program, participants are: 1) introduced to various academic resources within engineering and the university; 2) enrolled in a math prep seminar focused on calculus and/or pre-calculus; and 3) engaged in daily group study sessions with upper division engineering peer mentors who are available to provide peer assistance with developing effective study strategies and solving advanced math problems in pre-calculus and calculus. In this paper, our intent is not to provide an in-depth overview and evaluation of the entire program. Instead, we focus on one, very important component of the program - the math prep seminar (i.e., Pre-Calculus/Calculus course). Herein, we capture: 1) our motivation/need to alter the format of the pre-existing Pre-Calculus/Calculus course; 2) the instructors' philosophy and methodology for course content delivery in the redesigned math prep seminar; and 3) the instructors' perceived benefits of the new approach. We provide a summary of student performance outcomes from the redesigned math prep seminar, using pre/post math placement exam scores as a measure to assess student learning. We close with instructors' recommendations on future work for continued course improvement to further enhance ESBP participants' preparation for subsequent math courses in the engineering curriculum.

Brief Overview - Engineering Summer Bridge Program

The four-week residential Engineering Summer Bridge Program (ESBP) is designed to prepare students for success in their first year at Texas A&M and the College of Engineering. A primary objective of the program is to improve students' preparation in mathematics. In addition, through intentionally designed program elements (i.e. cohort-based housing in residence halls, formation of living-learning community and study groups, and personalized introductions to university/college resources), the ESBP builds an on-campus community and support network to allow students to build technical confidence and their sense of belonging within Texas A&M. Our aim is that students who participate in the program will: 1) increase their skills to make a smooth transition from high school to college; 2) complete an intensive pre-calculus or calculus prep seminar with a faculty instructor; 3) develop a greater sense of

confidence and self-awareness as a student; 4.) understand expectations for success in college; and 5) develop skills to enhance their ability to network with peers and be engaged in the Texas A&M community.

Prior to the first day of the Engineering Summer Bridge Program (ESBP), participants are required to complete the university's Math Placement Exam (MPE). The exam is used to determine students' readiness for calculus by assessing their prior knowledge of algebra, trigonometry, logarithms, and exponentials. Using test scores from the MPE exam, participants are placed in an appropriate level math prep seminar that focuses primarily on pre-calculus or calculus. Each version of the 4-week long math prep seminar meets for five 90-minute classroom sessions and five 180-minute group study sessions each week. Additional weekend classroom sessions are held at the discretion of the faculty and/or upper division engineering peer mentors who are hired to facilitate study groups and support ESBP students through supplemental instruction and individual consultation.

In 2016 and 2017, our program model required that ESBP participants enroll in a 3-credit hour Pre-calculus or Calculus course during summer session II. To reduce overall program costs (e.g., tuition and fees for a 3-credit hour course) and eliminate logistical challenges (e.g., altering admission codes and entry terms for ESBP participants - from "Fall admit status" to "Summer admit status"), we adjusted our program model in 2018 to include a 4-week long math prep seminar instead of an official Pre-calculus/Calculus course for academic credit. With this shift in our delivery model, we defined program goals for the math prep seminar and we took into consideration participants' readiness for calculus at the start of the program (Table 1). Next, we explore ESBP instructors' philosophy and methodology for course content delivery in the redesigned math prep seminar during summer 2018.

Table 1. Program Goals for Math Prep Seminar (disaggregated for ESBP Participants based on their calculus readiness using practice Math Placement Exam (MPE) scores).

Prior to Math Prep Seminar		**Program Goals for Math Prep Seminar**
Student demonstrating readiness to enroll in:	MPE Score	Summer 2018
ENGR 289 College Algebra & Pre-Calculus	1-12	-Enhance fluency and confidence for ENGR 289 -Enhance preparation/potential to earn A or B in ENGR 289 during Fall
	13-14	-Improve MPE to > 14 (for placement into M150 for Fall)
M150 Pre-Calculus	15-19	-Enhance fluency and confidence for M150 -Enhance preparation/potential to earn A or B in M 150 during Fall
	20-21	-Improve MPE to > 21 (for placement into M151 for Fall)
M151 Calculus	22-33	-Enhance fluency and confidence for M151 -Enhance preparation/potential to earn A or B in M 151 during Fall

ESBP Math Prep Seminar Philosophy & Methodology

The instructors would like to acknowledge that amending the ESBP math seminar to be a non-credit course was extremely important. This decision allowed for a more flexible program

that exists in a space away from any pre-defined sets of curricula. For instance, in the Calculus I for-credit course, it was certainly possible to find opportunities to help students develop a deep understanding of derivatives, their importance to math, and its applications because that objective exists within the for-credit Calculus experience. Unfortunately, it would not have been possible to pause instruction and explain the derivations of the laws of logarithms since that objective is not closely related to the objectives of Calculus I and there simply was not time to revisit this topic (especially considering the semester-long course was already being condensed to a few weeks). By choosing to instead offer the students a non-credit seminar, the instructors were now free to target weaknesses and adjust instruction as they observed students and received feedback. Being completely freed of any existing course curriculum led to the biggest question: What are we going to teach?

While many of the students had a strong desire to work on their calculus skills during their time in the ESBP, the authors had seen time and time again that first-year engineering students often had pre-calculus gaps in their mathematical knowledge that would create huge roadblocks on their quest to an engineering degree. Interestingly, these gaps—often in areas like functions, trigonometry, and vectors—seemed to be present in large numbers of students regardless of how much advanced math they had experienced in high school. Complaints that students tend to fail calculus, not because of their calculus skills, but because of their lack of algebraic and trigonometric skills are rampant amongst university professors and AP Calculus teachers alike. This common complaint finds backing in the research done on this topic. The National Study of College Calculus performed by the Mathematics Associate of America (MAA) found that students who score a 3 or less on an AP Calculus exam have about the same success rate in a university-taught Calculus I course as their peers that *never even saw Calculus in high school* [2]. In other words—for many students, seeing Calculus in high school is not giving them any advantage when they take Calculus at the university level. The MAA study concluded that the rush to advanced math in K-12 education is misguided since students achieving some of the highest levels of math were not necessarily at an advantage for doing so. Clearly there is some training or math-understanding that is being lost in the rush to advanced math. Taking this all into consideration, the instructors decided it would be a mistake to focus only on Calculus concepts in the ESBP math seminar. Instead, we would seek to bolster and strengthen those pre-calculus topics that often get in the way of Calculus-success.

Drawing on the experience of the instructors and their colleagues in Math and Engineering disciplines, a list of topics to cover in the 4-week seminar was constructed and is listed in Table 2. These were the topics that the majority of students in the ESBP math seminar would tackle. However, after some consideration, it was decided that students who scored above a 22 on the MPE at the beginning of the ESBP would forgo the instruction on “ugly-math”. The reasoning to include ugly-math in the course was to focus on the mechanics of math as well as bolster students’ confidence for those times when the math on the page gets a little hairy. The instructors felt strongly that the MPE does a fine job of assessing math mechanics, so it was reasonable to allow those that demonstrated mastery of this to forgo this week and instead receive instruction on introductory Calculus topics. This Calculus review (as the overwhelming majority of these students had already completed a Calculus class) would not focus on the

mechanics of Calculus, but instead would attempt to help students understand what Calculus is and why it becomes a powerful tool that can be used to solve problems that pre-calculus topics cannot.

Table 2. Topics covered in the ESBP math seminar, 2018.

Topic	**Emphasis**
1. Functions	-Parent functions as building blocks. -Transformations of functions –especially how they work in equation form
2. Exponential Functions & Logarithms	-Inverses—what they are and what is special about this relationship -Digging into the explanations of the Laws of Exponents and how to derive them -Understanding the relationships between logarithms and exponents
3. Trigonometry	-The unit circle & the Pythagorean Theorem -Understanding trig identities and where they come from (rather than memorizing) -Transformations of sine and cosine functions
4. Gross Math (factoring, rationalization, fractional exponents, rational expressions)	-No tricks, no rule memorization. Just using what we know about math to simplify/solve complicated expressions/equations
5. Vectors	- Understanding their meaning, various notations and translating between them

With the topics set, it was time to give attention to *how* this material would be presented to the students. Many bridge programs have focused on improving math skills and placement [1], but the methods can vary widely with various levels of success. One bridge program using a supervised online mathematics instruction model was successful in raising participants math course placement but failed to retain students in engineering at a higher rate compared to their peers that did not participate in the program [3]. Another bridge program at Syracuse switched from a more traditional math course to a modeling-based mathematics approach and improved the first-semester mathematics course grades of their participants [4]. While improving the MPE score and grade-earning potential of each ESBP participant was a major goal, just as important was the goal to grow students' confidence and math fluency to weather the rigor of their first university-level math course. Research has found that students tend to be extremely confident about their math abilities when entering Calculus, but that by the time they get through their first year, many of them see a lack of preparation in math and science as a challenge to becoming an engineer [5]. David Bressoud, who wrote the summary of findings of MAA's National Study of College Calculus study, writes that while students who enroll in Calculus 1 are generally both talented and confident, that "one of the clearest conclusions to come out of our study was how effective this course is in destroying that confidence" [2].

How do we bolster students to help them survive their first semester math class? Prescribing students drill-and-kill exercises to get better at applying math concepts was certainly an option, but the instructors wanted to go further in hopes of shifting the self-efficacy, metacognitive skills and epistemic beliefs of the ESBP participants. The desire was to change the way students approach and react to math. Students today are bombarded with the message that math is an important subject to learn because it is useful, but this focus has driven instruction in the K-12 schools to too often be about *how to use math*. This is a problem. It lends itself to a teaching of procedural math that forces students to identify the type of problem being asked, and then apply a procedure that they were taught step by step to solve that problem. If a student needs to find the missing side of a right triangle, she will use the Pythagorean theorem to get the answer. If a student is asked to find the distance between two points on a coordinate grid, she will use the distance formula. However, it is rare that a student will realize that the two problems described above use the same mathematical truth to answer **both** questions (as the distance formula is a version of the Pythagorean Theorem). The message that the instructors wanted to convey to the ESBP participants is that, yes, math is an incredibly useful tool, but that it is also inherently interesting in and of itself. Furthermore, if we spend time digging into the "big math concepts" that underlay many of the rules learned in high school and drawing connections between them, we will find that the number of tools needed to do math will shrink and become easier to manage. For instance, we wanted them to know trigonometry is not a list of definitions and identities; it is a unit circle with three simple ratios (or what students refer to as SOHCAHTOA). The rules of exponentials are actually the same set of rules that govern logarithms. Even if vectors have many different notation schemes, each vector is part of a right triangle—and solving that right triangle is just trigonometry. While it is possible to memorize every single rule and theorem in a math book and learn how to effectively apply each one, the instructors strongly believed that empowering students to think deeply about math would help students consider two questions: 1) what is math? and 2) what does it mean to understand math? Is math simply application? If we can use a "math wrench" to complete a math problem, do we know and understand math? Or do we need to consider how that "wrench" actually works? The hope was to nudge students towards an understanding of math that is not based on rules and rote memorization but instead is based on understanding the big concepts and knowing how those concepts contribute to the myriad of tools used as part of the mathematician's toolbox to solve application problems.

To help along this journey, the instructors designed a few specific activities designed to generate discussions about math, what it means to understand math, and even what it means to be good at math. To start the course, students were asked to read, reflect on, and write a response to the well-known essay, *The Mathematicians Lament,* by Paul Lockhart. This was followed up with an in-class discussion in which students were asked which part of the essay resonated with their experiences and why. While far outside the normal workings of a math classroom, this exercise proved incredibly insightful.

As a second metacognitive exercise in the first two days of instruction, the authors dedicated time to explaining the difference between math that is done using a procedure compared to math that is done from a point of understanding. (It was emphasized that testing at the collegiate level

will rarely test procedural knowledge but will require students to synthesize ideas together during the testing period.) Students were asked which math they felt they had been doing in high school. Overwhelmingly, students felt the majority of math they had been exposed to in their high schools had been procedural math. To conclude this exercise, the instructors challenged students to look beyond the utility of math and attempt to pull back the curtain to see its inner workings. It was important that the students understood that this was a major objective of the seminar, and as a result it was discussed and alluded to many times throughout the seminar.

From here we began our exploration of the math topics listed in Table 2. Students would spend 90 minutes per day with the instructors. This time was a blend of discussion and active learning. Agendas were tentative, so the students could affect the pacing of the class by asking questions, engaging in discussion, and pausing to address misconceptions being observed. There were three major ways in which the instructors collected feedback to amend their instruction. The first method was through direct observation of the students in class. If active engagement was observed, then the course pressed forward. If there was any sense of confusion, instructors would stop to discuss with students (and often get students to actively engage with each other) to determine the root of the confusion. The second feedback path involved being in communication with the undergraduate peer mentors leading the small-group evening study sessions. They would often attend the seminar and would report back on where students were getting stuck, which problems were proving the most difficult, etc. In addition, they kept the instructors up-to-date on the mood of the students. Were they frustrated or energized? These data points helped us adjust active learning segments to give students time to digest and ruminate on specific topics that needed to be spiraled back into the classroom. In the case of students who were outliers, we would implement personalized interventions to try to determine what was going on. The final feedback mechanism in place was a quiz each Friday. These quizzes allowed instructors to pin-point misconceptions of individuals and intervene. In addition, the quiz and solutions were shared with the peer mentors to discuss with their small groups in weekend sessions.

Results - Student Performance Outcomes from the Redesigned Math Prep Seminar

After completing the Engineering Summer Bridge Program (ESBP) with the redesigned math prep seminar in summer 2018, 74% of program participants improved their entering mathematics placement exam (MPE) scores; overall gains ranged from 2 to 32 points and the average gain was 9.4 points. Additionally, we observed higher gains for participants who initially scored lower on the practice MPE prior to start of ESBP. Table 3 provides an overview of student performance outcomes broken down by sub-groups according to their MPE score prior to the math prep seminar.

Prior to the 2018 ESBP, only 30.8% of program participants were Calculus ready. After completing the ESBP math prep seminar, 56% of program participants demonstrated readiness to enroll in Calculus I (MATH 151). Moreover, prior to the 2018 ESBP, 19 participants were slated to enroll in College Algebra (ENGR 298); after the ESBP math prep seminar, this figure was reduced by more than 50%, from 19 students down to 8 students. After one semester, the retention rate in engineering for 2018 ESBP participants is 94.2%. Additional academic

performance data and one-year retention data will be available in September 2019 after 2018 ESBP participants complete their first year of coursework in engineering.

Table 3. Student Performance Outcomes (broken down by sub-groups using MPE scores prior to start of ESBP's math prep seminar).

MPE Score Prior to Math Prep Seminar		**Student Performance Outcomes Post Math Prep Seminar**
ENGR 289 College Algebra & Pre-Calculus	1-12	-88% (15 of 17) improved MPE score. -For this group of 15, gains ranged from 2-32; average gain was 12.7 pts.
	13-14	-100% (2 of 2) improved MPE score. -For this group of 2, gains ranged from 5.5-17.5; average gain was 11.5 pts.
M150 Pre-Calculus	15-19	-75% (12 of 16) improved MPE score. -For this group of 12, gains ranged from 4-12; average gain was 8.4 pts.
	20-21	-100% (1 of 1) improved MPE score; gain was 7 pts.
M151 Calculus	22-33	44% (7 of 16) improved MPE score; -For this groups of 7, gains ranged from 2-7; average gain was 3.9 pts.

Implications and Considerations for Future Iterations of the ESBP math seminar

Aside from quantitative measures, qualitative measures indicate that this program was successful. Students were generally engaged in the classes and regularly requested additional face time with faculty to go more in-depth with the material. Students were clearly more confident after seeing their improved MPE scores, and many of them shared their excitement with the instructors at the closing ceremony on the last day of the program. Students continued to feel a strong connection to the faculty members even after the program. Whether it was informal interactions in the hallway or formal appointments, students asked math-related, career, and even academic major specific questions. Each and every time students expressed gratitude for the jump start the program provided related to their college career and the confidence instilled as a result.

The current plan is to replicate the topics and teaching style from the 2018 program in the upcoming 2019 program. Due to a professional change in location of one of the instructors, only one of the two faculty members will return in 2019. As new instructors are included, integration of their ideas and attainment of their buy-in related to the class will be important. Future plans include conducting a longitudinal study with the summer 2018 students as they progress through their college career.

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