Board 20: STEM Bridge Program Participation Predicts First and Second Semester Math Performance

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Abstract

To combat math underperformance among incoming STEM majors, Rice University designed a summer bridge program with National Science Foundation (NSF) S-STEM funding that included an intensive calculus course. Students invited to participate in the program were identified as being underprepared for STEM classes based on their standardized test scores, high school STEM coursework, and socioeconomic status. One of the program's goals is to improve students' preparation for the advanced math courses required for all STEM majors at Rice. The bridge program is designed to teach the material that has historically been most challenging for underprepared students, meaning the math content covered primarily second-semester calculus topics. We explored the impact of bridge program participation on math performance in first and second-semester math. First, we examined group differences in math preparation. Though program administrators attempt to create equivalent bridge and comparison groups, the bridge program is optional, meaning group assignment is not completely random. Bridge students were less prepared than comparison students on number of high school calculus AP (or equivalent) credits received. We analyzed group differences in final class grades from 2012-2017 among the comparison group, the bridge group, and the rest of the class (i.e. non-comparison and non-bridge), standardizing grades using *Z*-scores. Planned contrasts found that bridge students performed slightly better than, but not significantly different from, comparison students in first-semester math. Conversely, planned contrasts found that the bridge group significantly outperformed the comparison group in second-semester math. These results suggest that bridge program exposure to calculus may improve performance relative to a comparison group, which is especially noteworthy because bridge students are the least math-prepared STEM students entering the university. Future research will analyze outcomes in more advanced math classes. We will use these findings to refine the bridge program's approach to teaching students how to succeed at collegiate-level math classes and, ultimately, as STEM majors at Rice.

Introduction

Math underpreparedness, defined based on incoming college students' exposure to and success in math classes in high school, is a persistent issue that detracts from students' likelihood of successfully passing required college classes and graduating from college [1]. At a national level, math is the subject for which the greatest number of incoming college students are insufficiently prepared and in which students most often qualify for remedial coursework [2].

Math underpreparation within the U.S. can be traced back to factors occurring long before high school students apply to college. Notably, math standards in public high schools vary not only from state to state, but among different school districts within each state [3]. Wealthier school districts tend to offer a broader array and more advanced math classes (classes past Algebra 2) [4], and college graduates who completed substantial college coursework in STEM subjects were more likely to have taken three to four years of STEM courses in high school, including advanced math and science classes [5].

This lack of equity in educational opportunities contributes to certain students, independent of their ability level, entering college with much less math preparation than other matriculating students [6]. Further, within the context of this underpreparedness, there is inequity in preparedness representation. Black and Hispanic students, who are already more likely than other students to require remedial coursework in mathematics, also have lower rates of successful remediation than other students [7]. First-generation college students are also significantly more likely to require remedial math coursework at the post-secondary level [8].

Math Underpreparedness and STEM Retention

Math underpreparedness is a particularly important concern in the context of entering STEM students' persistence in STEM majors. At many universities, STEM students must complete certain math courses, sometimes oriented specifically toward the math skills the university believes STEM majors need, regardless of the specific degree that students are pursuing [9]. Facility with the techniques and sophistication required in college-level mathematics is a central factor in students' ability to perform well in many STEM courses, and failure in math coursework may damage students' math self-efficacy, or their belief in their own capability to do math [10], [11]. Lower math self-efficacy may in turn impact students' STEM intent, or their choice of whether and which STEM fields to pursue [12].

STEM retention in the U.S. is a national concern for many reasons. International math and science assessments of elementary and middle school students have ranked the performance of American students behind many other industrialized nations' scores [13]. Further, an achievement gap in STEM academic performance and graduation rates persists between students of different races, ethnic backgrounds, and genders, despite decades of efforts to eliminate it [14]. One of the potential consequences of a supply shortfall of American STEM workers is that the U.S. will fall behind other developed nations' abilities to produce top STEM workers and STEM-related economic advancements, resulting in a decline in the U.S.'s global competitiveness [15].

To increase matriculating students' preparation for and success in STEM majors, many colleges and universities have implemented summer bridge programs over the last several decades. These programs usually teach foundational STEM knowledge that other incoming students already have, with a primary goal of reducing STEM attrition rates [16]. Notably, there is broad concern over the attrition of STEM students who have the aptitude and persistence to succeed in STEM coursework but who leave STEM for reasons such as lack of STEM preparation or lack of social support [17]. The U.S. federal government, including the Department of Education, the National Science Foundation (NSF), and Health and Human Services, funds many efforts to increase STEM retention at the post-secondary level, including through STEM bridge programs [18].

Rice University's Bridge Program

To combat math underperformance among incoming STEM majors, Rice University designed the Rice Emerging Scholars Program, or RESP, a STEM summer bridge program that is partially supported by NSF S-STEM funding. RESP includes an intensive calculus course (among two other STEM courses). Classes are student-centered and designed to encourage student engagement with the topics. Small groups are integral to the program, emphasizing group discussions, problem-solving tasks, and study sessions led by teaching assistants. Research has linked supportive learning environments, small learning groups, and study skills training to successful improvements in underprepared college students' math performance of [19].

Because being required to pay could prohibit students from low SES backgrounds from being able to afford to participate in RESP, inadvertently preventing many of the students who most need extra STEM preparation from participating, the program waives all costs to students. It also pays a stipend to further reduce any adverse impact on students who need to support themselves or their family financially over the six weeks of the program.

Math Content in the Rice Emerging Scholars Program

RESP is designed to teach students the STEM material which has historically been most challenging for underprepared students, meaning the math content covers primarily second-semester calculus topics. First- and second-semester math classes are the first and second half of single variable calculus. The topics taught in the bridge program that cover first-semester math material are primarily rules for differentiation and applications of the derivative. Topics that address second-semester math material include vectors, sequences, limit comparisons tests, ratio and root tests, power series, and Taylor series.

Participation in RESP is designed to lead both to near and far transfer of math knowledge gained during the summer to the first- and second-semester calculus classes required of all STEM majors at the university [20], [21]. Because primarily second-semester calculus topics are taught in the bridge program, near transfer refers to second-semester math performance, whereas far transfer refers to less-familiar calculus topics, which would be reflected in first-semester math performance. The goal was to bring RESP students' ability to transfer math knowledge to the level of other incoming students, who enter with higher levels of math exposure.

After RESP participants complete the bridge program, those who choose to continue in STEM must take first and second-semester calculus during the regular school year for course credit in order to meet the math requirements of all STEM majors at Rice. Alternatively, students with the appropriate AP credits are not required to take first-semester calculus, though the program encourages participants to take the class regardless.

The Current Study

The current study was designed to explore whether RESP successfully increased students' performance in first and second-semester math classes, relative to a comparison group of similarly underprepared incoming STEM students. One of the program's goals is to improve students' preparation for the advanced math courses required of all STEM majors. We explored the impact of RESP participation on math performance in first and second-semester math.

Our hypotheses reflect our expectation that RESP participation, and consequently exposure to calculus coursework at Rice University's level of pace, rigor, and depth, would improve students' performance relative to a comparison group.

One notable aspect of this study (and all other non-mandatory bridge programs) is that its design is necessarily quasi-experimental, in that though the program administrators select a group of students identified as broadly underprepared, they cannot require students to participate. As a result, comparison and experimental group assignment is not completely random.

Because the program is optional [22], there are also likely to be motivational differences between students who participate and those who qualify for but decline to participate [23]. To control for the possibility that students who perceived themselves as less prepared for STEM coursework would be more motivated to participate in the program, we first intended to explore whether bridge and comparison students exhibited equal amounts of math underpreparation.

Preparation was determined by Calculus AB and Calculus BC AP test credits (the university only accepts 4s and 5s). Students were coded as having either having or not having high school AP calculus credit. This analysis, if there were significant differences, would allow us to control for math underpreparation when analyzing subsequent hypotheses.

Hypothesis 1: RESP students will be less prepared in math than comparison group students, based on high school math preparation.

Next, we intended to explore whether RESP students outperformed comparison group students in terms of final class grades in first and second-semester math.

Although the bridge program primarily covered second-semester topics, we hypothesized that exposure to higher-level content would nevertheless predict performance in topics the program administrators deemed less difficult, due to far transfer.

Hypothesis 2: RESP students will outperform comparison group students in first-semester calculus, when controlling for high school math preparation.

Second, we expected bridge program students to outperform comparison group students on second-semester calculus, due to near transfer of primarily identical course content taught during RESP.

Hypothesis 3: RESP students will outperform comparison group students in second-semester calculus, when controlling for high school math preparation.

We also explored bridge students' performance compared to the rest of the class. We did not specifically hypothesize whether bridge students would outperform other students in first and second-semester math, but we determined that these findings would be useful in further understanding the impact of RESP participation.

Research Question 1: How does RESP students' performance compare to other (non-bridge, non-comparison) students in first-semester calculus?

Research Question 2: How does RESP students' performance compare to other (non-bridge, non-comparison) students in second-semester calculus?

Research Methods

Participants. Students in this sample were those who took first-semester and or second-semester math any semester (fall, spring, summer) between Fall 2012 and Fall 2017. For repeat takers, we only included grades from the first time that students took the class (i.e. repeat performance was excluded). Students were classified as either 1) RESP participants, 2) the comparison group (students who declined their offer to RESP or for whom an invitation was unable to be offered due to limited space; selection criteria for the bridge program are below), or 3) the rest of the class ("other"), who are the remaining students at the university and are assumed to be more prepared for STEM coursework than bridge and comparison students. Bridge and comparison group students were largely underrepresented minorities (Black, Hispanic, or Native American) and first-generation college students, whereas the "other" group was primarily non-first generation White and Asian students.

Selection criteria. Students invited to participate in the program were identified as being underprepared in high school STEM coursework, with weak scores on a math and science diagnostic exam being a major criterion for eligibility for the bridge program [24]. Bridge program administrators also review prospective students on the basis of their ACT or SAT scores, SAT Subject Test scores, AP credits, the competitiveness of the high school the student attended, and whether the student is a first-generation student. This process results in selection of students who are primarily underrepresented minorities and/or from low SES backgrounds, but qualifying students can be from any demographic and SES background.

Quasi-independent variables. Students in this analysis were classified as being either a RESP participant (n=90 in first-semester calculus; n=118 in second-semester math); in the comparison group (n=73 in first-semester calculus; n=77 in second-semester math); or other (meaning they were neither bridge nor comparison group students; n=1,113 in first-semester calculus, n=1,502 in second-semester math). The total number of students in this analysis was 1,276 for first-semester math and 1,697 for second-semester math. Many students in all three groups choose to test out or "AP out" of first-semester calculus, which is why the sample size in second-semester math is larger.

Dependent variables. We examined students' exam performance in first-semester math and second-semester math, using final course GPA to assess performance. The university uses a +/- GPA scale, ranging from 4.33 for an A+ to 0.67 for a D-, and all below D- grades meriting a 0. Withdrawals and "passes" were not included in these analyses.

Statistical methods. To test our first hypothesis, we used an independent samples t-test, comparing incoming calculus credits between the comparison and bridge group. To test the remaining hypotheses and research questions, we used one-way between-subjects ANOVAs with incoming advanced calculus credit as a fixed factor to test for group differences in class performance for both first and second-semester math. We used planned contrasts in the ANOVAs to compare the performance of the comparison v. bridge group and bridge group v. other (non-bridge, non-comparison group) students. All analyses were conducted in SPSS.

Results

We first examined group differences in math preparation for first and second-semester math. We found support for Hypothesis 1, that RESP students were less prepared than comparison group students based on whether they received AP calculus (or IB equivalent) credit in high school ($t(165)=2.44$, $p=.02$, d=0.37). Consequently, in all the following analyses we control for high school calculus AP credit as a fixed factor when reporting results.

We then analyzed group differences in final class grades from 2012-2017 among the comparison group, the bridge group, and the rest of the class (i.e. non-bridge, non-comparison group). Because classes were taught by different professors, we standardized all final class grades using *Z*-scores. Grades were standardized within course reference number (meaning within course section and professor) for both first-semester and second-semester calculus.

To determine whether there were differences based on the semester a student took either class (spring, fall, or summer), we ran a between-subjects ANOVA on final class grades, comparing fall, spring, and summer semester *Z*-scores. The overall ANOVA showed no significant differences among the three semesters in final standardized class grades for either first-semester or second-semester math, so we collapsed results across all years and all semesters. See Table 1 for the number of students, means, and standard deviations of class performance for first and second-semester math.

Table 1. *Sample sizes, means, and standard deviations of final class grade Z-scores by group for second-semester math from Fall 2012-Fall 2017.*

	First Semester Math			Second Semester Math		
Group	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
Comparison	73	-0.51	1.03	77	-0.63	1.13
Other	1113	0.10	0.94	1,502	0.07	0.95
RESP	90	-0.43	0.89	118	-0.19	0.98

Next, we examined first-semester math performance by group. Planned contrasts found that RESP students performed slightly better than, but not significantly different from comparison group students in first-semester math ($p=.35$). Thus Hypothesis 2 was not supported.

Addressing Research Question 1, RESP participants' grades lagged the rest of the class ($F(1,1192)=17.25$, $p < .001$, partial-eta^2=.014). See Figure 1 for the *Z*-scores of all three groups for first-semester math.

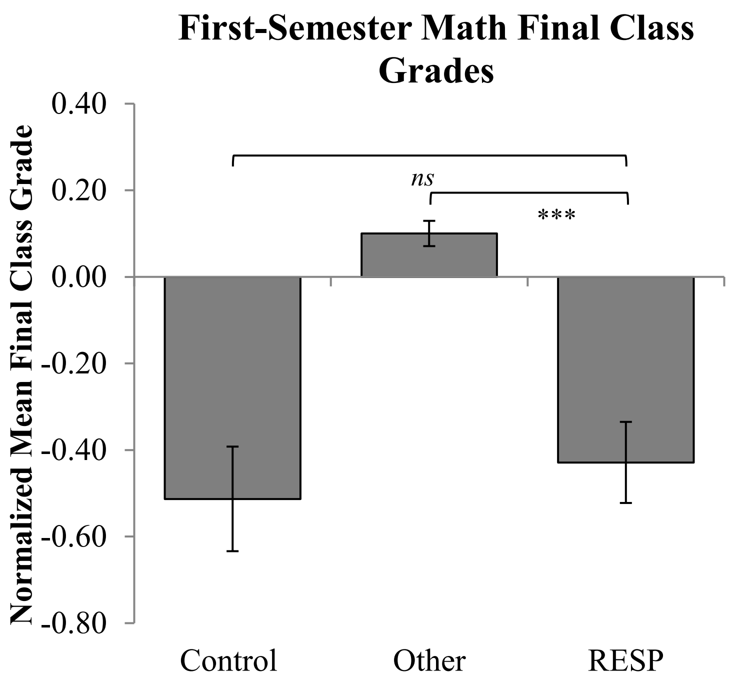

Figure 1. First-semester math normalized final class grades by group. Error bars represent +/- 1 std. error; *ns* is not significant, *** $p<.001$

Next, we examined second-semester math performance by group. Planned contrasts found significant outperformance by the RESP group compared to the comparison group ($F(1,1601)=7.49$, $p=.01$, partial-eta^2=.005), supporting Hypothesis 3.

Addressing Research Question 2, RESP participants' grades were significantly lower than the rest of the class in second-semester calculus. See Figure 2 for the *Z*-scores of all three groups for second-semester math.

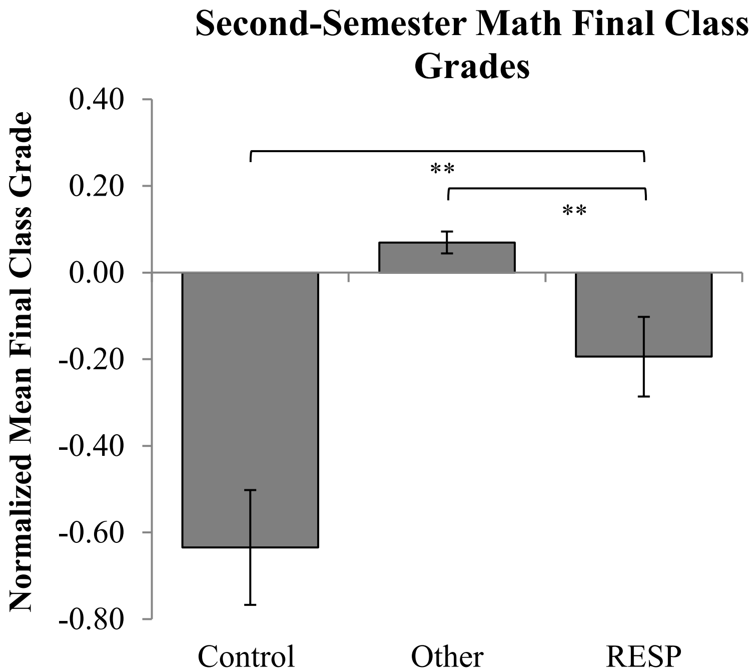

Figure 2. Second-semester math normalized final class grades by group. Error bars represent +/- 1 std. error; ** *p*<.01

Notably, Rice allows first-semester freshmen to drop classes as late as the last day of the semester. This option means that many first-semester math students (regardless of whether they are bridge participants, the comparison group, or other students) choose to withdraw from the class if they believe they will perform poorly in it. Therefore, we have no way of knowing the grades and groups of students who selected this option, because the registrar's office has deleted those data.

One potential way to mitigate this concern is to examine only students presumed to be on a traditional course trajectory, taking first-semester math in the fall semester and second-semester math in the spring semester. If our findings change significantly, we would expect that there would be a significant impact of these missing data, such that bridge students dropped out of first-semester calculus at a different rate than comparison group or other students.

For both first and second-semester math, we found that the general patterns remained the same when analyzing first-semester math grades only in fall semesters and second-semester math grades only in spring semesters. Because the patterns of our findings did not change for either math class, we chose to use the full student sample for both analyses of first and second-semester math performance.

Discussion

We found that bridge program participants were significantly less prepared for calculus in terms of AP calculus credits than the comparison group. This finding supports the claim of a recent extensive review of STEM bridge programs that bridge participants and non-participants may have fundamental differences that should be controlled for statistically before evaluating the effectiveness of a bridge program [25].

We also found that bridge program participation predicted students' performance relative to a comparison group. This finding is especially noteworthy because the calculus topics taught were deemed to be the most difficult for first-year STEM students. The bridge program appears to be successful in teaching bridge students this content, and these findings support our broader theory that near transfer should occur from bridge content to similar math content taught during the second semester. These results may be a function of increasing bridge students' math skills and/or offering them academic and peer support through the summer program that increased their confidence in their academic potential in math. The results also suggest that students in general may feel incapable of succeeding in introductory-level math courses if they have only been exposed to the most difficult material once. RESP provides students multiple opportunities to learn and practice this material over the length of the program, which may render the concepts more accessible to students and increase the general sophistication of their math reasoning skills.

Conversely, we did not find evidence for far transfer, as RESP students did not significantly outperform the comparison group in first-semester math, though there was a trend toward higher performance for the bridge group. Further, the rest of the class significantly outperformed the bridge group.

Future Directions and Conclusion

This study found support for the necessity of controlling for the high school preparation of comparison and bridge participant students. Many bridge programs report quantitative findings for participants compared to a comparison group, but few use statistical techniques (e.g. regression on high school GPA or through matching comparison groups on GPA, gender, and race) to control for group differences [26]. Such analyses are necessary in order to more accurately determine a program's effectiveness. Although this study attempted to control for one group difference relevant to college math performance (high school advanced calculus credit), the comparison and participant samples are conceivably different on other important academic and psychological measures, which we were unable to explore in this analysis.

Though we found evidence for near transfer, further exploration of the mechanisms that RESP might use in the future to encourage far transfer should be conducted. One avenue for future analysis reflects the fact that about one-fifth of bridge students who intended to take the first semester math course at Rice opted out of much of the second semester math material covered in RESP to instead focus on first semester material. In the future we hope to more precisely track these two groups of students to determine which semester of math coursework would be considered near or far transfer.

Future research will also analyze students' performance in more advanced math classes, as well as the mechanisms by which the bridge program may reduce math anxiety, since highly math-anxious students experience self-fulfilling prophecies in their math performance [27] and tend to reject math-heavy STEM career paths for which they might otherwise be well-suited [28].

Ultimately, we will use these findings to refine the bridge program's approach to teaching students how to succeed in collegiate-level math classes through near and far transfer and graduate as STEM majors.

Acknowledgements

We are grateful to the National Science Foundation (NSF-DUE #1565032) for funding this study.

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