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# The development of collegiate STEM self-efficacy: A longitudinal study of first-year students

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## Abstract

This NSF S-STEM Grantee poster examines the longitudinal impact the Rice Emerging Scholars Program (RESP), Rice University's comprehensive science, technology, engineering, and math (STEM) summer bridge program, has on student perceptions of STEM self-efficacy. STEM self-efficacy, or students' belief in their ability to execute the actions necessary to perform within the STEM domain, can impact both goal setting (e.g., the desire to attain a STEM degree) and goal striving (e.g., the efforts taken towards earning a STEM degree).

STEM self-efficacy was captured three times each during four successive cohorts of students' first year of college (i.e., fall of freshman year, early spring of freshman year, and after the end of the freshman spring semester). For students who participated in the RESP program, STEM self-efficacy was additionally captured at a T0 in the summer before the RESP program began. STEM self-efficacy was measured using an eight-item measure from the Motivated Strategies for Learning Questionnaire [1] , adapted to be specific to the domain of STEM courses. Findings were contrary to expectations. Perceptions of STEM self-efficacy did not significantly differ between program participants and non-participants. Participation in the program changed participant's sense of STEM self-efficacy such that STEM self-efficacy was higher immediately after completing the summer portion of the program than before participating in the summer portion of the program, when controlling for scores on a diagnostic exam of STEM skills and conceptual prior knowledge (n= 195; $t = 2.52$, $p = .03$). Implications for intervention participation and possible future directions are discussed.

## Introduction

Improving rates of undergraduate degree attainment in science, technology, engineering, and math (STEM) fields is an issue of both national and student-level importance [2], [3]. On a macro level, STEM graduates are needed to fill a projected deficit of employees with the necessary knowledge and skills to perform key STEM roles [2]; on a micro level, many fewer students leave college with a STEM degree than entered with the goal of STEM degree attainment [3]. The psychological construct of self-efficacy, or an individual's belief in their own ability to perform the behaviors necessary to achieve a desired outcome [4], is an important dimension in this discussion. If self-efficacy is key to broad goal attainment, STEM self-efficacy (i.e., a sense of self-efficacy within the STEM domain) is an important psychological dimension of STEM student success.

A sense of self-efficacy develops from a person's evaluation of their past performance (i.e., efficacy expectations) and their belief in their ability to shape future performance in a desired direction (i.e., outcome expectations) [4]. Self-efficacy beliefs impact students' motivation [5] and goal setting, including STEM career goals [6]. Self-efficacy has also been found to positively relate to academic performance such that higher self-efficacy leads to both the setting of higher goals and greater task-related effort, which together improve academic performance [7]. An accurate, rather than over- or under-confident sense of self-efficacy, is key for performance within a domain (see: [8]). It is important for undergraduate STEM students to accurately develop their sense of STEM self-efficacy relative to the demands of their new collegiate environment.

The process of STEM self-efficacy readjustment upon entering college may be particularly relevant to high-ability students who attended high schools that are less rigorous than the students' chosen colleges. High-ability students in this situation may arrive in the collegiate environment and need to integrate new information about discrepancies between their current level of STEM knowledge and skills and the level the environment demands of them. The decisions students make in this situation will be impacted by their perceived STEM self-efficacy and will impact that sense of STEM self-efficacy in turn. The current study examines the impact of matriculation into a rigorous collegiate STEM environment on high-ability undergraduates who attended under resourced high schools. Specifically, the current study explores how participation or non-participation in RESP, an anti-remedial, comprehensive summer bridge program, impacts students' sense of STEM self-efficacy throughout the first year of college.

**RESP Program**

The RESP Program is a comprehensive, anti-remedial (see below), summer bridge program conducted at Rice University. Founded in 2012, the program was designed to improve undergraduate STEM retention numbers at Rice University. The program aims to support admitted Engineering and Natural Science students who have the ability needed to be successful in STEM, but who lacked access to strong high school STEM education and thus may not possess the same level of STEM knowledge and skills as peers who attended more rigorous high schools. RESP has supported nearly 350 undergraduates to date. The RESP program has two major components: an intensive six-week residential summer bridge, followed by comprehensive term-time support through graduation.

RESP selects students from within the pool of Engineering and Natural Science students already admitted to Rice University each year (see: [9] for a full review of the RESP selection process). Program administrators examine the pool of admitted students to find those undergraduates who had less access to strong STEM education in high school than their peers and thus enter Rice University at a competitive disadvantage. For example, a typical RESP student may not have had access to AP Calculus in their high school; the median STEM student at Rice University enters with 17 hours of STEM AP credit.

The summer bridge component of RESP is explicitly anti-remedial, meaning the curriculum is designed to target the most challenging concepts and skills demanded of students during Rice University's first-year STEM curriculum. Students complete three non-credit-bearing courses, which include midterms and finals, as well as a project-based learning sequence in engineering design, natural science research, or computer coding depending on their major(s) of interest. Students are encouraged to develop new skills, such as group work and office hour attendance, to compliment the STEM curricular knowledge. Students also experience extra-curriculars designed to foster community bonding, adjustment to college, and a sense of belonging within the program, at Rice University, and within STEM. Students are supported by trained near-peer mentors (many of whom are program alumni), professional staff, and STEM faculty (see: [9]–[13] for additional discussion of RESP).

The ongoing support offered to students through graduation includes individualized, pro-active advising conducted by 3 full-time professional staff. These sessions cover both academic and non-academic issues, with the goal of identifying and addressing barriers to success before derail student progress. First-year students have the option of participating in additional group advising sessions led by upperclassmen program participants. All students can apply for funds to address episodic financial crises that may impact student success. Through the combination of the summer program and the term-time support, RESP aims to ameliorate any obstacle to student success and support students in achieving their goals.

**The Current Study**

The current study analyzes data collected during the 2016-17, 2017-18, 2018-19, and 2019-20 school years as part of an on-going research project funded by an NSF S-STEM grant exploring the efficacy and impact of an anti-remedial, comprehensive summer bridge program on STEM retention. These longitudinal data reflect students' perceptions of their own STEM self-efficacy at four points during the crucial first-year of college: 1) the summer before matriculation (i.e., T0, only collected for RESP participants); 2) early in the fall semester of their freshman year (i.e., T1); 3) early in the spring semester of their freshman year (i.e., T2); and, 4) late spring, or the end of their freshman year (i.e., T4). A breakdown of participants by group for each timepoint can be found in Table 1 of the participants section below.

**Research Methods**

This study explored changes in STEM self-efficacy throughout the first year of college. The authors were particularly interested in whether participation in RESP impacted students' perception of STEM self-efficacy.

Because of the anti-remedial nature of RESP, we expected that the experience of summer bridge program participation would challenge students by providing a realistic preview of what STEM education at Rice University entails. As discussed above, RESP participants are selected on the basis of an anticipated discrepancy in rigor between participants high school STEM environments and the expectations of the STEM environment at Rice University. As such, we anticipated that the realistic preview offered by participation in the program would adjust participants' STEM self-efficacy downward compared to pre-program participation and compared to a non-participating comparison group.

Hypothesis 1: Participation in the summer bridge portion of RESP would lead to a decline in student perceptions of STEM self-efficacy (i.e., perceived STEM self-efficacy would be lower for RESP participants at T1 than at T0).

While the realistic preview was hypothesized to adjust participants STEM self-efficacy downward, many aspects of the RESP program align with factors theorized to increase self-efficacy. Self-efficacy theory suggests individuals based their expectations of their own self-efficacy on different sources of information, including their performance (i.e., performance accomplishments), the performance of role models (i.e., vicarious experience), and feedback or verbal encouragement (i.e., verbal persuasion) [4]. During both the summer and term-time portions of the program, participants experience verbal encouragement, individual feedback designed to improve performance in STEM coursework, and potentially see both near- peers (i.e., upperclassmen mentors who are program alumni) and true-peers (e.g., other first-year students in the RESP cohort) as role models for STEM performance. For these reasons, we expect participants in RESP to report higher STEM self-efficacy during the academic year (i.e., T1, T2, and T3) than matched comparison students who do not have guaranteed access to the supports offered by the RESP program.

Hypothesis 2: Participants in the RESP program would have higher self-efficacy throughout the first year (i.e., T1, T2, and T3) than a quasi-experimental control group of program non-participants.

Participants: This study explores the experiences of four cohorts of students during their respective first years at Rice University. In July of 2016. 2017, 2018, and 2019, incoming students who had agreed to participate in the RESP program were invited to complete a survey. First-year RESP participants plus first-year matched-comparison group participants were invited to complete the same survey at three additional time points during the first year: early fall semester (T1), early spring semester (T2), and after the conclusion of the spring semester (T3; see: Table 1).

Because we were not interested in the developmental experience of students across these four timepoints, participants were collapsed (i.e., T0 was analyzed by pooling 2016, 2017, 2018, and 2019 responses to the T0 survey, rather than as four independent samples). Overall, 172 total RESP participants and 141 total matched comparison participants were invited to complete the survey at each time point. Pooled participant numbers by group membership are shown for each time point in Table 1.

Table 1. *RESP vs comparison group respondents by timepoint*

| Timepoint | Participants | | |
|---|---|---|---|
| | RESP | Matched Comparison | Total |
| T0 (July) | 86 | NA | **86** |
| T1 (August/September) | 109 | 47 | **156** |
| T2 (January/February) | 76 | 54 | **130** |
| T3 (April/May) | 84 | 59 | **143** |

Demographic data for respondents by group membership can be found in Table 2.

Table 2. *RESP vs comparison group respondents by gender and race or ethnicity.*

| Group | Female | Male | Gender identity unknown | African American | Asian American | Caucasian | Mexican American | Multiracial | Native Hawaiian or Other Pacific Islander | Other Hispanic | Unknown |
|---|---|---|---|---|---|---|---|---|---|---|---|
| RESP | 83 | 58 | 0 | 27 | 4 | 18 | 47 | 2 | 0 | 16 | 27 |
| Matched Comparison | 32 | 38 | 5 | 9 | 9 | 12 | 19 | 3 | 1 | 9 | 13 |

Quasi-independent variables*:* Student participation in RESP or inclusion in the matched comparison group was captured and dummy coded. The process by which students are selected for participation in RESP or inclusion in the control group is non-random (i.e., students can decline an invitation to RESP and be included in the matched comparison group; alternatively, not all matched comparison group participants were given the opportunity to participate in the program due to limited resources). Thus, participant group-membership is a quasi-independent variable.

Predictor variables: Self-efficacy can be impacted by prior experiences [4]. Thus, it was important to control for differences in students' pre-collegiate STEM experiences. All incoming undergraduate STEM students at Rice University are invited to take an exam after they've been accepted to Rice University but before they've arrived on campus to begin their first year. The diagnostic was developed jointly by RESP and faculty in the Schools of Engineering and Natural Sciences as part of the RESP selection process to capture students' entering STEM knowledge (i.e., prior exposure to challenging calculus, chemistry, and physics concepts) and skills (i.e., comfort with multi-step word problems). The diagnostic has been found to account for an incremental 9% of variance in STEM grades above SAT performance [9], and was used in this study to control for student's prior STEM experiences.

Outcome variables: Students' STEM self-efficacy was measured using an eight-item measure adapted from the Motivated Strategies for Learning Questionnaire [1] to specifically encompass students' attitudes towards STEM courses. Items were measured on a five-point Likert scale with responses ranging from “strongly disagree” to “strongly agree.” Participants were instructed to rate their attitudes about only the STEM field they were most interested in (e.g., mathematics), rather than for all STEM fields. The adapted measure is provided in the Appendix.

Statistical methods: Analyses were conducted in R [14]. Four one-way analyses of covariance (ANCOVA) were conducted, comparing the effects of RESP program participation on STEM self-efficacy scores, while controlling for prior STEM experience using scores on the diagnostic exam. The first ANCOVA compared perceived STEM self-efficacy scores for RESP participants at T0 and T1. The remaining compared perceived STEM self-efficacy scores for RESP participants against scores of the matched comparison group respondents at T1, T2, and T3, respectively. Tukey's HSD Test was conducted post-hoc for each ANCOVA.

## Results

Uncontrolled means and standard deviations of perceptions of STEM self-efficacy by group for each time point can be found in Table 3.

Table 3. *Uncontrolled means and standard deviations for perceptions of STEM self-efficacy by group at each timepoint of interest.*

| Timepoint | RESP<br>Mean (SD) | Matched Comparison<br>Mean (SD) |
|---|---|---|
| T0<br>(July) | 3.4 (0.67) | NA |
| T1 (August/September) | 3.67 (.78) | 3.6 (.84) |
| T2<br>(January/February) | 3.41 (.84) | 3.52 (.68) |
| T3<br>(April/May) | 3.21 (.98) | 3.35 (.87) |

Perceptions of STEM self-efficacy did not significantly differ between program participants and non-participants at any timepoint. Participation in the program did change participant's sense of STEM self-efficacy such that STEM self-efficacy was higher immediately after completing the summer portion of the program than before participating in the summer portion of the program when controlling for scores on a diagnostic exam of STEM skills and conceptual prior knowledge (n= 195; $t = 2.52$ , $p = .03$). A post-hoc exploratory ANCOVA was conducted comparing perceived self-efficacy for RESP participants at T0 with that of program non-participants at T1. Perceptions of STEM self-efficacy between groups in this exploratory analysis did not significantly differ.

## Discussion

This study sought to address two questions: 1) what is the impact of participation in a comprehensive, anti-remedial STEM summer bridge on STEM self-efficacy for high-ability students in a newly rigorous environment, and 2) does participation vs non-participation in such a program differentially impact students' perceptions of STEM self-efficacy throughout the crucial first year of college?

Our findings suggest that participation in a rigorous summer bridge program can increase students' perceptions of STEM self-efficacy. These results were unexpected, as the program is designed to prepare high ability students with comparatively weak STEM preparation for a rigorous undergraduate STEM curriculum; an immediate drop in self-efficacy could represent an appropriate adjustment indicating students leave the RESP program with a realistic understanding of what their new collegiate environment will demand of them. Instead, results suggest the program intervention could be increasing students' perceptions that they have the skills needed to succeed in their new environment.

Our findings did not support our hypothesis that RESP participants would report higher STEM self-efficacy than matched comparison group members at times 1, 2, and 3. This non-differentiation deserves further exploration.

We hypothesized that RESP participants would experience greater self-efficacy than program non-participants during fall and spring semesters of the first year for two reasons. RESP participants, as opposed to matched comparison group members, had already experienced the shock of adjustment between T0 and T1; matched comparison group participants, in comparison, had no such preview of the STEM expectations of Rice University. Additionally, RESP participants have access to an intensive support structure including professional staff, near-peers, and true-peers, as well as a program of proactive advising and access to resources. We hypothesized that these supports would act as a buffer and aid in STEM self-efficacy resilience for RESP participants compared to matched comparison group members.

One possible explanation for these combined findings is connected to the quasi-experimental nature of the program selection. It is possible that students who have a lower sense of STEM self-efficacy accept the offer to participate in the program and that such participation brings their sense of STEM self-efficacy in line with peers who did not opt-in to the intervention. This possibility could be explored in future research.

RESP's anti-remedial model has raised questions about whether participation in such a challenging experience is detrimental to students' sense of self-confidence and self-efficacy; this study suggests participation does not negatively impact students' self-efficacy, or at least no more than the general transition into college for a similarly situated group of students. Because prior findings suggest RESP may increase STEM graduation outcomes [10], further work is needed to determine how, if at all, the relationships between summer bridge participation or ongoing program support and students' STEM self-efficacy impact desired student outcomes (e.g., STEM retention, STEM degree attainment).

**Future Directions**

Future directions include expanding the longitudinal analysis of collected STEM self-efficacy data to include additional timepoints through students' graduation from Rice University. This line of research will allow for the development of a group-level model of STEM self-efficacy development throughout college. Connecting these STEM self-efficacy data with outcomes of interest (e.g., STEM major declaration, STEM degree attainment, and STEM career outcomes) would enhance our understanding of STEM self-efficacy's impact on student goal setting, striving, and attainment, as well as whether bridge participation mediates the expected relationship between reduced STEM self-efficacy and desirable STEM outcomes. Intra-individual analyses of these data could also help elucidate the effects of specific experiences or crucial junctures impacting students' perceptions of STEM self-efficacy.

## Limitations

As group-membership is not random, there are potentially systematic differences between RESP participants and matched control group participants that might influence study outcomes. While the study does include multiple time-points, only one method (i.e., the adapted STEM self-efficacy questionnaire) was used to capture students' sense of STEM self-efficacy. Finally, at all timepoints students in the matched comparison group had a lower response rate than students who participated in the RESP program.

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## Appendices

Appendix 1

*Measure of STEM self-efficacy, adapted for the STEM domain from items on the Motivation and Strategies for Learning Questionnaire [1]*

1. I generally believe I will receive excellent grades in my STEM classes.
2. I'm certain I can understand the most difficult material presented in the course readings in my STEM classes.
3. I'm confident I can learn the basic concepts taught in my STEM courses.
4. I'm confident I can understand the most complex material presented by my instructors in my STEM courses.
5. I'm confident I can do an excellent job on assignments and tests in my STEM courses.
6. I expect to do well in my STEM courses.
7. I'm certain I can master the skills being taught in my STEM courses.
8. Considering the difficulty of my STEM courses, the teachers, and my skills, I think I will do well in most of my classes.