Adopting a Holistic Conception of Student Success in Undergraduate Mathematics: Investigating Student Experiences With a Calculus Support Course

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This study investigates student experiences in undergraduate mathematics education, highlighting the importance of addressing inequities related to race and gender in student success rates. Focusing on support courses for Precalculus and Calculus I, where students participate in regular Supplemental Instruction sessions and an online course led by the university Math Equity Coordinator, I examine how these interventions influence student success beyond traditional measures such as grades and persistence to include the impact on students' confidence, sense of belonging and the perception of instructional practices. Results from this mixed-methods analysis show that students enrolled in the support course report higher levels of confidence and a stronger sense of belonging in mathematics. Interviews further emphasize the critical role of instructional practices have in fostering these positive outcomes. These findings suggest that to investigate the success of at-risk students effectively, researchers ought to broaden the scope of success indicators to include identity-related aspects of student experience.

Keywords: identity, confidence, belonging, calculus, student success

Introductory undergraduate mathematics, particularly Precalculus and Calculus courses, have long functioned as an access-controlling mechanism for STEM fields, often filtering students out and limiting progression through their majors (PCAST, 2012; Weston et al., 2019). National data highlights troubling trends, such as Koch and Drake's (2018) finding that 34.3% of students at 36 higher education institutions received a D, F, Withdraw, or Incomplete (DFWI) in Calculus. The barriers are even higher for Black or African American students and Hispanic or Latinx students, who experience DFWI rates of 47.8% and 47.9%, respectively. Moreover, women are 1.5 times more likely to exit STEM pathways compared to men (Ellis et al., 2016). Addressing these persistent disparities requires mathematics educators to invest in listening to student experiences and enacting meaningful, equity-driven reforms in instructional practices.

In response to these challenges, this study focuses on a large Southwestern University (SWU) that has faced similar racial and gender disparities in Calculus success rates. Over a two-year period, the institution has employed a holistic approach aimed at closing equity gaps in its Precalculus through Calculus courses. A central component of this effort is the introduction of support courses for Precalculus and Calculus I. These courses offer students an opt-in 1-unit program that incorporates regular attendance at Supplemental Instruction (SI) sessions and engagement with an online Canvas hub, overseen by the university's Math Equity Initiative coordinator. These courses represent a hybrid model of student support, occupying a middle ground between fully integrated corequisite courses and traditional SI programs.

This paper builds upon the findings presented in last year's preliminary report, moving beyond initial observations to provide a more comprehensive analysis of the impact of these support structures. Using a mixed-methods framework that integrates survey data and semi-structured interviews conducted in the Spring 2023, Fall 2023, and Spring 2024 semesters, I examine how students enrolled in Precalculus and Calculus I perceive the inclusivity of instructional practices and the effect of these support courses on their confidence and sense of belonging in mathematics. Our findings underscore that, while academic outcomes such as

grades and course completion are important, student success must also be understood through broader lenses—particularly the cultivation of confidence and a sense of belonging within the mathematical community. These results advance the argument that holistic support, including mentorship and equitable instructional practices, plays a critical role in addressing long-standing inequities in undergraduate mathematics education.

Relevant Literature and Theoretical Perspective

Investigating the experiences of students in mathematics courses requires careful attention to the unique and evolving identities they bring to the classroom. Student identities are not static but are continually reshaped by interactions with their peers, instructors, and the broader learning environment (Collinson, 2006). Within a mathematics context, these identities take on additional dimensions. Martin (2012) describes mathematical identity as the ways in which students see themselves as "doers" and "learners" of mathematics. This concept extends beyond mere participation, encompassing students' perceptions of their interest, enjoyment, and confidence in the subject. In this research, mathematical identity is explored as a multidimensional construct that intertwines with students' broader self-concepts and is closely tied to their sense of belonging within mathematics. By focusing on identity and belonging, the results in this paper illuminate some of the complex factors contributing to the persistence challenges observed in STEM fields, where nearly half of all students in the U.S. who begin a STEM degree do not complete it (National Center for Education Statistics, 2018).

Confidence plays a crucial role in shaping students' experiences and success in mathematics. Research shows that students' confidence in their mathematical abilities significantly impacts their willingness to engage in mathematical tasks and persevere through challenges (Nunez-Pena, Suarez-Pellicioni, & Bono, 2013). In the context of undergraduate mathematics, studies have indicated that students with higher levels of self-confidence are more likely to persist in STEM-related courses (Ellis, Fosdick, & Rasmussen, 2016). Conversely, low confidence has been shown to correlate with higher dropout rates and disengagement, particularly among women and underrepresented minorities (Boaler, 2016). As students navigate the often-intimidating terrain of calculus and precalculus, building and maintaining their confidence is essential not only for their academic performance but also for their long-term persistence in STEM fields. Therefore, fostering environments that actively promote confidence in mathematics can play a key role in reducing attrition and supporting a more equitable learning experience.

Closely tied to confidence is the sense of belonging, which is increasingly recognized as a critical factor in students' success in mathematics. A robust sense of belonging has been associated with improved academic outcomes, increased motivation, and greater persistence in mathematics courses (Good, Rattan, & Dweck, 2012). Particularly in the context of underrepresented students, feelings of exclusion or marginalization can undermine academic performance and lead to disengagement from the subject (Walton & Cohen, 2011). In undergraduate mathematics, where large lecture formats and competitive environments are often the norm, fostering a sense of belonging can help mitigate the alienation that many students feel, especially in fields traditionally dominated by white male students. As such, promoting inclusive instructional practices and creating supportive peer interactions in settings like Supplemental Instruction have the potential to significantly enhance students' sense of belonging and, in turn, improve their mathematical engagement and persistence.

These considerations necessitate a shift in how student success is conceptualized in mathematics education, moving beyond traditional metrics like grades and course persistence. A critically informed theoretical perspective, such as Critical Race Feminism (Crenshaw, 1989),

calls for an evolution in research approaches that view aspects of the student experience, such as student success, more holistically. Rather than focusing solely on academic outcomes, this perspective emphasizes the importance of examining how systemic inequities shape students' experiences in mathematics classrooms by listening to and believing their lived experience. By integrating insights from identity, confidence, and belonging, mathematics education research can advocate for changes that recognize the socio-cultural dynamics of learning and strive to dismantle structures that perpetuate exclusion and marginalization. A critically informed approach to systemic change in mathematics education thus positions identity and belonging as central components of student success, urging departments to reframe their strategies for fostering equitable, inclusive learning environments.

Methods

SWU is a large, public 4-year HSI research university. Administration of a survey resulted in 807 responses across two semesters of students enrolled in Precalculus and Calculus. The focus of this study are 60 total students (gender and race/ethnicity shown in Table 1) who opted-in to enroll in the newly developed Precalculus or Calculus I SI-based support course that also responded to a survey sent at the end of spring 2023 and fall 2023 semesters. While the survey collected demographic data beyond two genders, there are only two present in this subset of the sample population. Of these 60 students, 41 were enrolled in Precalculus and 19 were enrolled in Calculus and their respective support courses. The remaining data of 747 students were not enrolled in the support course with 367 enrolled in Precalculus and 380 enrolled in Calculus.

Table 1. Students self-reported identity. This table shows a count of each gender present by race/ethnicity.

Support Course Student Demographics									
	Alaskan Native or Native American	Black or African American	Hispanic/ Latinx	Middle Eastern or North African	East Asian	White	Native Hawaiian or Pacific Islander	South Asian	Southeast Asian
Man	1	1	14	1	3	11	1	0	6
Woman	0	2	5	0	1	13	0	1	4

Ten of these sixty students participated in a one-hour long, semi-structured individual interview that focused on a variety of topics related to their experiences in their current mathematics courses as well as their own histories of experiences with mathematics in general. Topics that were discussed included how their identity has impacted their learning of mathematics, how their confidence in their mathematics ability has changed, and the extent to which they have utilized university-offered support structures such as SI.

In order to develop a broader sense of experiences across all precalculus and calculus courses, the administered survey was an amalgamation of items built from subsets of two existing surveys. One of these surveys is the student postsecondary instructional practice survey (SPIPS-M), which specifically focuses on students' interpretations of instructional practices, changes in attitudes towards learning and doing mathematics, and their perceptions of the climate in the classroom (Apkarian et al., 2019). Supplemental to the focus of this survey, the second

survey developed by Brown and colleagues at Penn State University called the Inclusive Instructor Behaviors (IIB) survey was included to leverage student experience to determine various aspects of the perceived inclusivity of teaching behaviors and sense of belonging in mathematics.

Qualitative analysis of the interviews as well as free-response items from the survey was performed using MaxQDA, through multiple cycles of open coding, axial coding, and constant comparison. Quantitative analysis of the survey was performed using SPSS and R, utilizing methods appropriate for the large amount of ordinal data from the dataset and the large population size difference across support course enrollment. These methods include two-sample proportions tests, chi-squared tests, Wilcoxon Signed-Rank tests, and Mann-Whitney U tests.

Results

The results of this analysis are a subset of a larger study, my dissertation that is in publication. This paper contains selected results with an attempt to deliver important aspects of student experiences while still capturing the larger scope of the dissertation. I first present select quotes from student interviews specifically focusing on instructional practices that improved confidence and mediated aspects of their identity they found to be a barrier to their success in undergraduate mathematics. Following these qualitative results, I present select quantitative results that focus on shifts in confidence towards mathematics and sense of belonging compared across students who enrolled in the support course and those who did not.

Qualitative Results

Interviewed students shared their experiences with their perception of instructional practices that they perceived to have helped them due to their self-reported intersectional identities of women in STEM, English Language Learners (ELL), or first-generation college students. While the scope of these quotes reaches themes beyond their interactions with solely the support course and the SI leader, the comfort students found in engagements with all of their instructors (Lecturers / Professors, TA's, and SI leaders) indicates a broader effect of availability, approachability, and words of encouragement on students' confidence and sense of belonging.

Amy, a first-generation Asian American woman in STEM, shared about her experience with her TA for the recitation course for Calculus I. When prompted about instructional practices that assisted the barriers they found to succeeding in undergraduate mathematics, Amy said,

> One of the things that really helped me was my TA. He was always there during office hours, and he explained things in a way that made sense to me. He never made me feel stupid for asking questions, and he encouraged me to keep trying even when I was struggling. It was a huge boost to my confidence.

The encouraging interactions and support from Amy's TA indicate the significant role of personalized interactions in fostering a positive learning environment. She also spoke about impactful instructional practices of the professor for the lecture section:

> In one of my classes, the professor always made sure everyone had a chance to speak. He would go around the room and ask each person for their input. It made me feel valued and like my opinion mattered. It was a stark contrast to some of my other experiences, and it really changed how I viewed myself in the classroom.

Facilitating an inclusive classroom environment where the instructor actively seeks input from all students helped Amy combat feelings of marginalization. For her, this practice validated her contributions and fostered a sense of belonging, positively influencing her identity by changing her self-perception and her place in the math classroom.

Belinda, a first-generation Latina in STEM, spoke about group work and the positive experiences she had from attending SI due to her enrollment in the support course. When asked about instructional practices that mediated aspects of her identity and alleviated barriers she faced, she said,

> College group work is still a challenge, but having more support from SI sessions helps. It makes collaboration more effective. In SI, we often work in small groups to solve problems together, and the leader encourages us to explain our thinking, which helps me practice my English and math skills at the same time … the supportive environment in SI sessions makes me feel more comfortable asking questions and participating… and this has made a huge difference in my overall confidence and willingness to engage in class.

Belinda's experiences underscore the profound impact that specific instructional practices within SI sessions can have on a student's identity and confidence in math. The step-by-step problem breakdowns, small group dynamics, encouragement of peer explanations, and supportive, interactive environment provided in SI sessions have transformed Belinda's relationship with math in the classroom. These practices have helped her overcome language barriers, reduce feelings of isolation, and build her confidence and competence in both math and English.

Collectively, the instructional practices identified to help mediate identity-related barriers to engagement and increased self-confidence in women and first-generation students enrolled in the support course should appear familiar to an educator focused on equitable experiences for their students, as noted by multiple pedagogical frameworks in the field of mathematics education. For example, inquiry-based mathematics education promotes instruction that emphasize a focus on equity and engagement in one of its four pillars of implementation.

Quantitative Results

This section focuses on comparing aspects of student success across support course enrollment. First, I present the results from typical metrics such as grades and math course persistence. Then, I present results from a broader conceptualization of student success that includes shifts in student confidence as well as sense of belonging.

One metric that universities and math departments typically investigate is the DFW rate, which is the percentage of students who received a D, F, or WU in the course. For students enrolled in the support course and not enrolled in the support course, the DFW rates are 17.24% and 19.36%, respectively. A two-sample proportions Z-test was conducted to determine if there is a significant difference between these two DFW rates and the results indicate there is no statistically significant difference between them ($Z = -.401$, $p = 0.688$). A chi-square test of independence was conducted to statistically compare the distributions of all grades across both groups. The results revealed a significant difference in the grade distributions between the two groups, $\chi^2\ (5) = 14.102$, $p = 0.015$. This indicates that the distribution of grades for students enrolled in the support course differs significantly from those not enrolled, suggesting an association between support course enrollment and student grades. Further investigation revealed that this difference favored students in the support course slightly, with students in the support course more likely to receive a B and less likely to receive a D compared to their peers.

Next, I present three categories of persistence in students' math course plan: students who plan to take the next logical course, students who plan to take the same course, and students who do not plan to enroll in another math course. I conducted a series of chi-square tests of independence to compare the persistence rates between students enrolled in the support course and those not enrolled, across the three categories of interest. The results showed no statistically significant differences in the rates of students planning to enroll in the next logical course (χ^2 =

0.026, $p = 0.871$), retake the same course ($\chi^2 = 2.010$, $p = 0.156$), or not enroll in another math course ($\chi^2 = 0.029$, $p = 0.864$). Although some of the observed differences in percentages were notable, with 55.93% of support course students and 39.10% of non-support course students planning to enroll in the next logical course, the chi-squared tests indicate that these differences could be due to chance. Similarly, the rates for retaking the same course (13.56% vs. 2.06%) and not enrolling in another math course (1.69% vs. 1.51%) did not show significant differences, suggesting that the variations in observed counts are not statistically significant.

Moving beyond grades and course persistence, students were also asked survey questions regarding their shifting confidence in mathematics from the beginning of the semester versus near the end of the semester, as well as a group of items that targeted sense of belonging in mathematics spaces.

First, I ran a Wilcoxon Signed-Rank test to compare the paired ordinal data to determine if there is a significant difference in the median of the differences in confidence reported by students. This test considers the magnitude and direction of the changes in confidence levels for each individual student, providing an overall look at how positive and negative shifts in each group are distributed. This test revealed that while the shifts in confidence levels overall for students not enrolled in the support course were statistically significant ($W = 36103.0$, $p < 0.0001$), the difference in confidence levels overall for students enrolled in the support course did not show statistical significance ($W = 362.5$, $p = 0.166$). However, there is more detail I can extract from the data. I calculated confidence shift categories to indicate how many students were in each category of a positive shift in confidence, a maintained confidence, and a negative shift in confidence.

A chi-squared test was performed across the three confidence shift categories and revealed that there is a statistically significant association between support course enrollment and the confidence shift categories ($\chi^2(2) = 11.779$, $p = 0.00277$). To investigate the detail of these differences, a series of two-sample proportions tests that compared the proportion of students in each confidence shift category across support course enrollment showed that there was no significant difference in negative shifts ($Z = -1.054$, $p = 0.292$), a significant difference in maintained confidence ($Z = -2.127$, $p = 0.033$), and a highly significant difference in positive shifts ($Z = 3.404$, $p < 0.001$).

The negative Z-score from the difference in the number of students who maintained confidence indicates that a larger proportion of students not enrolled in the support course showed maintained confidence. The positive z-statistic from the difference of the proportion of students who showed a positive shift in confidence indicates that a larger proportion of students enrolled in the support course showed a positive shift in confidence. That is, not only is there no statistical evidence that students in the support course lost confidence more than students not enrolled, but that students in the support course reported they gained confidence significantly more than students not enrolled in the support course.

I performed one final analysis to determine the effect size of these changes with 95% confidence intervals, to add a finer detail to the results from the two-sample proportions tests. For effect sizes in differences in proportion, Cohen's h was calculated for each test result. The effect size of the differences from each category across support course enrollment are a negative shift in confidence with $h = -0.147$, 95% CI [-0.263, -0.031], a maintained confidence with $h = -0.299$, 95% CI [-0.418, -0.180], and positive shift in confidence with $h = 0.434$, (95% CI [0.302, 0.565]. Interpreting these effect sizes based on the standard scale, the negative shift difference of $h = -0.147$ is approaching a small but non-trivial effect but likely not practically significant, the

maintained confidence difference of $h = -0.299$ falls between a small and medium effect size, and the positive confidence difference of $h = 0.434$ is approaching a medium effect size suggesting a moderate and practically significant effect. Each of these effect sizes are in the direction that favors students enrolled in the support course. Since none of the confidence intervals contain zero, these effect sizes are statistically significant.

To investigate sense of belonging, factor scores based on the PCA loadings for the sense of belong items group were computed. These factor scores represent each student's overall sense of belonging captured by combined items that target sense of belonging. The median factor score for students enrolled in the support course is 0.377 (IQR = 2.456), while the median factor score for students no enrolled was -0.430 (IQR = 2.467).

To investigate the nature of the differences between these two groups, I used a Mann-Whitney U test to compare the combined sense of belonging items across support course enrollment. The results indicated a significant difference in factor scores between the two groups ($U = 36933.0$, $p = 0.011$), suggesting that students in the support course reported a higher sense of belonging compared to their peers. The effect size of this difference is computed to be 0.599 (95% CI: [0.524, 0.674]), which indicates a moderate effect size in favor of the students enrolled in the support course. Thus, students in the support course reported a higher sense of belonging in mathematical spaces.

Discussion

While students enrolled in the support course did not show many notable significant differences in grades and mathematics course persistence, they did report higher levels of confidence and sense of belonging in mathematics. One interpretation of the effect of the support course is that students who opted-in to a course for more support may have had a difficult time succeeding without it. That is, the experiences from being enrolled in the support course leveled the playing field to the point where there are only marginal statistical differences between their performance and success in terms of grades and course persistence.

With grades and course persistence relatively equal, with some results leaning towards a benefit for support course students, expanding the conception of student success to include affective measures such as confidence and sense of belonging illuminates the quantitative difference of experiences in mathematics between these groups. With a significantly greater positive shift in confidence and greater self-reported sense of belonging, students in the support course have "succeeded" beyond the scope of this one course. While grades and course persistence may often live in a static conception of one's mind as they navigate the myriad obstacles faced throughout the college mathematics experience, growing confidence and sense of belonging intertwine with the dynamics of identity and sense of self that endure beyond the semester or academic year context. Furthermore, the conversations I had with students about their evolving identities in mathematics were inspirational and highlight the impact humanistic and holistic experiences have on students' mathematical success.

Relating to the broader field of systemic change research, I contend researchers ought to broaden the conception of student success and listen to students' lived experience. I look forward to explaining any details or information omitted from this report and speaking with colleagues about how a support course may fit into their context.

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