

# Operation STEM: increasing success and improving retention among mathematically underprepared students in STEM

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## Abstract

In 2012, Cleveland State University implemented a comprehensive program, called Operation STEM (OpSTEM), funded by two National Science Foundation grants, federal work study, and Cleveland State University. Its goal is to increase retention and graduation rates among mathematically underprepared Science, Technology, Engineering, and Mathematics (STEM) students by helping them complete the precalculus-calculus sequence successfully. OpSTEM provides support to all mathematically underprepared students, and it also creates a special cohort of under-resourced students that become OpSTEM Scholars and receive additional supports. OpSTEM Scholars are predominantly freshmen pursuing STEM majors who are members of minority groups that are underrepresented in STEM, first-generation college students, and/or women. The majority of OpSTEM Scholars begin their mathematics coursework at the beginning of the precalculus sequence. OpSTEM provides these students with many services: a two-week summer institute, mandatory supplemental instruction, project-based instruction, mentoring, STEM speakers, free summer calculus, college success workshops, social activities, and stipends based on participation in these activities and successful completion of coursework. The implementation of the OpSTEM program created an experimental design with two treatment groups, where one group received all the treatments and one group received only mandatory supplemental instruction. They were both compared to a control group from before OpSTEM began. Student data collected have demonstrated that mandatory supplemental instruction alone is effective at increasing the pass rate for precalculus courses, and the additional services and incentives provided to the OpSTEM Scholars group increases the pass rate even further. This is especially significant because the population that received all the services (OpSTEM Scholars) is a population that is more at-risk than the typical population. The ultimate goal of OpSTEM is to increase retention and completion among STEM students by helping them succeed in the precalculus-calculus sequence. Additional time is needed to assess the rates at which these students are completing STEM degrees, but preliminarily data show that OpSTEM Scholars' retention rate is higher than the

university's retention rate as a whole and higher than the university's retention rate in STEM fields in particular.

## Introduction

In 2013, Cleveland State University (CSU) implemented a comprehensive program, called Operation STEM (OpSTEM), funded by two National Science Foundation grants, federal work study, and CSU. Its purpose is to increase retention and graduation rates among mathematically underprepared Science, Technology, Engineering, and Mathematics (STEM) students by helping them complete the precalculus-calculus sequence successfully. OpSTEM provides support to all mathematically underprepared students, and it also creates a special cohort of under-resourced students that become OpSTEM scholars and receive additional supports. OpSTEM Scholars are predominantly freshmen pursuing STEM majors who are members of minority groups that are underrepresented in STEM, first-generation college students, and/or women.

The impetus for OpSTEM was the abundance of research suggesting that there are too few STEM graduates and that these graduates are frequently members of groups that are overrepresented in STEM fields. The President's Council of Advisors on Science and Technology (PCAST) released a report that projected a deficit of one million STEM graduates over the next decade. It suggests that while too few students graduate with STEM degrees, there is no shortage of students who enter college desiring to complete a STEM degree. On a nationwide level, "fewer than 40% of students who enter college intending to major in a STEM field complete a STEM degree" (PCAST, 2012).

Not only are there problematically low retention and graduation rates in STEM fields, but retention and graduation rates differ drastically between under-represented minority students and white and Asian students. Data from the 2004 Freshman Survey and the 2010-2011 National Student Clearinghouse of 56,499 2004 STEM aspirants show that 44.5% of white and Asian students completed a STEM degree within six years while 25% of African American, Latino, and Native American students completed a STEM degree within six years (Figueroa et al, 2017). At Cleveland State University (CSU), things are no

different. In 2009 there were 151 freshmen who were enrolled in a STEM major at CSU. As of 2015, 51 of them had graduated with a STEM major within six years (33.8%). Additionally, underrepresented minorities continue to receive less than a proportional number of STEM degrees. In 2009, African American students made up 21.9% of the incoming first-year class but only 9.2% of those who graduated within six years, and only 6.8% of those who graduated with a STEM major within six years.

According to the PCAST report, the most efficient way to increase STEM professionals is to better retain the students who intend to major in STEM fields. Even a modest increase in retention (from 40% to 50% nationwide), would generate most of the needed STEM professionals (2012). Furthermore, the PCAST report states that "low-performing students with a high interest and aptitude in STEM careers often have difficulty with the math required in introductory STEM courses with little help provided by their universities" (2012). In order to increase retention and graduation in STEM fields, it is essential to work toward solutions to these problems.

With these goals in mind, CSU applied for and received a NSF STEM Talent Expansion Program (STEP) grant in 2012. Using that grant together with funding in 2013 from the NSF Louis Stokes Alliance for Minority Participation (LSAMP) program, CSU created Operation STEM (OpSTEM), a program that combines a summer institute, project-based instruction, mandatory supplemental instruction in precalculus and calculus, mentoring, and peer support to increase retention and graduation among primarily underrepresented minorities and first-generation college students who intend to major in a STEM field.

Success with STEM students emerging from CSU programs provides the Greater Cleveland Metropolitan community with a transformative pipeline of skilled workers who are typically underrepresented in STEM disciplines in the 21st century. Local employers are looking for workers with STEM skill sets. The Greater Cleveland Metropolitan area abounds in national engineering firms, scientifically based industrial companies, and national insurance companies. Companies such as Lubrizol and Parker Hannifin, agencies such as NASA and Progressive Insurance are not only partners in the STEM effort, but also leaders in the

industries which employ CSU STEM graduates.

CSU has increased the number of students engaging in STEM disciplines. Active awards with flourishing programs include: NSF Scholarships in STEM (S-STEM), two NSF Robert Noyce Teacher Scholarship programs, CSU STEM Fellows, McNair Scholars, and Choose Ohio First (COF) STEM Scholarships. CSU continues to lead this effort and provide a future for our students by preparing them with skills that are relevant to our regional community and beyond. Student enrollment continues to rise in the scientific and engineering fields—approximately 40% over the five years prior to the submission of the grant (Book of Trends, 2011), and an additional 8% since OpSTEM’s implementation (Book of Trends, 2015). However, the number of underrepresented minority students and first-generation college students continues to lag behind the gains made by non-minority, male students who have college-educated parents. A secondary goal of OpSTEM is to cultivate, support, and retain underrepresented minority and first-generation college students already enrolled, help them remain in college, and graduate in the STEM disciplines.

## Rationale/Background for the Opstem Program

Calculus creates a barrier to success in STEM. OpSTEM seeks to provide STEM-centered and directed transdisciplinary educational opportunities for students who are underprepared in mathematics—particularly, those who enter college needing precalculus—by supporting them to successfully forge ahead through the current “choke point” of mathematics. The ideal freshman STEM student enters the university ready for calculus; however, CSU has a large precalculus enrollment (approximately 300 annually).

In addition, a major factor contributing to low graduation rates in STEM is the lack of strong academic K-12 preparation, particularly in mathematics. There is a disconnect between the Ohio end of course examinations

given in high school and the actual mathematics classes required to successfully advance through the STEM disciplines. While students may come to CSU proficient in state standard tests, the end of course examinations include mathematics concepts through geometry. Students entering CSU with this minimal mathematics preparation are at a great disadvantage and often will spend two to three remedial semesters getting to calculus. The number of students in our precalculus sequence reflects this disconnect. Further, high school graduates in Ohio were only recently required to complete four years of high school mathematics and only need to include courses up to Algebra II, which is not sufficient prerequisite preparation for college calculus.

In addition, studies indicate that mathematical proficiency is a factor predicting success in STEM and college courses (Tai et al, 2005; Sadler et al, 2007; Wilson and Shrock, 2001; Achieve, 2008; Conley, 2003; Adelman, 1999 and 2006). All engineering, chemistry, physics, computer science, and mathematics majors must successfully complete mathematics through Calculus II (Integral Calculus). Biology majors must succeed through Calculus I (Differential Calculus). OpSTEM’s goal is to provide additional support to students in the precalculus to calculus track in order to enable success in pursuit of their STEM degree. OpSTEM serves STEM majors by forming a cohort of students and begins with a two-week summer bridge program, offering mandatory supplemental learning sessions with project-based instruction (Kober, 2012), and providing extracurricular STEM-related activities to build content knowledge and social capital among vulnerable students during precalculus and calculus courses.

The purpose of OpSTEM is to increase retention and graduation among mathematically underprepared college students using a variety of interventions that are well-known to increase persistence. For OpSTEM Scholars, in addition to providing support to move students successfully through the precalculus-calculus sequence, it creates an interdisciplinary STEM cohort group that participates in social,

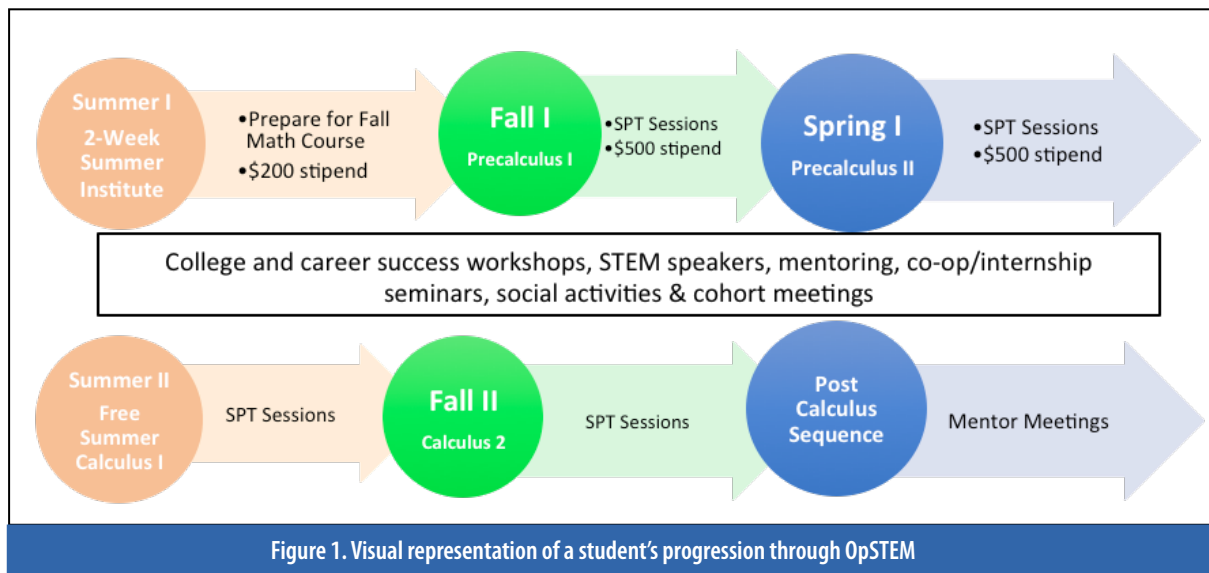
academic, and STEM-related cohort activities together.

It is well known that student engagement increases retention (Chen, 2013; Kuh et al., 2008; Ohland et al., 2008), learning communities enhance learning and persistence (Tinto, 1997; Tinto, et al., 1993), cohort groups that bond in social and academic settings retain and graduate at higher rates (Executive Office of the President, 2014; Gilmer, 2007), project-based learning (PBL) increases student learning and retention (Kober, 2015; National Research Council, 2011; National Research Council, 2012), peer-led supplemental instruction is correlated with higher pass rates, lower withdrawal rates, higher retention and graduation rates (Dawson, et al, 2014), and summer bridge programs can improve retention of STEM majors (Raines, 2012).

## Components Of The OpSTEM Program

### Goal

OpSTEM works on two levels. First, it provides supplemental instruction to all mathematically underprepared STEM majors who enroll in precalculus courses. Second, it creates a cohort group, called OpSTEM Scholars. These students are primarily mathematically underprepared STEM majors, First Time Full Time Freshman (FTFTF), who are first generation college students, members of a minority group that is underrepresented in STEM, and/or women. Scholars enroll in a two-week Summer Institute that engages them in mathematics reviews, study skills sessions, orientation to campus resources, meeting STEM professionals, and connecting socially with their peers. OpSTEM Scholars continue to attend STEM-related activities in their cohort group for the first academic year. In addition, STEM Peer Teachers (SPTs) provide mandatory supplemental learning sessions (called SPT sessions) and PBL activities in their precalculus and calculus classes, mentoring, and individualized attention. Finally, for OpSTEM Scholars who have participated in the eight day



Summer Institute and who have successfully completed Precalculus I and II in their first year, Calculus I is provided at no cost in a special summer session, which includes SPT sessions and support. All of the OpSTEM programming helps to reach the primary goal, which is to enable all students to succeed in the mathematics courses required for STEM degrees and, upon effectively passing Calculus II (or Calculus I in the case of biology and pharmaceutical majors), students continue on their path toward graduation with their desired STEM degree.

The OpSTEM programming effectively creates two treatment groups: 1) Precalculus I and II students who are not OpSTEM scholars but receive SPT sessions and typically PBL and 2) OpSTEM Scholars. OpSTEM Scholars receive the Summer Institute, SPT sessions, PBL, college success workshops, cohort bonding activities, summer calculus, and mentoring.

### Summer Institute for OpSTEM Scholars

Every year a new cohort of 80 students begins with a two-week summer institute. Cohorts are comprised of primarily FTTF who are invited to arrive on campus two weeks before the start of the Fall semester to engage in eight full days of varied activities. Cuyahoga Community College (Tri-C), an LSAMP partner, may also send 6-13 students to the Summer Institute as well to establish a pipeline for the 2-year to 4-year transition. Students review precalculus or calculus skills, learn about campus support services and academic success strategies, explore the campus, and attend STEM guest speaker presentations.

The mathematics review portion of the OpSTEM Summer Institute consists of 18 hours of basic math and algebra skill review in both lecture-style lessons and group work. Students are given pre-tests and post-tests using the online math software program, Assessment and Learning in Knowledge Spaces (ALEKS, 2016), to assess their previous knowledge and knowledge gained during the eight days.

To encourage students to attend class rather than pursue part-time summer employment, each OpSTEM Scholar receives a \$200 stipend for attending the Summer Institute and receives an additional stipend of \$500 after the each of the first two semesters. The conditions attached to financial remuneration are attending six STEM cohort activities, two mentoring sessions, and passing the required mathematics course.

### Mentoring for OpSTEM Scholars

OpSTEM Scholars receive additional mentoring by the SPTs and the OpSTEM director, LSAMP coordinator, or mathematics department faculty. This mentoring is given in addition to the typical advising that students receive through the CSU first-year advising office, but it goes far deeper than the traditional support students get through advising. Mentoring for OpSTEM Scholars involves meeting one-on-one twice each semester with the math

department faculty and staff, as well as weekly contact with the STEM Peer Teachers in class, SPT sessions, and office hours. The mentoring entails discussing academic progress, social/personal challenges, teaching study skills, planning the following year's course schedules, and discussing STEM degree plans and career options. The OpSTEM mentors form relationships with the Scholars that often persist throughout their time at CSU.

### Supplemental Learning Sessions for All Mathematically Underprepared STEM Students

In Fall 2013, mandatory supplemental learning sessions also known as SPT sessions began to be offered in three of the five sections of Precalculus I. The following semester, Spring 2014, Precalculus II courses began mandatory supplemental instruction sessions. Initially, the SPT sessions were an additional 130 minutes per week. The following year, Precalculus was changed from a 4-credit course to a 3-credit course, and supplemental instruction decreased to 100 minutes per week. In the third year, supplemental instruction was lengthened to 150 minutes and the SPT sessions were included in all academic year sections of Precalculus I and II. Tuition-free Summer Calculus I with SPT sessions and support began in Summer 2014. Additionally, beginning in Fall 2015, some sections of Calculus I and II offer mandatory SPT sessions, and OpSTEM Scholars are required to enroll in one of these sections.

### STEM Peer Teachers

SPTs are trained peer instructors who engage pairs or small groups of students in hands-on learning activities that reemphasize concepts through additional practice examples and facilitate PBL. Creation of an SPT cadre has provided an unexpected benefit for undergraduates interested in a teaching career. The team of SPTs has increased from 12 to 35 since Fall of 2013. The team is comprised of undergraduate, graduate, and post-baccalaureate students from all walks of life, majors, genders, and backgrounds. CSU Teach students, who are studying to be high school teachers, are ideal SPTs.

New SPTs are recruited by current SPTs and faculty who recommend former students, and by collaborating with the College of Education's CSU Teach program. Additionally, during the OpSTEM Summer Calculus course, students interested in becoming an SPT take on the role of an SPT-in-Training.

In order to develop SPTs into informed, skilled and engaging teachers, a veteran SPT is paired with a new SPT to help develop his or her skills on the job. There are always two SPTs for a course, and, if the class is larger than 30 students, there are typically three.

SPTs also facilitate PBL. In order to prepare them to effectively facilitate PBL, they meet for one hour per week with the PBL coordinator to complete the weekly PBL activities, review difficult sections, and brainstorm student questions and problems.

All SPTs participate in a one- or two-credit, professional development STEM Peer Teacher Skills and Strategy course. They learn and/or review different engaged learning activities, for example, use of mini-white boards, competitions, small group and pair work, use of technology, and other strategies to move from passive learning to active learning. Lastly, faculty and coordinators observe SPTs and provide feedback several times per semester and SPTs observe each other to provide constructive criticism and gain insights about different teaching techniques.

SPTs dedicate ten hours each week on a course and are paid \$12 per hour. Funding for the SPTs is paid through Federal Work Study funds and course lab fees. A work week includes three hours in class while the professor is teaching, three hours in SPT sessions (one of which is implementing the PBL project), and four additional hours, which includes the PBL meeting, planning, creating study/practice materials, holding office hours, and mentoring students.

OpSTEM also works closely with three other entities on campus that provide tutoring for students, CSU's Math Learning Center, Math Emporium, and Tutoring for Academic Success Center. These directors appreciate having SPTs because they are trained and well-prepared. SPTs are sought after as one-on-one tutors for the other programs. Additionally, there are SPT summer opportunities in the tuition-free OpSTEM Summer Calculus class, tuition-based Precalculus and Calculus courses, the Summer Transition Enrichment Program (developmental math and English courses), and Math Corps (middle school math camp).

### Project Objectives

1. Recruit a cohort of OpSTEM Scholars who are STEM majors that are primarily first-generation college students, part of an under-represented minority, and/or women.
2. Provide them with a Summer Institute experience that increases their skills and confidence in mathematics, helps them form social bonds with the cohort group, and increases their preparedness to succeed in the university setting.
3. Offer Calculus I for free over the summer for OpSTEM Scholars with sufficient support to yield a high pass rate in order to accelerate the completion of STEM requirements.

### Research Questions

Specific research questions for the initial phase of this program are as follows:

1. Will the pass rate increase in Precalculus I among OpSTEM Scholars and all enrolled students? Note: all enrolled students are considered mathematically underprepared for a STEM degree.



- Will the pass rate increase in Precalculus II among OpSTEM Scholars and all enrolled students?

Note: all enrolled students are considered mathematically underprepared for a STEM degree.

- Will developing and implementing PBL components for each of these courses increase student engagement and pass rates?

Ongoing research questions (cannot be fully answered at this time because we are currently in the fourth year of the study):

- Will OpSTEM Scholars have higher rates of fall-to-fall retention as compared with non-OpSTEM Scholars?
- Will OpSTEM Scholars have higher 4- and 6-year graduation rates as compared with non-OpSTEM Scholars?

## Methods

OpSTEM creates two treatment groups to be compared to pre-OpSTEM students (**Control**). The groups are: 1) Precalculus students who are not OpSTEM Scholars that receive SPT sessions only (**Treatment 1**), and 2) OpSTEM Scholars (**Treatment 2**). OpSTEM Scholars attend an eight day OpSTEM summer institute and receive a stipend for it. They take precalculus courses with SPT-led mandatory supplemental learning sessions, attend extracurricular STEM events, receive additional faculty mentoring, and earn stipends each semester for participating in these activities and passing their mathematics courses. Additionally, if they begin the program in Precalculus I and pass both precalculus courses in the first year, they are eligible to take a free summer Calculus I class.

The remainder of precalculus students take mathematics courses with mandatory supplemental learning sessions and PBL.

These two treatment groups will be compared with data from the four years prior to OpSTEM's implementation.

## Recruitment Process for Operation STEM Scholars

In Spring 2013, recruitment efforts for the initial OpSTEM cohort (N=36) focused on FTTF who were STEM majors and who were enrolled in Precalculus I (MTH 167). The following year, primarily freshman and some sophomores who were majoring in STEM and enrolled in Precalculus I (N=29) and Calculus I (N=21) were accepted into the Summer Institute to establish the OpSTEM 2014 Scholar cohort. Forty-one precalculus and 33 calculus students comprised the 2015 Scholar cohort and the 2016 OpSTEM Scholar cohort included 48 precalculus and 38 calculus students.

Recruitment is executed through 1) mailings, emails, texts, and phone calls to students who potentially qualify, 2) first-year advisors, and 3) in-person recruitment during CSU's Freshman Orientation sessions. Recruitment materials are also sent to students who are not first-time freshman, and/or who have not successfully completed Precalculus I or Calculus I.

Dates	Treatment	Number of Students
Fall 2009-Fall 2012	Control: None	517
Fall 2013-Fall 2015	Treatment 1: SPT sessions (most with PBL)	484
Fall 2013-Fall 2015	Treatment 2: Summer Institute, SPT Sessions, PBL, cohort activities, mentoring	76

Table 1. OpSTEM Precalculus I Experimental Design

Dates	Treatment	Number of Students
Spring 2011-Spring 2013	Control: None	319
Fall 2014-Spring 2016	Treatment 1: SPT sessions (most with PBL)	390
Fall 2014-Spring 2016	Treatment 2: Summer Institute, SPT Sessions, PBL, cohort activities, mentoring	71

Table 2. OpSTEM Precalculus II Experimental Design

## Selection of Operation STEM Scholars

Among the students who apply, the first 80 STEM majors placing into precalculus (40) and calculus (40), and who are members of the following groups are invited into the program first-generation college students, under-represented minorities, and/or females.

## Control Group

When comparing precalculus pass rates to assess the goal of increasing the pass rate for all students enrolled in Precalculus I and II, previous results are used (Fall 2009-Fall 2012 for Precalculus I and Spring 2010-Spring 2013 for Precalculus II), since these years represent the most recent group that did not engage in mandatory supplemental learning sessions (SPT sessions). Average ACT scores from the Control, Treatment 1, and Treatment 2 groups are similar, indicating that these groups are, indeed, comparable. Pass rates are considered to be a grade of "C" or better, since this allows continuation to the following course.

## Data Collection

Precalculus I and II are coordinated courses, where syllabi, course schedules, grading, homework, exams, and a cumulative final exam are common across all sections of the course. Course grade and final exam data were obtained from the Office of Institutional Research. Passing grades are considered to be grades of A, B, and C, while D, F, W, X, and I grades are considered failing grades, because these grades do not allow students to advance to the following course. (Note: X is a grade given when students fail to attend the last part of the course for unknown reasons.)

When collecting Precalculus I and II data, only the traditional-sequence semesters will be included. For Precalculus I, students traditionally take the course in the Fall semester, so data only includes Fall Precalculus I courses. For Precalculus II, data only includes Spring semester courses. This helps to give the most consistent results

since many students who take these courses off of the traditional sequence do so because they have placed into, transferred credit for, or failed one or more of these courses.

Summer Calculus I data were collected from the online gradebooks at the end of each summer session.

Early on when implementing PBL, some sections of Precalculus I and II had supplemental instruction that included PBL while others had supplemental instruction without PBL. In order to examine the effectiveness of PBL to increase student engagement and pass rates among students who participate, the pass rates between these two groups will be analyzed.

## Data Analysis

Pass rate data for Precalculus I and II courses (Control vs. Treatment 1 vs. Treatment 2 and PBL vs. non-PBL) sections will be analyzed using a one-tailed z-test to determine whether the differences in the pass rates are statistically significant. Descriptive statistics are included for other data in the study.

## Results And Discussion

We will consider each of the three project objectives, and then we will consider the three specific research questions of the initial phase of the project. Finally, we will briefly discuss the first of our ongoing research questions.

- Recruit a large cohort of OpSTEM Scholars who are STEM majors and are first-generation, part of an under-represented minority group, and/or women.

Among the 235 OpSTEM Scholars that participated in the 2013-2016 Summer Institutes, the demographic breakdown is as follows:

	College of Science/ College of Engineering	OpSTEM
White/Caucasian	61%	52%
Black/African American	12%	27%
Hispanic/Latino	4%	3%
Two or more races	3%	13%
Native American	0.1%	0.9%

Table 3. OpSTEM Scholars by race, as compared with CSU STEM students (Book of Trends, 2015).

All 235 participants are STEM majors, and of those participants, 136 (57.9%) are first-generation college students. Ninety-five (95), 40.4%, are female, and 140, 59.6%, are male. This percentage of female students is significant because the College of Engineering, where the majority of OpSTEM students major, has only 16.2% female students (Book of Trends, 2015).

2. Provide them with a Summer Institute experience that increases their skills and confidence in mathematics, helps them form social bonds within the cohort group, and increases their preparedness to succeed in the university setting.

The Summer Institutes have had remarkably high attendance throughout the two weeks (>95%), most likely as a result of the \$200 stipend, which is contingent upon attendance (\$25/day). Students in the Summer Institute refresh their mathematics skills, gain knowledge of CSU colleges and resources, and engage in organizational and time management skills as well as college success workshops. Additionally, they listen to STEM speaker presentations given by professionals, faculty, and upper-class students who provide positive, encouraging insights and helpful career information. The Scholars also form social bonds with their peers through their cohort activities and study groups. SPTs who facilitated the Summer Institute gained valuable teaching, coaching, mentoring, organizational skills, and work experience. OpSTEM Scholars report they gain confidence on their first day as a college student, start the semester with resources, and have a built-in peer network to help them succeed in their courses, particularly mathematics.

For the 2013–2015 summers, 170 students attended the eight day Summer Institute program (2013 n=36, 2014 n=52, 2015 n=82). 169 of the Summer Institute participants completed a follow-up survey in which one-hundred percent (100%) of those surveyed said they would recommend the OpSTEM Summer Institute to a friend who is planning to attend CSU next Fall. The survey also indicated that 97% met fellow students that they believe they will see, study, and/or socialize with in the fall semester, and 91% indicated they would consider becoming an SPT in the future.

In Summer 2014, students took a pre- and post-summer institute Mathematical Knowledge Test. Of the 27 students that participated in this test both times, the pretest had an average of 38% and the posttest had an average of 56%. In Summer 2015, the Precalculus pre-knowledge test average was 30% and the posttest average was 47%. While it is unlikely that the students learned a significant amount of mathematics in this short time, the increase in the pre- and post- test likely indicates that reviewing the mathematics topics was helpful, and students gained confidence in their skills during the Summer Institute.

3. Offer Calculus I for free over the summer for OpSTEM Scholars with sufficient support to yield a high pass

Year	Number of Students	Pass Rate
2014	42	86%
2015	30	83%
2016	39	87%
<b>Total</b>	<b>111</b>	<b>86%</b>

Table 4. Summer Calculus Pass rates

rate in order to accelerate the completion of STEM requirements.

Summer Calculus I has been implemented successfully. In 2014, students attended class five times a week, for six weeks for 150 minutes per day. In 2015 and 2016, it increased to eight weeks, five times per week and 180 minutes per day. This course is offered tuition-free in order to decrease student costs and advance the STEM majors one semester in their mathematics sequence in order to allow them to take science and engineering courses for which Calculus I is a prerequisite. Credit is given through the university's credit-by-exam mechanism. Because of this, grades for the course do not appear on students' transcripts, but rather they simply pass or fail. In 2014 and 2015, a stipend was given to Operation STEM Scholars who passed the course. In 2014, scholars who passed were given \$1000, and in 2015 the stipend was given according to the grade earned, with \$500 given for an A and \$50 given for a C, with gradation in between. In 2016, the stipend was eliminated.

The pass rate for Summer Calculus I has been very high, especially when compared to a typical semester pass rate for Calculus I. Historically, pass rates for Calculus I have been approximately 60%.

### Research Questions

1. Will the pass rate increase in Precalculus I among OpSTEM Scholars and all enrolled students?

In Precalculus I, the fall semester pass rate has increased from 58% (pre-OpSTEM) to 72% (post-OpSTEM).

In Fall 2013, a total of 152 students enrolled in five sections of Precalculus I. Class size ranged from 25 to a 37 in the five sections. Each class met for 4 credit hours and had the equivalent of 2.4 credit hours of mandatory supplemental instruction.

The pass rate (grade of C or better) in Fall 2013 was 81%. The average 2009–2012 historical pass rate is 58%. The withdrawal rate was lower as well. The withdrawal rate for Fall 2013 was 5%, compared to the historical average rate of 15%.

OpSTEM Scholars did better than non-OpSTEM Scholars (90% pass rate for OpSTEM Scholars compared with 79% for non-OpSTEM Scholars). This indicates that the additional treatments the OpSTEM Scholars receive (summer bridge, mentoring, cohort activities, and stipends) provide a measurable benefit. Students treated

with PBL did slightly better than the non-PBL sections (83% compared to 79%). Taken together, the difference between the PBL and non-PBL supplemental instruction does not produce a significantly different pass rate (although in Fall 2014 alone, students in the PBL sections did pass at a significantly higher rate with  $p = 0.015$ ).

The syllabus did change from previous years to take into account attendance in the mandatory supplemental learning sessions and to reward work during those sessions that involved either PBL or other mathematical applications (in the non-PBL) sections.

The cumulative final exam is consistent with gains in learning from before OpSTEM to afterward. The final exam remained approximately constant in content and difficulty because ALEKS was used to generate algorithmically similar questions as the previous years' final exams. In Fall 2012, 111 students took the final exam and the average score was 71%. In Fall 2013, 134 students took the final exam and the average score was 83%.

Survey results indicate that 66% of students indicated they would prefer to take another mathematics class with the mandatory supplemental instruction with SPTs. 83% of the students indicated they benefited from the supplemental instruction sessions.

In Fall 2014, a total of 156 students enrolled in five sections of Precalculus I. Each class met for 3 credit hours and had the equivalent of 2 credit hours of mandatory supplemental instruction. The shift from 4 credit hours to 3 credit hours was as a result of a university-wide shift to 3 credit hour courses. The content of the Precalculus I course did not change because of state-mandated curriculum guidelines, but the number of credit hours decreased, which presented a significant challenge.

The pass rate in Fall 2014 was 62%. Although this was lower than the previous year, it is still higher than the historical average.

In Fall 2015, Precalculus I continued to meet for 3 credit hours, but supplemental instruction was increased by 50 minutes to a total of 150 minutes per week with supplemental instruction including PBL in all sections of Precalculus I. In Fall 2015, the pass rate was 73% (N=175) in total with a 71% pass rate for non-OpSTEM Scholars (N=141) and 82% for OpSTEM Scholars (N=34).

In conclusion, OpSTEM has increased the pass rate, with both levels of treatment contributing to significant increases in Precalculus I pass rates. Both the difference between the control group and Treatment 1 group and the

<b>Precalculus I Pass Rate</b>	<b>N</b>	<b>Pass Rate (<math>\geq C</math>)</b>	<b>PBL</b>	<b>Non-PBL</b>
<b>Control—Fall 2009-2012</b>	511	58%	n/a	n/a
<b>Fall 2013</b>	152	81%	83%	79%
<b>Fall 2014</b>	156	62%	67%	52%
<b>Fall 2015</b>	175	73%	73%	n/a

Table 5. Precalculus I Success (Grades of A, B, or C) Compared with Historical Rates

In a 1-tailed z-test, after OpSTEM, students overall (Treatment 1 and 2 combined) passed Precalculus I at a significantly higher rate than prior to OpSTEM (Control) ( $p < 0.0001$ ).

<b>Precalculus I Pass Rate</b>	<b>N</b>	<b>Pass Rate (<math>\geq C</math>)</b>	<b>Withdrawals</b>	<b>Final Exam</b>
<b>Control—Fall 2009-2012</b>	511	58%	15%	74%
<b>Treatment 1—SPT Only</b>	396	70%	6%	78%
<b>Treatment 2—OpSTEM Scholars</b>	92	83%	1%	76%
<b>Treatment 1 and 2 combined</b>	484	72%	6%	78%

Table 6. 3-year effect of OpSTEM on Precalculus I

In a 1-tailed z-test, in Fall 2013, 2014, and 2015 combined, OpSTEM Scholars (Treatment 2) passed Precalculus I at a significantly higher rate than students who received SPT sessions only (Treatment 1) ( $p = 0.00714$ ).

difference between Treatment 1 and Treatment 2 groups are statistically significant. In other words, students receiving SPT sessions alone achieve significantly higher pass rates in Precalculus I, and the interventions that OpSTEM Scholars receive provide an additional benefit to those pass rates over and above SPT sessions alone.

2. Will the pass rate increase in Precalculus II among OpSTEM Scholars and all enrolled students?

In Precalculus II, a trigonometry course, total pass rates have increased from 61% before OpSTEM to 77% during the program. In the first spring semester of the

grant, all students in Precalculus II met for 4 credits of class time and then the equivalent of 2.4 credit hours of SPT sessions.

Among 135 students enrolled in Spring 2014, 87% earned a grade of C or better. The pass rate among OpSTEM Scholars was about the same, 88%. The withdrawal rate was very low—3% compared to the historical rate of 15%. The PBL sections did better than the non-PBL sections (91% compared to 83%). The final exam was similar in Spring 2014 as the exam in Spring 2013 (again using ALEKS). In Spring 2013, 85 students took the final exam,

and the average score was 71%. In Spring 2014, 127 students took the final exam and the average was 79%.

In the Spring 2015 semester, all sections of Precalculus II were offered with mandatory supplemental instruction. Here, there was a success rate of 72% with a grade of C or better. This course also faced the issue of going from 4 credits to 3 credits; however, the semester we are considering is the second semester after the university-wide conversion, and professors and students were more accustomed to the pace.

The results for Spring 2015 and 2016 semesters for

<b>Precalculus II Pass Rate</b>	<b>N</b>	<b>Pass Rate (<math>\geq C</math>)</b>	<b>PBL</b>	<b>Non-PBL</b>
<b>Control—Spring 2010-2013</b>	419	60%	n/a	n/a
<b>Spring 2014</b>	135	87%	91%	83%
<b>Spring 2015</b>	123	72%	72%	n/a
<b>Spring 2016</b>	133	71%	71%	n/a

Table 7. Precalculus II Success (Grades of A, B, or C) Compared with Historical Rates

In a 1-tailed z-test, after OpSTEM, students overall (Treatment I and II combined) passed Precalculus II at a significantly higher rate than prior to OpSTEM (Control) ( $p < 0.0001$ ).

<b>Precalculus I Pass Rate</b>	<b>N</b>	<b>Pass Rate (<math>\geq C</math>)</b>	<b>Withdrawals</b>	<b>Final Exam</b>
<b>Control—Spring 2010-2013</b>	419	60%	15%	71%
<b>Treatment 1—SPT Only</b>	318	76%	6%	74%
<b>Treatment 2—OpSTEM Scholars</b>	72	81%	4%	76%
<b>Treatment 1 and 2 combined</b>	390	77%	5%	74%

Table 8. 3-year effect of OpSTEM on Precalculus II

In a 1-tailed z-test, in Spring 2012, 2013, and 2014 combined, OpSTEM Scholars (Treatment 2) passed Precalculus II at a higher rate than students receiving SPT only (Treatment 1), but this difference was not statistically significant ( $p = 0.2089$ ).



Precalculus II (MTH 168) were encouraging. The pass rates of 72% and 71% respectively are lower than the first year, Spring 2014 (86%), but higher than the historical average and comparable to the previous semester results in MTH 167. The pass rate for the three years of the grant, using a weighted mean, is 77%, compared with a historical pass rate of 61%.

In conclusion, OpSTEM has increased the pass rate, with both levels of treatment contributing to a statistically similar increase in Precalculus II pass rates. Treatment 1 and Treatment 2 are providing a statistically significant benefit as compared with the control group, but the difference between Treatment 1 and 2 is not statistically detectable.

3. Will developing and implementing PBL components for each of these courses increase student engagement and pass rates?

In the Fall 2013 semester, Precalculus I students designed a bridge and estimated the cost to build that bridge using equations that modeled physical aspects and costs related to the project. For Fall 2014, PBL was modified to involve three somewhat-related projects. The first project still involved a bridge, but now students used bridges in the Greater Cleveland Metropolitan area and calculated vertical force, horizontal force, and maximum tension for the bridges, and they determined unsafe weight conditions for the bridge.

A second project had students use quadratic equations to model free body motion using a video of a baseball play. They generated an equation to model each movement of the ball and used Maple to map the trajectory of the ball. A third project exposed students to the use of exponential functions to model stochastic processes. The students tracked their caffeine intake, and, using the average half-life of caffeine, calculated the rate at which caffeine is metabolized, created an equation, and graphed the amount of caffeine in their systems over an entire day.

In Fall 2015, a fourth project was created, and the bridge project was eliminated because the mathematical concepts in the course were better represented in the new PBL projects. The fourth project asks students to guide a robot through an obstacle course that contains a series of terrains and obstacles that requires them to model the robot's path using different types of equations they studied in Precalculus I.

In Precalculus II, students worked on a PBL project titled "Exploring Trigonometry Through Sound." Students

created a ring tone for a cell phone of at least five discrete tones (one of which had to be a complex tone) and ten seconds in length, provide harmonic equations used to model the tones used to make up the ring tone, generate an audio file of the ring tone, and provide a graph of the equations used to make the ring tone.

PBL projects are presented either in a poster-session format or in a final session, where SPTs and faculty outside of that course judge the projects. In the first year, only students in the on-sequence semester courses completed PBL projects, but in the second year, PBL was expanded to all Precalculus I and II courses.

In the Summer Calculus I class, students work on a PBL project developing a Formula One racing strategy. Here students have to determine the best strategy for refueling a racecar, given several parameters that need to be optimized, using algebraic methods and integration to optimize the strategy. They have to write a final paper that will explain their methods and an explanation of their mathematical thinking during the project. A race day simulation occurs on the last day of the class where each pair's strategy will be tested against each other, and a class winner is determined. Students were enthusiastic and found this project not only applicable to calculus concepts, but also enjoyable.

Initially, PBL was used in certain sections while other sections that had mandatory supplemental instruction did not include PBL (results shown in Table 5 and Table 7). This was used to test its effectiveness. Overall, both PBL and non-PBL sections achieved similar pass rates, typically with PBL sections having slightly higher pass rates that were not statistically significant. Because of this result, after the first year, PBL was used in all sections of precalculus and several sections of calculus with mandatory supplemental instruction in order to increase consistency among the sections of the courses. PBL and its impact on student learning and engagement will be discussed in another paper, which is currently under preparation.

4. Will OpSTEM Scholars have higher rates of fall-to-fall retention as compared with non-OpSTEM Scholars?

With increased pass rates, more mathematically underprepared STEM students are now moving on to Calculus I and II. It is not possible to assess how OpSTEM alone is affecting the retention rates of STEM students throughout the university because of the absence of a control group; however, it is possible to consider how OpSTEM schol-

ars rates of retention compare to others. Additional time is needed to assess the rates at which OpSTEM Scholars are graduating with STEM degrees, but preliminarily data show the retention rate of OpSTEM Scholars is higher than the university's retention rate as a whole (see Table 9).

Since OpSTEM scholars are a more under-resourced population than CSU students as a whole, this retention rate is even more significant. As more retention and graduation data become available, a deeper analysis will be done. Aside from retention rates, 27 OpSTEM Scholars have become STEM Peer Teachers, demonstrating a significant commitment both to the OpSTEM program and to the field of mathematics.

### Growth of Operation STEM

In Fall 2013, three years ago, 12 SPTs started in only the Precalculus I classes which were comprised of a total of 152 students, 36 of whom were OpSTEM Scholars. As of Fall of 2016, 35 SPTs will serve nearly 500 students in Precalculus I and II, Calculus I and II, and there will be 80 new OpSTEM Scholars. OpSTEM has expanded in the number of SPTs, OpSTEM Scholars, math courses, sections, and students served.

### Analysis And Implications

OpSTEM set out to address three specific research questions: whether it could improve the pass rates of Precalculus I and II, and whether PBL would increase student engagement and pass rates in these courses.

Both levels of treatment have shown improvements in the pass rates of Precalculus I and II. This demonstrates that the SPT sessions (Treatment 1), even without additional services, are sufficient to increase the precalculus pass rates. At the same time, calculus pass rates have also improved; so it can be concluded that precalculus pass rates are not being increased at the expense of calculus success.

The additional services provided in the second level of treatment (Treatment 2—OpSTEM Scholars) increases pass rates and retention over and above the gains made by the SPT sessions alone.

Precalculus I and II have seen remarkable gains in their pass rates during the implementation of OpSTEM. The mandatory SPT sessions alone are effective at significantly increasing the precalculus pass rates. Students are moti-

Year	OpSTEM Scholars	CSU Students	CSU Engineering and Science Students
2013	81%	70%	74%
2014	85%	71%	73%
2015	81%	Data not available	

Table 9. OpSTEM Fall-to-fall retention rate vs. CSU students (Book of Trends, 2016)

vated to attend this mandatory supplemental instruction because participation and attendance points are included in the grade for the SPT sessions. SPTs provide extra help during lectures, and SPTs engage students with interactive activities in small and large groups to master content during the SPT sessions. They also encourage students via text to complete homework and study for tests, which in turn helps to establish stronger relationships between the SPTs and their students.

The additional treatments provided to OpSTEM Scholars (summer bridge, mentoring, cohort activities, and stipends) were effective to increase the pass rates even further.

After initial implementation of PBL, it was determined that the pass rates were slightly higher, but statistically no different than the non-PBL sections, and as a result it was decided that PBL would be implemented in all sections. This created consistency among the sections, which was a benefit for the students, course coordinators, instructors, and SPTs.

## Summary Of The Current Study

At this point, it has been demonstrated that SPT sessions alone are effective at increasing the pass rate for precalculus, and the additional services and incentives provided to OpSTEM Scholars increase the pass rate even further. OpSTEM's summer institute has been shown to be effective and appreciated, project-based learning has been implemented with moderate success, and Summer Calculus I has achieved high pass rates. PBL has been implemented effectively. Retention shows promising results, but additional time will be needed to fully analyze the effects of OpSTEM on retention and graduation rates among OpSTEM Scholars.

## Study Limitations

The finding that is statistically significant at this point is the difference in the pass rates in Precalculus I and II for the Treatment 1, Treatment 2, and Control groups. Regarding this finding, there are important limitations to consider.

There are numerous variables that impact the pass rate and the success of the students in the precalculus to calculus sequence. There are numerous factors that affect the pass rates for a single section of precalculus: the abilities and type of student, professor, or SPTs; student attendance and level of grit; time of day and the "on or off" semester the class is taught (out of or within sequence); number of students in the class; incorporation of project-based learning or not; and method of how the student is placed in a course within the sequence, i.e., math placement exam, ACT score, high or low passing grade from previous course within the sequence, transfer student, or repeating the course due to a failing grade.

In our study, we have considered all the sections of on-sequence semesters for Precalculus I and II. This allows

us to control the time of day (since we include all sections at all times of day, the sequence, the professor, the SPTs, use of PBL or not). Additionally, the same math placement exam has been in use during the entire study (and control) time frame. Course caps have fluctuated between 30–40 students depending on the particular semester, and class sizes have fluctuated near that range. While it is difficult to gain meaningful information from the pass rate for an individual section, when taking the pass rate for all sections in one semester of the same course, the numbers yield helpful information.

The first year of OpSTEM saw the best results, likely because that year took place before CSU's 4–3 credit hour conversion, which is one significant confounder in this study. During the second year of the OpSTEM program, CSU converted from a 4-credit hour undergraduate course system to a 3-credit hour undergraduate course system. Prior to the conversion, Precalculus I and II were both 4-credit hour courses and after the conversion, they were both 3-credit hour courses. While many courses' content changed during the conversion, the content of both precalculus courses remained the same, so students and faculty had to adjust to learning and presenting the same material in a significantly shorter time (25% less time per week of class instruction). Finally, after the conversion, students had to adjust to taking more courses each semester. All of these considerations help explain the slump in the pass rates during the second year of OpSTEM. One additional consideration for the excellent results in the first year is the Hawthorne Effect, in which study participants were aware of the study and expected to do well as a result, much like a placebo effect.

Another potential confounding factor in course pass rate is that the grading scheme for precalculus and calculus courses changed slightly with the introduction of SPT sessions. Attendance and participation in SPT sessions along with PBL projects (if applicable) comprise 5–6% of the course grade. While this does introduce a confounding factor, the increase in final exam scores over the same semesters is consistent with the conclusion that participation in SPT sessions (and for some, other OpSTEM activities) is increasing student learning in these courses.

## Conclusions and Recommendations

Increasing pass rates in Precalculus I and II is an encouraging step toward the ultimate goal of increasing STEM retention and completion among mathematically underprepared students. In the coming years, additional studies will examine how OpSTEM is affecting retention and graduation both among the smaller group of OpSTEM Scholars, and among the larger group of STEM students that are affected by the program through mandatory supplemental instruction.

Although it is not certain that increasing precalculus

and calculus pass rates will result in increasing numbers of STEM graduates, the interventions used by the OpSTEM program have effectively opened up this "choke point" and allowed more students to pass through.

Although OpSTEM Scholars (who attend the summer institute, extracurricular STEM activities, and receive additional faculty and peer mentoring as well as the mandatory supplemental instruction and the support of the SPTs) have made the greatest gains in pass rates, it is encouraging that the largest portion of the difference in the pass rates is likely due to the mandatory SPT sessions and SPT support. The SPT sessions reach many more STEM students, and they are financially sustainable because SPTs are paid through federal work-study and course lab fees.

## Future Research

There is a need for further study to follow the students who have taken and passed the precalculus sequence and see how they do in the calculus sequence. Many STEM majors begin mathematics courses in Calculus I or II, but particular attention needs to be paid to how successful those students who have come through the precalculus sequence are when they arrive in calculus courses.

In the future, more study needs to be done to determine how the increasing pass rates are affecting different groups of students, such as under-represented minority students, female students versus male students, and first-generation college students.

More study can also help determine what other factors predict success in the precalculus-calculus sequence and, more broadly, success in STEM degrees. With that information, OpSTEM can further target its efforts to have the greatest impact.

Additionally, more years of data will provide the opportunity to study how increasing pass rates in precalculus affect pass rates in calculus, retention of STEM students, and graduates with STEM degrees. While raising the pass rate of the precalculus sequence and offering tuition-free summer Calculus I with a high pass rate are exciting accomplishments of the OpSTEM program, more time is required to determine whether success in these courses predicts successful completion of a STEM degree.

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