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Examining First-Year Chemistry Outcomes of Underprepared STEM Students Who Completed a STEM Summer Academic Bridge Program

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Abstract

This NSF S-STEM Grantee poster examines the results of Rice University's summer science, technology, engineering, and mathematics (STEM) bridge program, the Rice Emerging Scholars Program (RESP), on participants' introductory chemistry grades in a quasi-experimental design that compared performance of participants in RESP, a control group with similar preparation as RESP participants, and the remaining students in the class. The outcome of interest was first and second-semester chemistry exam performance. The researchers also examined performance on first-semester exam items that directly tested concepts taught in RESP versus concepts that were not taught during the program, as well as class grade distribution by group for both first and second-semester chemistry. Results showed that engaging in RESP enhanced performance on items that directly assessed content taught in the program but did not significantly improve performance on items not taught in RESP. However, the proportion of students in RESP earning As and Bs was no different from other students in the class during the first semester. Although not all results were significant, trends in the data point to the promise of RESP. Implications for near and far learning transfer as a result of program participation are discussed.

Introduction

To address concerns about attrition in Science, Technology, Engineering, and Mathematics (STEM) fields in college, Rice University implemented the Rice Emerging Scholars Program (RESP), a STEM summer bridge program, in 2012. RESP is funded by Rice University and a National Science Foundation grant, enabling the program to offer students who have been identified as needing additional preparation for the rigors of STEM college coursework tuition and room and board for the duration of a six-week summer program, as well as an additional stipend for participation. The intent of providing a stipend is to reverse potential adverse selection into RESP of only students who can afford not to work for the summer attending the program.

Students are selected for invitation to RESP based on a variety of factors, including their scores on the university's own math and word problem-focused diagnostic exam [1], SAT and ACT scores, first-generation student status (i.e., when students' parents do not have post-secondary educational experience), and evidence of STEM preparedness in high school operationalized as the amount of Advanced Placement (AP) coursework in which the student participated. Participation in RESP is encouraged but not mandatory for admission to Rice.

STEM fields generally have a high degree of perceived course difficulty compared to humanities and social science courses [2]. As RESP-qualifying students potentially have less preparedness for college-level STEM classes, the task difficulty that students who qualify for the RESP experience can be presumed to be relatively higher than the rest of the class. Task difficulty reflects the level of complexity and information processing, as well as the skill or knowledge, required to accomplish a certain activity [3]. When students perceive tasks as being too difficult to accomplish, this belief is linked to many detrimental academic outcomes, including producing anxiety that may further restrict one's cognitive resources to accomplish a goal [4], attributing the failure to lack of one's ability [5], and incentivizing unethical behavior [6]. To the extent that RESP can bring qualifying students' task difficulty to the same level as the rest of the class, one might expect to see academic outcomes, such as exam performance, that are similar to the rest of the class.

The purpose of this study was to examine the effect of RESP on student performance in STEM. Both near and far transfer of course material are examined for purposes of increasing knowledge and indirectly decreasing task difficulty. Near transfer refers to the retention of material directly taught in the summer program to STEM coursework. Far transfer refers to the generalization of knowledge beyond what was directly taught in the summer program [7]. Another relevant distinction to examine is the concept of "low road" and "high road" transfer. Low road transfer occurs when the new context is similar enough to existing knowledge that the individual can transfer his or her own existing knowledge to the new context with relatively little mental effort; conversely, high road transfer involves deliberate mental processes and evaluation of the situation and prior learning to attempt a solution to the problem [8]. Though low road transfer is generally associated with near transfer and high road with far transfer, the two are distinct mechanisms and are not mutually exclusive [9].

In the context of this study and its focus on challenging STEM topics, demonstrating evidence for far transfer might indicate that RESP has also influenced the thought processes of participants in generating solutions to problems with which they may not have had direct prior experience, via the mechanism of high road transfer. Due to the level of problem-solving and mental processes required in these classes, for the purposes of this study we take the perspective that far transfer can only occur if high road transfer is occurring. Similarly, our perspective is that because RESP directly teaches content that will also be taught during the regular school year, applying existing information taught in RESP to similar exam problems during the regular semester should require relatively little mental exertion, and thus we consider near transfer to encompass the same construct as low road transfer for purposes in this study.

Although the effects of different types of instruction on transfer have been studied (e.g., active learning interventions such as problem-based learning [10]), as well as the transfer of STEM-specific content to primary and secondary school-aged students [e.g. 11], we know of no prior research that has explicitly examined the effect of a pre-college bridge program on near and far (or alternatively, high road and low road) transfer.

RESP Coursework

RESP’s summer curriculum includes chemistry, physics, and calculus, as program administrators have determined those to be the courses students struggle with most in their first year in STEM at Rice [12]. Further, as not all topics can be covered in six weeks, individual topics within each subject area have been selected to ensure students are taught material on which underprepared students at Rice have historically performed poorly compared to the rest of the class.

Summer courses in RESP are taught by university professors, who cover the same content during RESP that is taught in their classrooms during the regular semester. RESP students receive grades for their work that reflect the same grading standards as regular fall and spring semester classes, though these grades do not count as part of the student's official GPA.

Introductory Chemistry Coursework

This paper focuses on introductory chemistry grades during the regular fall and spring semesters at Rice. These introductory chemistry classes are designed to be student-centered and are conducted in an environment that produces student engagement. Most sections use small group discussions and involve instructor-led discussion, voting on content questions, and student problem solving within small groups, with assistance available from teaching assistants in the classroom. A required lab course accompanies each semester, with discussion sections in which students analyze data as part of their assignments.

Apart from having a student-centered model with an emphasis on learning, introductory chemistry is an ideal subject for analysis of outcomes in this study for two main reasons. First, chemistry is a topic that is taught during RESP, and we have access to specific exam question content, student performance, and student drop rates. Access to exam content allows us to identify which exam items reflect the information that is directly taught in RESP and which exam items are outside of the summer curriculum, enabling us to examine both types of transfer. Second, first and second-semester chemistry are centrally taught at Rice, with classroom experiences, course material, and exam content that are consistent across course sections and professors.

The Current Study

We examined the impact of participation in RESP by comparing three different groups of students: participants in RESP; a control group of students who were qualified and/or invited to attend RESP, but who did not attend for a variety of reasons; and all other students in the course who were not invited to attend the program because they were identified as being relatively prepared for the STEM curriculum at Rice based on test scores and AP courses taken. Our approach is quasi-experimental in that we did not randomly assign students to condition, but the design permitted us to compare RESP students to the control students, who were similarly prepared, as well as to compare both control and RESP groups to other students in the class.

Our hypotheses reflect the general expectation that participation in RESP would positively affect exam performance on items taught during the summer (i.e., near transfer). Furthermore, we hypothesized that the benefits of the summer program would transfer to chemistry content that was not specifically taught in the program (i.e. far transfer). As such, we expected that RESP students would have better performance on exam items not directly taught in the summer program in the first-semester chemistry course relative to the control group. We also examined mean differences in second-semester chemistry exam performance among RESP, control, and other students, with the expectation that RESP participation would generalize to better performance for RESP versus the control group beyond the first semester of introductory chemistry, which would demonstrate far transfer. As such, our hypotheses were:

Hypothesis 1: Performance on chemistry exam questions taught during the summer program will be better for RESP students than it will be for control group students in first-semester chemistry due to near transfer of knowledge.

Hypothesis 2: Performance on chemistry exam questions that were not taught during RESP will be better for RESP students than it will be for control group students in first-semester chemistry due to far transfer of knowledge.

Hypothesis 3: Chemistry exam performance will be better for RESP students than it will be for control group students in second-semester introductory chemistry due to far transfer of knowledge.

In addition to examining mean differences in performance among RESP, control, and other student groups, we examined the percentage of students in these groups who ended the first and second semester of introductory chemistry with a grade of B- or better. This analysis reflects a specific goal of RESP, which is to encourage students to persist in STEM with relatively good grades while acknowledging that attaining the highest course grades may be out of reach for many of these students during their first year in college. Thus, RESP aims for students to finish the semester in the top two-thirds of the course, which in most cases reflects grades of B- or better.

Hypothesis 4: RESP participants will receive proportionately more B- or higher grades than the proportion received by control group students in first-semester chemistry.

Hypothesis 5: RESP participants will receive proportionately more B- or higher grades than the proportion received by control group students in second-semester chemistry.

We did not make specific hypotheses comparing RESP students' performance to other students in the course (i.e., neither RESP nor control students) in part because we hoped that RESP student performance would be on par with other students in the course, which would lead us to propose a null hypothesis. Rather, we posit two research questions for comparing RESP, control, and other student performance across both semesters of introductory chemistry as follows:

Research Question 1: How will RESP and control student exam performance compare to other students (neither RESP nor control students) on RESP-taught items and items not taught in the summer program in the first and second semester of introductory chemistry?

Research Question 2: How will RESP and control students' grade proportions compare to other students (neither RESP nor control students) in the first and second semester of introductory chemistry?

Research Methods

Participants. Students at Rice University who took the first half of introductory chemistry in Fall 2013, 2014, or 2015, and/or the second half of introductory chemistry in Spring 2014, 2015, or

2016. Students could be in any year (freshman, sophomore, junior, or senior) while taking either class.

Quasi-independent variables. Student classification as RESP student (n=64 took first-semester chemistry; n=54 took second semester chemistry), control group students (n=52; n= 47 for first and second semesters respectively), and other (neither RESP nor control students; n=1,018, n= 751 for first and second semesters respectively).The total number of students in first-semester chemistry is collapsed across Fall 2013, Fall 2014, and 2015, and the total number of students in second-semester chemistry is collapsed across Spring 2014, Spring 2015, and Spring 2016.

Selection criteria. RESP administrators identify matriculating STEM students as prospective RESP students based on admissions data provided by the Office of Admissions, including factors such as their ACT or SAT score, SAT subject scores, AP credits, high school competitiveness (based on four-year college attendance rates), first-generation college student status, and scores on Rice University's 11-question mathematics diagnostic exam. Many students are low-income and/or underrepresented minorities, although neither of these factors is considered in the selection process.

Students are contacted by the program administrators via letter and phone call. Students who decline their invitation to participate or who are unable to be offered a spot due to limited resources are tracked as the control group.

Dependent variables. For first-semester introductory chemistry, we examined students' exam performance based on whether the question covered RESP-taught content (over three exams and one final exam, there were 18 questions covering material that were taught in the program, and 19 questions covering content that was not taught in the program). Very little content in second-semester introductory chemistry is directly covered in RESP. As such, we examine only overall exam performance for the second semester of introductory chemistry.

For the second analyses, we compared the number of students who achieved a B- (which corresponds to a GPA of 2.67) or higher in both first and second-semester chemistry with those who received a C+ or lower.

Course grades were based on Rice University's GPA scale, which uses the plus/minus grading system and assigns GPAs from 0 for an F, 0.67 for a D-, and up to 4.33 for an A+.

Statistical Methods. In the first analysis, one-way between-subjects ANOVAs were conducted in SPSS. Two planned contrasts were used to differentiate performance between groups using the one-way ANOVA. Planned contrasts, or planned comparisons, compare two means established *a priori* by the study's hypotheses as different from each other. We compared 1) RESP student performance versus other student performance (non-RESP and non-control students), and 2) RESP student performance versus the control group's performance. Chi-square tests were used to determine the relative frequency of grades earned per group for each class.

Results

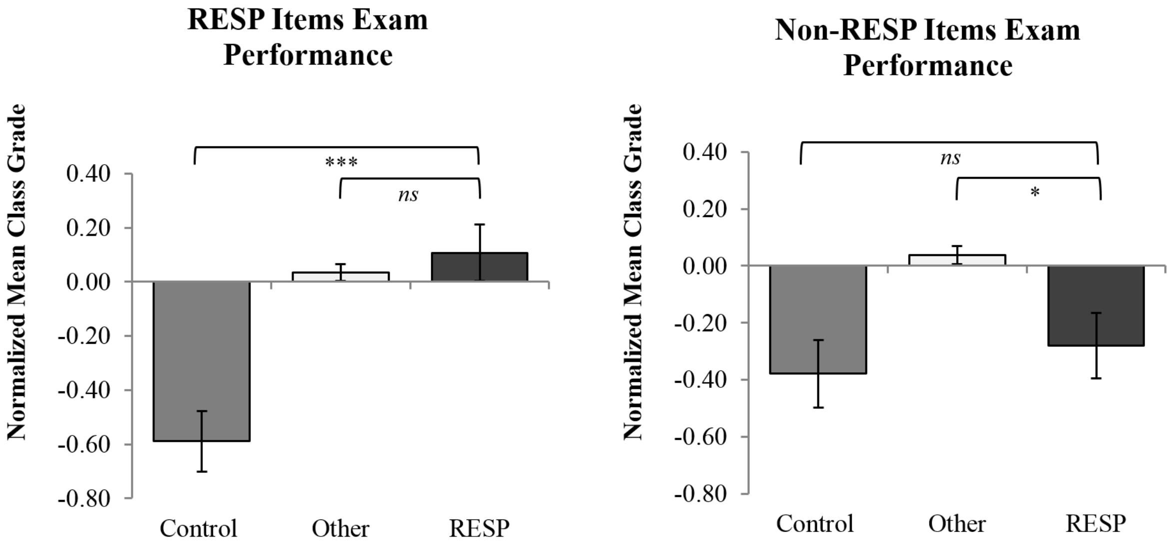
We created *Z*-scores for exam performance and RESP-taught versus other item performance within each semester to facilitate the interpretation of results. See Table 1 below for the means and standard deviations by question type and group.

Table 1. *Mean and standard deviation of standardized exam Z-scores by group and type of question for first-semester chemistry.*

	RESP Items		Other Items	
Group	**Mean**	**SD**	**Mean**	**SD**
Control	-0.59	0.81	-0.38	0.85
Other	0.04	0.98	0.04	1.00
RESP	0.11	0.84	-0.28	0.93

For first-semester chemistry, RESP students outscored the control group on items taught in the program ($F(1,1128) = 14.86$, $p<.001$, partial-eta² $=.013$), supporting Hypothesis 1 (see Panel A on Figure 1). Further, addressing Research Question 1, there was no significant difference between RESP participants and the other (neither RESP nor control) students' scores on items taught during RESP ($F(1,1128) = 0.34$, $p = .56$, partial-eta² $<.001$).

For first-semester chemistry, on exam questions that covered content not taught during the summer program, there was no significant difference between RESP participants' and control students' exam scores ($F(1,1111) = 0.29$, $p = .59$, partial-eta² $<.001$), providing no support for Hypothesis 2 (see Panel B on Figure 1). In terms of Research Question 1, a planned contrast showed that RESP students lagged other students' (neither RESP nor control) performance on these items ($F(1,1111) = 6.13$, $p = .01$, partial-eta² $=.005$). See Figure 1 and Table 2 on the following page for these results.



Panel A **Panel B**

Figure 1. Panel A shows performance for items taught during RESP for control, other, and RESP students. Panel B shows performance for items not taught during RESP for control, other, and RESP students. *N*'s are 52 for control, 1,018 for other, and 64 for RESP. Error bars represent +/- 1 std. error. *** $p<.001$ * $p<.05$

Table 2. *Planned contrasts of first semester standardized exam performance comparing group performance and question type.*

Planned Contrasts	***df***	***F***	***p***	**partial-eta²**
RESP				
RESP versus Control	1, 1128	14.86	<.001***	.013
RESP versus Other	1, 1128	0.34	.56	<.001
Other Items				
RESP versus Control	1, 1111	0.29	.59	<.001
RESP versus Other	1, 1111	6.13	.01*	.005

Note: Degrees of freedom are lower for items taught outside of RESP because the first exam only covered RESP content, and some students dropped before the second exam, which was the first to contain items not covered in RESP.

For second-semester chemistry performance, there was not a statistically significant difference on exam performance between the RESP group and the control group ($F(1,847) = 1.93$, $p = .16$, partial-eta² =.002), though the trend was toward higher scores for students in the summer program. Addressing Research Question 2, there was a statistically significant difference between the RESP group's performance and other students (neither RESP nor control), such that the RESP group generally had lower scores than the other students ($F(1,847) = 10.28$, $p = .001$, partial-eta² =.012). See Table 3 for group means and standard deviations and Figure 2 and Table 4 for the results of these analyses.

Table 3. *Mean and standard deviation of standardized exam Z-scores for second-semester chemistry by group.*

Group	Mean	SD
Control	-0.65	1.12
Other	0.07	0.98
RESP	-0.38	0.90

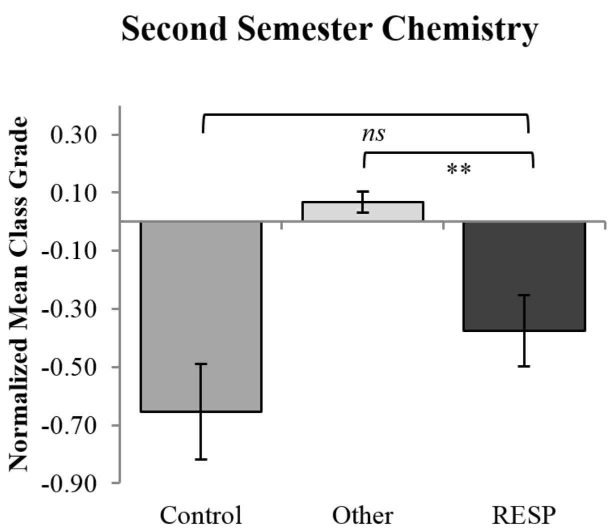


Figure 2. Relative performance on second-semester chemistry exam questions. *N*s are 47 for control, 751 for other, and 54 for RESP. Error bars represent +/- 1 std. error. ** $p<.01$

Table 4. *Planned contrasts of second semester chemistry exam performance by comparing group performance.*

Planned Contrasts	*df*	*F*	*p*	partial-eta²
RESP versus Control	1, 847	1.93	.16	.002
RESP versus Other	1, 847	10.28	.001**	.012

Next, to explore Hypotheses 4 and 5, we compared the proportion of students who received a B- exam average or higher with students who received a C+ or lower.

For first-semester chemistry, a chi-square test found that the RESP group (total $n = 59$) received more As and Bs compared to the control group (total $n = 55$; $X^2(114) = 4.11$, $p = .04$), providing support for Hypothesis 4. Further, there was no significant difference between RESP and other students (neither RESP nor control). See Table 5 and Figure 4, which includes student withdrawals. Although we have no *a priori* hypotheses about students withdrawing from the first-year chemistry sequence because the number of students is small in each group, we include them in the figure for completeness.

Table 5. *Comparison of first-semester chemistry grade distribution by student group.*

Grade Comparisons (As/Bs vs. Cs and below)	*df*	X^2	*p*
RESP versus Control	114	4.11	.04*
RESP versus Other	975	2.38	.12

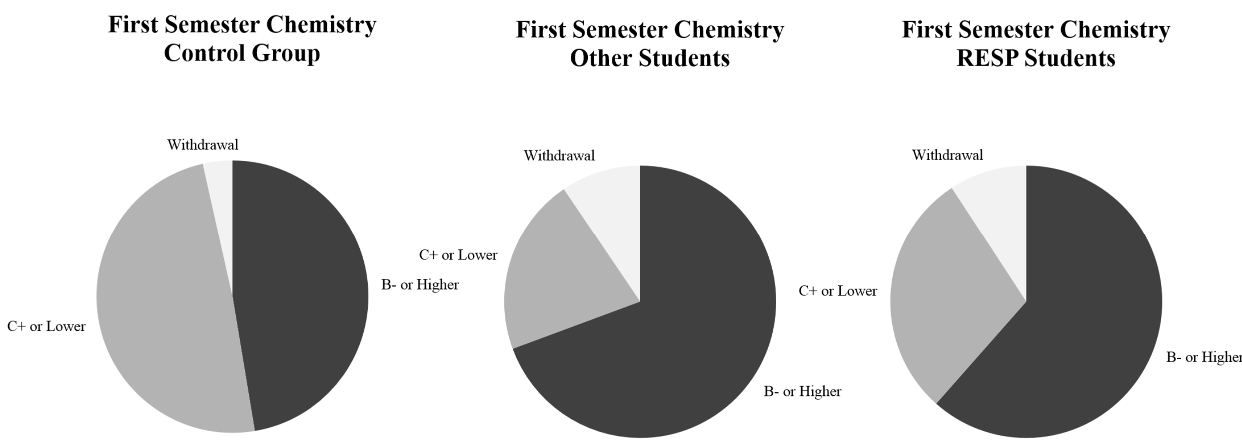


Figure 3. Grade distribution in first semester chemistry by group.

For second semester chemistry, a chi-square test found that the proportion of As and Bs of RESP students (n = 48) compared to the control group (n = 39; X^2(87) = 1.49, p =.22) was not significantly different, which did not support Hypothesis 5, although the trend was for higher grades for RESP students than the control group. Further, there was not a significant difference between the proportions of the RESP group receiving a B- or above and the other students (n = 674; X^2 (722) = 1.69, p =.20), though the trend was for higher grades among the other students. See Table 6 for these results and Figure 4 for the grade distribution among groups. As with Figure 3, we include student withdrawals in the figure for completeness.

Table 6. Comparison of second-semester chemistry grade distribution by group.

Grade Comparisons (As/Bs vs. Cs and below)	*df*	X^2	*p*
RESP versus Control	87	1.49	.22
RESP versus Other	722	1.69	.20

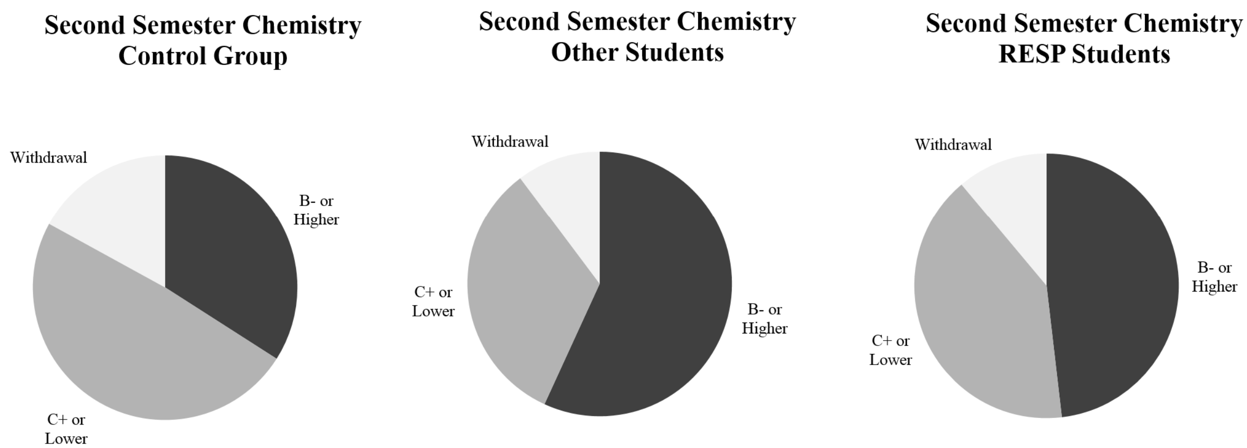


Figure 4. Grade distribution in second semester chemistry by group.

Discussion and Future Directions

The purpose of this study was to examine the efficacy of RESP in impacting near and far transfer and course performance in introductory chemistry. We compared RESP students to students in a control group who were equally prepared for STEM coursework at Rice University, and to other students in the class in first and second-semester introductory chemistry during the regular school year. A major strength of this study was its ability to distinguish between exam content taught within the RESP curriculum versus content that was not. Specifically, we examined near transfer by comparing performance on RESP-taught items during the first semester of introductory chemistry, and we examined far transfer both by comparing performance on items not taught in RESP during the first semester and comparing student performance during the second semester of introductory chemistry. We also examined the proportion of students in each group who received class grades of B- or better to assess whether RESP meets its goal of placing students in the top two-thirds of the course.

Our findings provide insight into the effectiveness of teaching STEM content in bridge programs. We found that RESP students appeared to retain and apply content taught during the summer to first-semester chemistry items compared to the control group, and that RESP student performance on items taught during the summer was not significantly different from the rest of the class, who were theoretically better prepared for college coursework. However, we did not find that participation in RESP produced better performance on items not directly taught during the summer. Nor did we find any significant difference between RESP and control group performance for second-semester chemistry exam grades (though the trend was toward higher performance for RESP students).

In examining grade distributions, we found evidence that RESP students were significantly more likely to achieve a B- or higher in first-semester chemistry than the control group, and that their performance was not significantly different from the rest of the class. For second-semester chemistry, the RESP group was not significantly different from either the control group or the rest of the class, though the trend was toward more B- and above grades for RESP students compared to the control group and fewer B- or above grades for RESP students compared to the rest of the class.

Although not all our hypotheses were supported, we see promising trends in the ability of a summer bridge program to affect academic performance during students' first year in college. In terms of near transfer, our findings clearly point to the benefits of participating in the program. Students appeared capable of applying the knowledge gained during the summer to exam items in the Fall semester, presumably through the mechanisms of near, or low road, transfer (which involves applying direct knowledge learned to new, similar problems with little additional mental effort [8]) Our findings with regard to far, or high road, transfer are not as promising in terms of statistical significance, indicating that the summer program may not be adequately altering students' learning processes to deliberately consider prior chemistry and other knowledge in solving chemistry problems in new topics. However, it is notable that trends in means and grade proportions tend to favor students who engaged in the summer program versus the control group. As the number of students in the RESP and control groups is quite small (approximately 50 students in each group), it may be that with a larger sample we would find stronger evidence for the effect of RESP on far transfer. Because of the nature of the program, however, we are limited in admitting students in each cohort. As such, we will need to wait for additional students to graduate from the program to further examine far or high road transfer effects.

Even with its strengths, this study has several limitations that are worth noting. First, as noted above, we had relatively few students in the RESP and control groups, which may have negatively affected our ability to find statistically significant results when the effects were small (e.g., in our examination of far, or high road, transfer). Second, because of the nature of RESP, we were not able to randomly assign students to either the control or RESP conditions. That is, students opt in to RESP and, even though these students are matched based on academic preparedness, there may be something qualitatively different between RESP and control students. For example, RESP students may be more motivated to do well in college than non-RESP control students who were invited, but who do not participate in the program. In summary, the quasi-experimental design of the current study limits our conclusions about causality, and we caution readers to interpret our results accordingly. Nonetheless, our study suggests the effectiveness of a summer bridge program to positively affect student performance.

Third, this study examined the effectiveness of RESP but did not examine specific instructional strategies that might affect near and far, or high road and low road transfer. Future research can explore how to effectively teach participants the skills to use the bridge program content as a foundation for learning other STEM topics and ultimately successfully graduating as a STEM major.

Last, our study examined the effect of RESP only on student academic performance in chemistry. We did not examine the effect of the program on attitudes toward STEM. That is, we were not able to examine whether the boost in first-semester chemistry course performance also boosted student self-efficacy and attitudes toward STEM majors and careers, a topic that will be explored in future analyses.

In conclusion, the current study provides insight into the transfer of STEM learning in bridge programs. The fact that participants successfully transfer the content taught during RESP to first-semester chemistry is promising, especially given that bridge participants' scores on RESP-taught content were actually brought to a level equal to the rest of the students in the class. Future research will examine the effectiveness of RESP on transfer to other RESP-taught subjects (i.e. physics and calculus), as well as student attitudes toward STEM. Additionally, further research is needed to examine methods for effectively increasing near and far transfer by teaching students how to use the bridge program content as a foundation for learning other and more advanced STEM topics and ultimately successfully graduate as a STEM major.

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