Longitudinal analysis of a diversity support program in biology: a national call for further assessment

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Abstract

National calls to improve the performance and persistence of students from historically underrepresented backgrounds in science have led to a surge of research on inclusive, evidence-based teaching methods. Less work has examined the effects of diversity support initiatives that improve campus climate and community cohesion. Here, we examine whether participation in the Biology Scholars Program (BSP) at Cornell University— a diversity support program at a prominent university—affects underrepresented racial minority (URM) student performance. We found BSP participants are less academically prepared when they enter college, but typically have similar GPAs to their non-BSP counterparts upon graduation, thereby closing achievement gaps. Although the BSP appears to help URM students, we cannot assert that the BSP alone is responsible for these effects; future work should isolate effective strategies that contribute to student success. In response to these results, we lay out strategies that support programs could implement to maximize positive impacts.

Keywords: STEM equity, science diversity program, Biology Scholars Program, minority students

Introduction

Minority demographics are underrepresented in science, technology, engineering, and mathematics (STEM) disciplines (Landivar 2013), highlighting the need for effective approaches that promote and retain student diversity (Brewer and Smith 2011). Underrepresented racial minority (URM) students in the United States include African American, Hispanic, Pacific Islander, and Native American undergraduates, and each demographic faces significant inequity before and upon entering university. Social challenges that disproportionately affect URM students include transitioning to college (Cooper et al. 2005), feelings of exclusion (Hurtado and Ruiz 2012), stereotype threat (Cohen and Garcia 2008, Steele 1997), and discrimination (Milkman et al. 2015). Within the classroom, URM students are more likely to struggle in large introductory science classes (Alexander et al. 2009) due to inadequate high school preparation and limited opportunities to interact with instructors (Hurtado et al. 2011). A negative learning environment can undermine self-efficacy, which reduces the number of URM students who enter STEM majors and complete a STEM degree (Olson and Riordan 2012). The gap in racial and ethnic demographic representation also widens as students progress through the STEM pathway and enter the workforce. For example, although 10.8 percent of the total workforce in the United States was black or African American in 2011, they held only 6.4 percent of STEM jobs. Similarly, 14.9 percent of the total workforce identified as Hispanic or Latino, but they held only 6.5 percent of STEM jobs (Landivar 2013). Initiatives supporting URM students in higher education thus require creative practices rather than the replication of past practices that have yet to achieve the desired goal of improving racial and ethnic diversity in STEM.

One way that many campuses have tried to promote and retain URM students in STEM is through diversity support programs that focus on aspects of student life outside the classroom. Although few URM support programs have identified specific strategies that improve student performance or other quantitative metrics of success, a handful of programs have been successful in their efforts to support URM students in STEM (Gándara and Maxwell-Jolly 1999; Cota-Robles and Gordan 1999; Matsui, Liu, and Kane 2003; Summers and Hrabowski 2006; Buchwitz et al. 2012; Barlow and Villarejo 2004). The overall lack of quantitative studies on diversity support programs in STEM could be due to low numbers of participating students, unfavorable results, or the inability to disseminate their data with the wider scientific community. Regardless, in order to clarify positive strategies, institutional programs should rigorously and regularly self-assess student performance in a manner consistent with the way STEM researchers address their own scientific questions.

Here, we analyze a longitudinal data set of students enrolled in Biological Sciences at Cornell University between fall 2008 and fall 2015. We compare performance metrics among non-URM and URM students that either participated in an institutional support initiative or did not. The Biology Scholars Program is an undergraduate program based out of Cornell University's Office of Undergraduate Biology in collaboration with the College of Agriculture and Life Sciences and the College of Arts and Sciences. The program's mission is to increase the satisfaction, retention, and graduation of historically underrepresented students in the Biological Sciences, and to promote the value of educating a diverse population of students in the sciences.

To assess the impact of the BSP at Cornell University, we evaluated the preparedness and performance of students that varied in their URM status and whether they participated in the BSP program with three metrics: 1) SAT scores; 2) cumulative GPA; 3) graduation rates. Thus, we use a quantitative approach that is modified from Matsui et al. (2003) to examine variation in both preparedness and performance among biology students at Cornell.

Research Participants

We gathered a longitudinal data set that spans 15 semesters from fall 2008 through fall 2015. We compared the academic performance of 3159 students distributed among four groups: 1) non-URM non-BSP (n = 2221; 'the majority'); 2) non-URM BSP (n = 51; including low-socioeconomic status or first-generation college students); 3) URM non-BSP (n = 706); 4) URM BSP (n = 181). We considered participants of the BSP students who are either currently active members or those who remained in the program for at least four semesters; we removed fifty students because they did not fit these criteria. Through follow up surveys with students who left the BSP, we found two emerging reasons students leave the program: because they decided to pursue a non-science career path, or the BSP was too large of a time commitment. All students who were included in the analysis were intended biology majors, or those who stated in their admissions application that they intend to study the fundamentals of biology and declare a concentration in one of the following: animal physiology; biochemistry; computational biology; ecology and evolutionary biology; genetics, genomics, and development; insect biology; marine biology; microbiology; molecular and cell biology; neurobiology and behavior; human nutrition; plant biology; systematics and biotic diversity. Of our entire student population who graduated, 41% of all students who entered biological sciences graduated with a bachelor of science (N = 615), and 59% graduated with a Bachelor of Arts (N = 877).

All experimental procedures on participants were approved by Cornell's Institutional Research Board for human participants (protocol 1410005010). Anonymized data is accessible through the DRYAD digital repository.

Program description

Between 2008 and 2015, 925 of 3,199 students enrolled in Biological Sciences described themselves as URM (29% of students). Of those URM students, 24% participated in the BSP, representing 7% of all biology majors. From data available between 2009-2015, 244 students were accepted to participate in the BSP out of a pool of 599 applicants (41%) entering Biological sciences. Prior to the program's conception, the university did not provide any unique support to historically underserved students. In response to a national call to action led by the Howard Hughes Medical Institute in 2005, teams of administrators from a number of universities across the country met to discuss the state of the nation's historically underserved student populations, and to generate new ideas on how to better support them. Following that meeting, the group that attended from Cornell met regularly in order to develop what became the BSP, including an on-site visit to Meyerhoff Scholars Program at University of Maryland, Baltimore County. Therefore, the BSP was conceived in an effort to promote and retain URM students within the sciences, with the ultimate goal of diversifying the STEM workforce. The program is institutionally funded out of provost office at Cornell.

According to personal communication with program directors (November 12, 2016), incoming URM students who intend to major in biological sciences are eligible for the BSP, which serves students primarily from economic, gender, ethnic, or historically underrepresented cultural groups and first-generation college students. In the summer prior to matriculation, all incoming freshmen biological sciences majors are notified about the BSP and must apply by the end of August. The program strongly encourages applicants from Cornell's pre-freshman Summer Program. The online application consists of questions and essays that help the BSP selection committee choose students who will be a good fit with

BSP. Students begin the program after university matriculation in mid-September. The BSP selection committee is comprised of staff from the Office of Undergraduate Biology and from each of the two Cornell colleges that support biological sciences majors. The committee looks not only for applicants who may need academic support, but those who are able to demonstrate a commitment to diversity in science are also eligible for the program (personal communication). Approximately 35 freshmen are accepted into the BSP each year and they remain members as long as they meet the program's expectations and continue on a science-related career path.

Activities that characterize the BSP take place in the first four semesters, and participation is voluntary. These include: 1) **academic monitoring and support** through participation in study groups. Biology Scholars are required to attend a weekly, two-hour study group for biology, chemistry, physics, or math courses through their sophomore year. Final grades in science and math courses are monitored by program coordinators and support is provided to any struggling students. Program coordinators are notified if struggling students perform poorly on an exam. Following the notification, they contact students to check on them, make sure they know what resources are available to them (e.g. the Learning Strategies Center, tutoring through the College of Arts and Life Sciences), and develop a plan to improve study habits. The BSP study group leaders are also notified so they can focus their efforts on struggling students; 2) **leadership development.** Leaders of the study groups described above are BSP members who received high grades in the courses they tutor. They are required to attend weekly training sessions where they discuss that week's study group experience and mentor more junior study group leaders, or are provided guidance by more senior study group leaders. BSP members may also serve on the BSP Executive Board. Approximately half of the students continue to serve in some leadership capacity within the BSP after the first two years of support, but this varies dramatically depending upon the cohort_; 3) **interaction with faculty**. Biology Scholars are required to participate in two one-credit seminar courses in their first and second years, in which they meet and work with faculty to learn how to interpret and articulate scientific literature. During this time, students may tour labs and are encouraged to pursue undergraduate research. Because we do not know the number of students who engaged in an authentic research experience as part of the BSP we do not know the impact of this experience on GPA or probability of graduating; 4) **career and professional development**. The seminars also provide information about medical and graduate school and advice for pursuing medical degrees. For example, the BSP offers trips to visit graduate and medical schools as well as financial support to attend off-campus science-related conferences; 5) **sense of community**. Students are required to participate in community service and social events each semester, and have access to a study space housed within the Office of Undergraduate Biology. Required activities for BSP participants only go through the first 4 semesters, and continuation in the BSP is voluntary.

Statistical analyses

Effect of URM Status and BSP Participation on Academic Performance

We used generalized linear models to quantify differences among the four previously described student groups with respect to three metrics: combined math and verbal SAT score, cumulative GPA upon graduation or at the time of data collection, graduation rates. We constructed a generalized linear model with a Gaussian distribution to quantify main and interactive effects of URM status and participation in the BSP program on combined SAT scores and cumulative GPA. We calculated a marginal R^2 value for our generalized linear models as an indicator of model fit and variance explained (Nakagawa and Schielzeth 2012) using functions in the MuMIn package (Bartoń 2009). We urge readers to exercise caution in comparing R^2 values for generalized linear models across studies, however, because substantial variation in methods for generating these summary statistics and their underlying assumptions preclude widespread generalizations (Nakagawa and Schielzeth 2012; Johnson 2014). We also computed the least-square means among all four groups to determine the statistical significance of each pairwise comparison. To examine variation in graduation rates among groups, we determined whether each student graduated from the university, and modeled this binary response variable with a logistic regression using the same predictor variables: URM status, BSP participation, the interaction effect between these two factors, and combined SAT scores. We also calculated a marginal R^2 value for this logistic regression of graduation rates (Nakagawa and Shielzeth 2012).

Results

Effect of URM Status and BSP Participation on Academic Preparedness and Performance

Comparing incoming SAT scores of URM BSP and URM non-BSP students by computing the least-squares means revealed a significant difference between each student group (Figure 1A; Table 1). Non-URM non-BSP students had the highest combined SAT score (mean = 2167; SE = 3.32), followed by non-URM BSP students (mean = 2033; SE = 22.04), URM non-BSP students (mean = 1967; SE = 5.94), and URM BSP students (mean = 1885; SE = 11.25). Computing the least-squares means for each of the four groups revealed statistically significant differences in mean cumulative GPA (Figure 1B; Table 1). We found that the cumulative GPA of non-URM non-BSP students (mean = 3.49; SE = 0.01) and non-URM BSP students (mean = 3.44; SE = 0.07) were significantly higher than both URM non-BSP students (mean = 3.04, SE = 0.02) and URM BSP students (mean = 3.10, SE = 0.03). There was no statistically significant difference in least-squares means between non-URM non-BSP students and non-URM BSP students nor between URM non-BSP students and URM BSP students.

Within our generalized linear models, we found a significant effect of URM status ($\beta_{URM} = -0.45$, $t = -21.99$; P = 8.57 x 10^{-100}) on cumulative GPA. BSP participation ($\beta_{BSP} = -0.05$, $t = -0.75$; P = 0.45) and the interaction effect between BSP participation and URM status were not significant ($\beta_{URM \times BSP} = 0.11$; $t = 1.42$; P = 0.16). The marginal R^2 value for this model was 0.15. We found a significant effect of URM status ($\beta_{URM} = -0.87$; $z = -3.67$; P = 2 x 10^{4}) on the probability of graduation with a degree. BSP participation ($\beta_{BSP} = 13.65$; $z = 0.025$; P = 0.980) and the interaction effect between these two predictor variables ($\beta_{URM \times BSP} = -13.65$; $z = -0.024$; P = 0.981) were not significant. The marginal R^2 value for this model was 0.49. These results suggest that there is a decrease in the probability of graduation for URM students, but that there is no statistically significant difference among URM students that participate in the BSP program and those that do not.

Effect of Incoming Preparedness on Academic Performance

When we included SAT scores as an index of incoming preparedness in our generalized linear models, we found a significant effect of SAT score ($\beta_{SAT} = 1.02 \times 10^{-3}$; $t = 17.658$; P = 3.37 x 10^{-66}) and URM status ($\beta_{URM} = -0.24 \times 10^{-3}$; $t = -10.20$; P = 5.53 x 10^{-24}) on cumulative GPA (Figure 2). BSP participation ($\beta_{BSP} = -0.24 \times 10^{-3}$; $t = 1.42$; P = 0.156) and the interaction effect between URM status and BSP participation ($\beta_{BSP \times URM} = -0.03$; $t =$

0.426, P = 0.670) were not significant predictors of cumulative GPA when SAT scores were included in the model. The marginal R^2 value for this model was 0.23.

When we included SAT scores in our logistic regression of graduation probability, we found that SAT score was the sole statistically significant predictor of graduation probability ($\beta_{SAT} = 2.30 \times 10^{-3}$; $z = 3.11$; P = 0.002). The remaining predictor variables, including URM status ($\beta_{URM} = -0.484$; $z = -1.64$; P = 0.10), BSP participation ($\beta_{BSP} = 0.14$; $z = 13.93$; P = 0.981), and the interaction effect between these two predictors ($\beta_{BSP \times URM} = -13.02$; $z = -0.02$; P = 0.982) were not statistically significant. The marginal R^2 value for this model was 0.50.

Discussion

Recent calls to action urge educators and institutions to increase the retention and performance of all students in STEM fields (eg. Brewer and Smith 2011). Our longitudinal study adds to a growing body of literature that highlights the need for national efforts to quantitatively assess diversity support programs and institute effective practices. After URM students participated in the BSP program at Cornell, we found that the statistically significant gaps in academic preparedness among URM students closed in terms of actual academic achievement. However, BSP participation does not improve the GPA of URM students beyond non-participants. Future research should identify which strategies among diversity support programs contribute most to URM student success.

We acknowledge one limitation to this study could be the self-selection of high-performing students to the BSP, since more motivated students may be more likely to apply to such a program. However, participation in the BSP program did not affect graduation rates. Furthermore, when we included SAT scores as a measure of incoming preparedness in our model, we found SAT scores and URM status strongly predict GPA upon graduation. SAT score was also the sole positive predictor of student graduation rates.

Changing strategies

The persistent performance gap between URM and non-URM students highlights the importance of implementing specific strategies that promote URM demographics. Measuring a range of programs in thoughtful and deliberate ways will allow us to identify the most effective approaches. Institutional support programs that have quantitatively assessed student performance offer points of comparison, but also differ widely in their approaches to supporting students. To further support URM students, Cornell University's BSP plans to experimentally implement a number of new evidence-based strategies. In addition to an annual quantitative assessment using the data presented here as a baseline comparison, the BSP will implement multiple approaches that are describe below. These actions were chosen based on their success in other programs that improved the academic performance or other relevant metrics for URM participants.

One experimental strategy will be to increase student engagement with research opportunities for undergraduates. While the BSP currently encourages students to conduct research, students may be more willing to pursue these opportunities if they are financially supported to do so or are given directed research credits. Research experiences place students in the middle of ongoing research in active laboratories on campus (Hernandez et al. 2013, Maton et al. 2012, Matsui et al. 2003, Olson and Riordan 2012, Villarejo et al. 2008). Through research opportunities, students are exposed to the process of discovery through an authentic project, and engage with professors and graduate students. This strategy may lead to publications, presentation opportunities, and other activities that serve as important steps in building a CV and academic confidence for students. This also places students in close proximity to faculty, who serve as important role models and collaborators. Hernandez (2013) showed in a longitudinal analysis of interventions across 38 institutions that the single most effective strategy that significantly contributes to positive academic motivation of minority students was engagement in undergraduate research.

Another common strategy employed by successful programs, and one that Cornell's BSP will implement starting fall 2016, is student guidance through mentorship by graduate students and faculty. Mentors can be people with whom students develop supportive relationships and from whom they receive professional advice throughout their undergraduate career. Positive role-models and regular contact with faculty are considered key experiences in higher education associated with student retention and development (Epstein et al. 2015, Wilson et al. 2012), including degree aspirations (Kim and Sax 2009), potential for degree completion (Newman 2011), and academic performance (Kim and Sax 2009).

Finally, the BSP will incorporate established learning theory into practice. For example, the BSP plans to extend programming to include juniors and seniors, with a focus on continued use of collaborative learning with peer groups (Toven-Lindsey et al. 2015). In this scenario, we expect increased motivation and persistence through elements of social constructivism, in which learning happens through social interactions with others (Au 1998). Beyond quantifying persistence and performance, an appropriate assessment tool for the BSP to quantify the effects of extended programming on motivation is the Motivated Strategies for Learning Questionnaire (Pintrich et al. 1993). Other established learning theories that the BSP will employ is the growth mindset and lay theory approaches to learning (Yeager David Scott and Dweck 2012, Yeager David S et al. 2016). In practice, teaching students about growth mindset is to stress that intelligence and performance are malleable; lay theory stresses the high prevalence of emotional challenges experienced by other students as they entered college. These types of interventions reduce the susceptibility of stereotype threat and narrow institutional achievement gaps (Levy et al. 1998, Yeager David S et al. 2016).

Challenges and opportunities for STEM

The critical importance of effective diversity programs for minority students has strong implications for the achievement of equity in STEM disciplines. In order to reveal positive outcomes and efficient use of resources, more quantitative research is required. One difficulty for many universities is selecting how to distribute funds for URM-support programs. While most large universities have URM support programs, few studies have explored the optimal allocation of limited resources to best serve students: does a university invest a finite amount of resources across a large pool of students or into few individuals? If they choose the latter option, is it better to invest in low-achieving students who most need the intervention, or top-achieving students who are most likely to succeed? There may be a critical financial threshold below which the amount of funding will not benefit students, or above which programs should consider widening their pool of recipients.

Another area that would benefit from further study is the exploration of nuanced quantitative metrics beyond GPA and retention rate that capture the positive effects of URM-support programs. Such metrics may include measures of intellectual breadth, extracurricular depth, self-efficacy and motivation, academic or extracurricular accomplishments, and life-long impacts. The lack of studies on these other metrics means that we cannot test how Cornell's BSP affects different facets of student success; yet the BSP may affect URM students in ways we have not quantified. Rigorous research on alternative metrics of performance is required if our field aims to evaluate the generality of different program impacts.

This assessment presents the BSP with the unique opportunity to apply and monitor evidence-based methodologies to close the majority-minority gap. In spite of inherent challenges, the promotion of diversity in STEM fields will be made possible through continued collaborative assessment and systemic change.

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	URM		Non-URM	
	BSP	Non-BSP	BSP	Non-BSP
SAT Score (SE)	1885.33 (11.25)	1967.01 (5.94)	2032.95 (22.04)	2166.85 (3.32)
GPA (SE)	3.10 (0.03)	3.04 (0.01)	3.44 (0.07)	3.49 (0.01)
n	181	706	51	2221

Table 1: Results from generating least-squares means to compare incoming SAT scores and cumulative GPA of students who differ based on their racial minority status (URM or non-URM) and participation in Cornell's Biology Scholars Program (BSP or non-BSP). Standard errors are shown in parentheses.

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Figure Legends

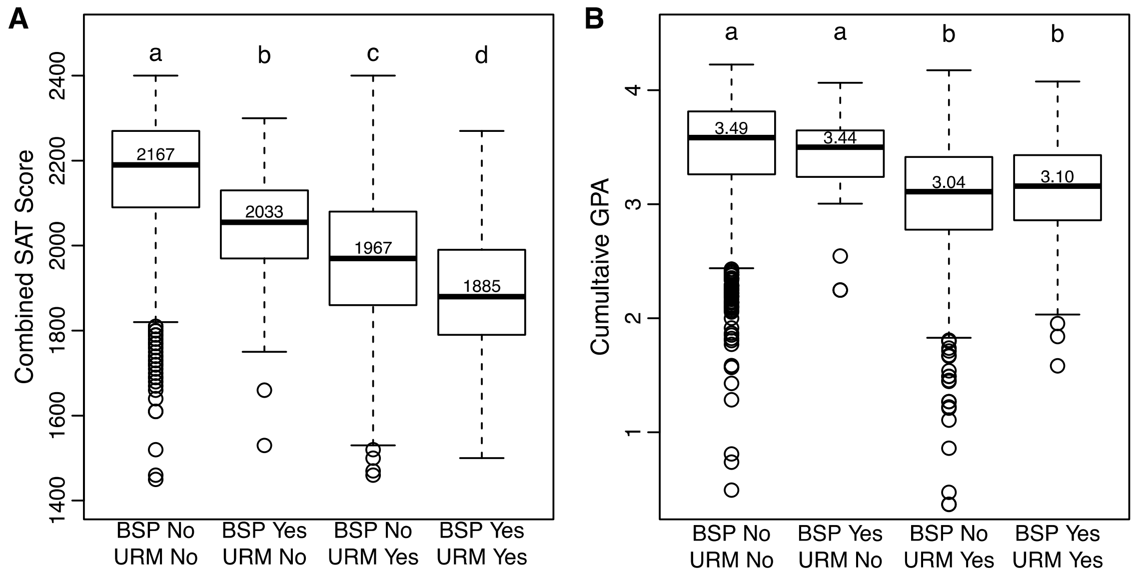

Figure 1: Differences in preparedness as estimated with (A) combined SAT scores and (B) cumulative GPA among students that varied in minority status and participation in the BSP program. The mean values are shown for each group above the median bar in the bar plot. Outliers are shown as circles. Significant differences in pairwise comparisons of least squares means estimates are shown above each boxplot.

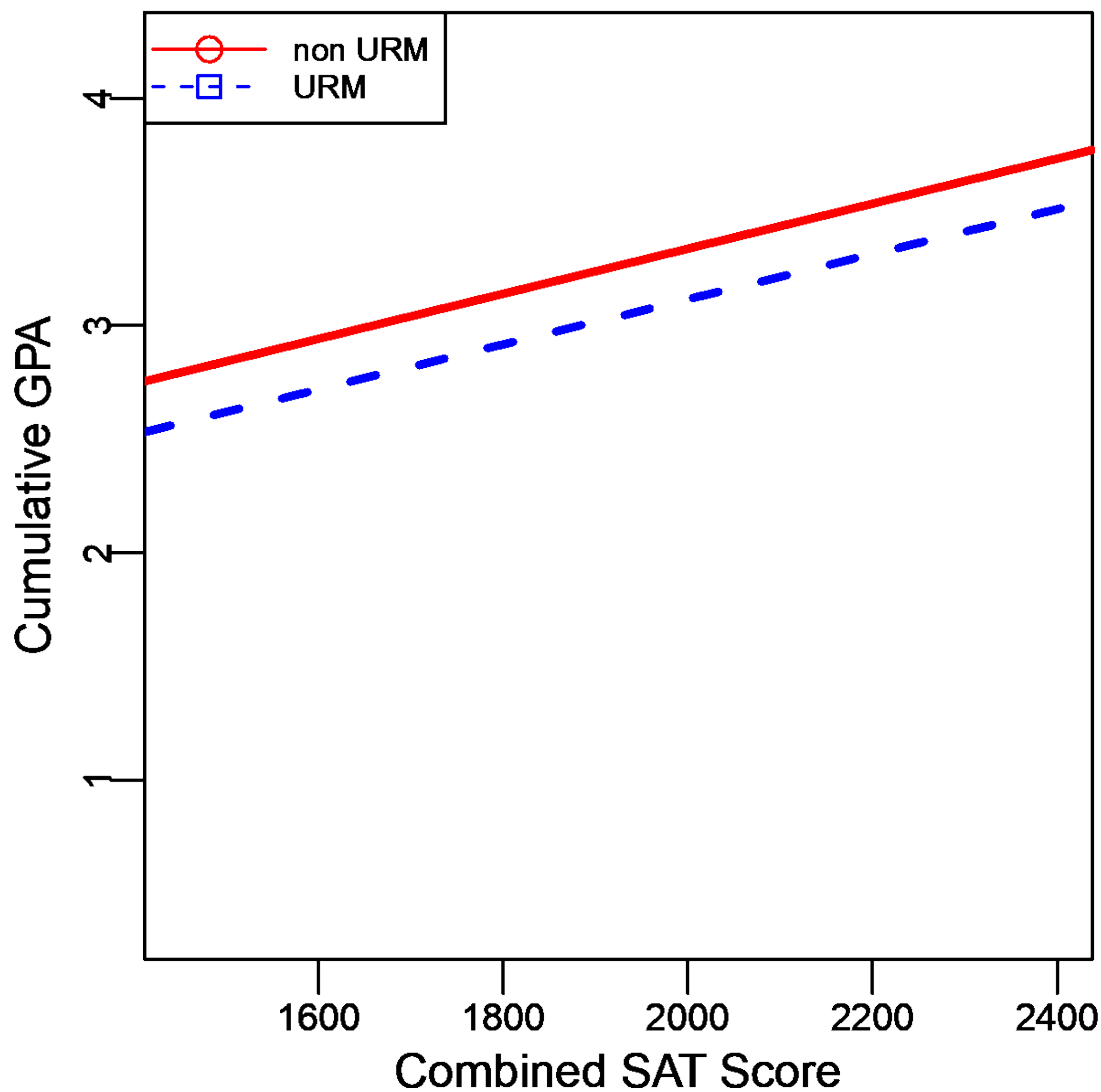

Figure 2: Scatterplot of combined SAT score and cumulative GPA, which shows a positive correlation between these two metrics. The solid line and circles represent non-URM students, while the dotted line and squares represent URM students.