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An Equity-minded Multi-dimensional Framework for Exploring the Dynamics of Sense of Belonging in an Introductory CS Course

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ABSTRACT

In this paper, we study three focus areas: investigating the identity-related sense of belonging in a gateway computer science course, examining the dynamics of the sense of belonging between the beginning and the end of the course, and offering actions to improve the sense of belonging that addresses the needs of students from intersecting identity groups.

We use multivariate logistic regression models to identify how students' identity, prior mathematics and programming knowledge, and social expectations of success shape their sense of belonging entering the course and after completing it. Our multi-dimensional approach allows for consideration of the intersectionality of students' identities as well as other multiple factors at the same time. Our analyses suggest that social perceptions persistently affect students' sense of belonging. Therefore, we argue that more direct interventions targeting social perception are needed to achieve equity.

CCS CONCEPTS

• **Social and professional topics → Adult education**.

KEYWORDS

Sense of belonging, Social expectations of success, Equity gap

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1 INTRODUCTION

Inequities and underrepresentation in post-secondary Science, Technology, Engineering, and Mathematics (STEM), especially in Computing, have been identified and studied based on gender, race, ethnicity, and socioeconomic status [4, 17, 23, 38]. The issue of underrepresentation is a twofold problem: recruitment and retention [25]. Prior work based on 10 years of institutional data investigated trends in STEM majors and revealed that underrepresented students (defined by investigators as non-White and non-Asian students) leave STEM majors at higher rates than other students [39]. Researchers also observed that women-identifying students who left computing outperformed men under the same circumstances, which implies that academic progress is not the leading cause of attrition [2].

The increase in enrollment in computing disciplines at most institutions exacerbates the issue of inequity [6, 19, 21, 27]. Research has shown that alleviating such inequities would require significant reforms at several levels, including curriculum, pedagogy, and revisiting departments' and institutions' policies [4, 35]. Findings also point to differences in local interactions and social positions that can impact students' sense of belonging and attrition factors, including opportunities for students to ask questions during the lecture, collaborate, and work on real-world problems, access to instructors, departmental, and campus infrastructure supports [4, 20].

A high DFW (grade of D or F and withdrawal) rate in introductory gateway computing courses correlates with high attrition rates. Prior work on understanding the possible causes of high DFW rates highlights students' academic under-preparedness [7, 41], lack of student and faculty ethnic and cultural diversity and interaction, and ineffective and inequitable instructional techniques as contributing factors [5]. Appropriate interventions such as High Impact Engagement Practices (HIEP) have shown promise in reducing the equity gap between underrepresented students and their peers [1, 36, 40]. These interventions focus on acquiring quality information to create accountability and remove systematic and societal barriers to success through establishing new practices and partnerships [12, 22, 37].

In this work, we focus on studying the equity gap from the lens of identifying factors that impact students' sense of belonging. These factors include students' identity and background characteristics such as gender, race/ethnicity, first-generation status, and socioeconomic status. These factors have been investigated in the literature but not in the aggregate form [16, 18, 42]. Additionally, we look into academic preparedness, prerequisite proficiency, and the social expectation of success (also known as stereotype threat).

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1.1 Sense of Belonging

A national longitudinal study explained that a sense of belonging and growth mindset are essential for retaining underrepresented STEM students [8]. Equity-minded assessment of equity gaps and belonging factors has become the focus of many STEM programs to broaden access to computing to diverse students while reducing attrition [20, 24, 30, 31, 33]. In one study, Krause-Levy et al. investigated students' sense of belonging in six gateway computing courses. They identified that sense of belonging is correlated with passing rate and course performance [15]. They also observed that the correlation is stronger in introductory courses and becomes less significant as students progress through the curriculum [15]. In another study by Sax et al. on the CS1 course, it has been shown that women show a lower sense of belonging starting the course, and their sense of belonging declines even further after completing the course [30]. The same study has also shown that students from underrepresented racial/ethnic groups do not demonstrate a lower sense of belonging at the beginning of the course [30]. Stout et al. found that LGBTQIA+ students were more likely to think about leaving computing due to a lower sense of belonging than their heterosexual counterparts [32]. The literature also established that students from underrepresented groups in STEM show a lower sense of belonging compared to their peers [15, 24, 26, 34]. As prior work on understanding the sense of belonging is limited in scope, does not consider students' intersecting identities when assessing sense of belonging implications, and show conflicting results, further research into understanding the sense of belonging is essential in improving equity in computing and decreasing attrition rates.

1.2 Imposter Phenomenon & Stereotype Threat

Imposter Phenomenon (IP) has also been shown to impact women-identifying students' persistence in computing. Research has shown that early family dynamics and later introjections of societal stereotypes contribute to the development of IP [10]. Research has also found that women are less confident in their ability in fields where cultural stereotypes hold that men are more competent than women [3, 11, 13].

Hunt et al. showed that women self-assess their computing ability lower than men and were less likely than men to make favorable comparative judgments about their knowledge relative to their classmates [13]. In another work, Rosenstein et al. used the 20-question Clance IP Scale2 (CIPS) [9] in a CS2 course to measure the students' dread of evaluation, fear of failure, the guilt of success, and perception of others versus themselves [28]. In their work, 57% of students exhibited frequent feelings of the IP, with a larger fraction of women (71%) experiencing frequent feelings of the IP than men (52%). Due to the negative feelings associated with IP and stereotype threat and their impact on retention and attrition rates, we study students' perception of society's expectations of individuals of the same gender and race/ethnicity. As will be described later, we will examine the impact of students' perceptions of social expectations of success on their sense of belonging.

2 EQUITY GAP STUDY DESIGN

In this work, we focus on collecting institutional data and survey information from students who have taken Introduction to Computer Systems and Assembly Language to understand multiple factors of equity gaps. As equity-minded curriculum design has been shown to increase the diversity of students in the field of computing and reduce the attrition rate in STEM [14, 29], we plan to draw insights from our analyses to understand the dynamics within this gateway course.

In Spring 2021, we designed and administered entry and exit course surveys to identify barriers in the course, focusing on the impact of students' programming and mathematics preparation entering the course, social expectations of success, and academic performance measured through the final course grade on students' sense of belonging entering the course and after completing the course. Our research questions are:

- **RQ1:** What do students in the computing assembly course report as their sense of belonging in computing at the beginning of the course, and how does this vary by gender and race/ethnicity?
- **RQ2:** How does the sense of belonging change at the end of the course, and how does this vary by gender and race/ethnicity?
- **RQ3:** What are the influential factors in the changes in students' sense of belonging between the beginning and end of the course? Factors studied include programming and mathematics preparation entering the course, social expectations of success, and academic performance measured through the final course grade.

2.1 Choice of the Gateway Course

There is a vast literature on equity analysis and difficulties students experience in introductory programming (CS1) and Data Structures (CS2) courses in the computing education literature [28]. Despite historically observing less participation of underrepresented students in hardware-related majors and lower performance in courses, little is known about the course dynamics within hardware courses and how it impacts students.

In our school of engineering, programming gateway courses that are required for engineering major declaration are CS1 (Introduction to Python), CS2 (Programming Abstractions in Python), Assembly (Introduction to Computer Systems and Assembly Language), and C/C++ (Computer Systems and C Programming). Figure 1 illustrates the prerequisite chain in gateway programming courses. Due to the enrollment impaction in our engineering majors, students who propose to major in engineering must complete all gateway programming and mathematics courses with a GPA of B or better with no more than one non-passing attempt (C- or lower) in these courses. Major declaration requirements must be completed within six quarters.

We identified the Assembly course as one of the main gateway courses with a high prevalence of equity gaps across various groups in multiple course performance measures. The equity gap between women, racially underrepresented students, and first-generation students and their counterparts have shown in Tables 1, 2, and 3. Please note that in this study, we refer to two genders, women and men, and due to a lack of information in our institutional database, we don't have information on non-binary students.

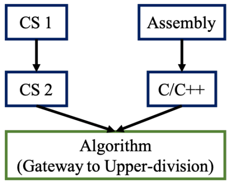

Figure 1: Prerequisite chain for gateway programming courses. Upon completing C/C++ and CS2 courses, students can declare their major.

Table 1: Passing rate and equity gap in the assembly course during the 20-21 academic year for women versus men students.[1]

% B or Better			Passing Rate		
Women	Men	Gap	Women	Men	Gap
68.36	72.62	**4.26**	78.52	82.60	**4.08**

Table 2: Passing rate and equity gap in the assembly course during the 20-21 academic year for racially underrepresented students versus their peers.[2]

% B or Better			Passing Rate		
UR	non-UR	Gap	UR	non-UR	Gap
57.43	75.0	**17.57**	71.08	84.41	**13.33**

Table 3: Passing rate and equity gap in the assembly course during the 20-21 academic year for first-generation and continuing-generation students.[3]

% B or Better			Passing Rate		
FG	Cont. G	Gap	FG	Cont. G	Gap
61.02	76.35	**15.33**	75.54	84.78	**9.24**

2.2 Description of the Data and Participants

Data was collected in Spring 2021 at the University of California Santa Cruz from students enrolled in the assembly course. Faculty and assessment specialists designed entry and exit surveys and collected surveys from 400 students. [4] Table 4 outlines the demographics of students in this study.

Table 4: Demographic of student participants. [5]

Demographic Groups		Women (n = 84)	Men (n = 307)	Total (n = 400)
Race/Ethnicity & International	African American/ Black	4%	4%	4%
	Asian American	57%	53%	53%
	Hispanic/LatinX	23%	13%	15%
	White/non-Hispanic	10%	22%	20%
	Unknown	6%	3%	4%
	International	1%	5%	4%
First Generation Status	First Generation	23%	24%	24%
	Continuing Generation	77%	76%	77%
Major	Computer Science	26%	74%	46.5%
	Computer Game Design	10%	90%	13.5%
	Computer Eng.	14%	86%	16.75%
	Electrical Eng.	18%	82%	5.5%
	Robotics Eng.	28%	72%	6.5%
	Tech. Management	33%	67%	6%
	Network & Digital Tech.	40%	60%	1.25%
	Non-Engineering	12%	88%	4%

3 MULTIVARIATE LOGISTIC REGRESSION ANALYSIS

This section describes measures and variables investigated through multivariate logistic regression analyses.

3.1 Mathematics and Programming Knowledge

The entry survey (administered in week 1) included four questions about whether students knew these topics: Boolean operators, a bit, conversion of decimal numbers to binary representation, and a truth table. For the analyses, a 4-point scale was recorded as 1= yes, fully knows, and 0= partially knows, does not know, or not sure for each question. Figure 2 summarizes students' self-reported knowledge about the four topics.

Based on these four mathematics questions, a measure of average mathematics knowledge was calculated as an average across the four recorded questions. The resulting measure ranges from 0, representing a student who does not know any of the topics, to 1, representing students who know all topics.

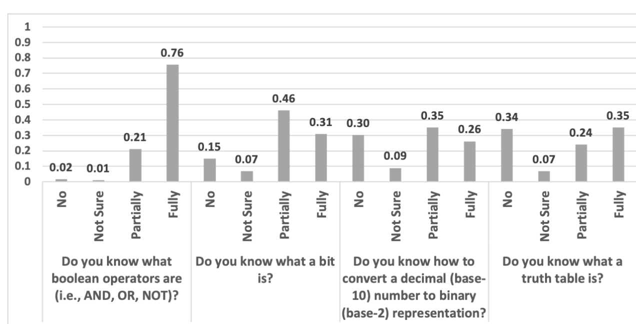

Figure 2: Self-assessment of students' mathematics knowledge in the relevant topics to the assembly course.

Similarly, students were asked about their programming knowledge at the beginning of the course, specifically in basic programming constructs such as functions, conditional statements, and

[1]The sample size is n = 1308 students over 3 quarters. Only 25 students were listed as non-binary or did not have gender information on file. As such, the table reports only on women and men students to avoid sample size bias.
[2]For the purpose of this table, our institution defines racial under-representation as domestic students who identify as either African American or Black, Hispanic or LatinX, Native Hawaiian/Pacific Islander, and American Indian/Alaskan Native.
[3]A first-generation student is defined as students who are first in their family to attend a four-year college.
[4]Students received extra credit for filling out the surveys, and therefore the response rate for the entry survey was 92%.
[5]The study has received IRB exemption as investigators are associated with the Institutional Research, Assessment, and Policy Studies unit and have completed the required training to engage in Human Subject Research.

loops. Most students reported knowing basic programming concepts (Figure 3). Since a programming course is not an explicit prerequisite for the assembly course and there was no distinguishable pattern in students' self-reported knowledge of basic programming constructs, we used the measure of *whether students had taken a high school programming course* in the model instead. Less than half of the students across different majors took a programming course in high school.

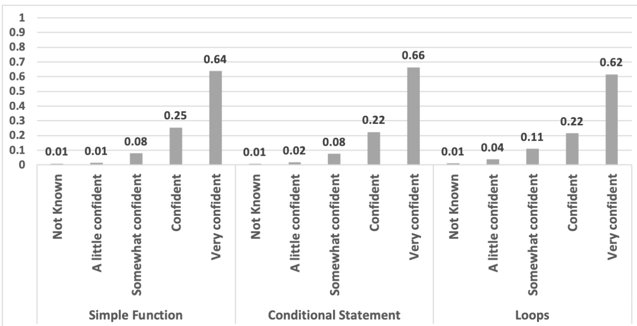

Figure 3: Self-assessment of students' knowledge of basic programming constructs.

3.2 Sense of Belonging

Students were asked to answer the following question to measure their sense of belonging.

Question: To what extent do these statements describe your experience in computer science and engineering courses? A 6-point scale: from Strongly disagree (1) to Strongly agree (6).

"I feel I belong in computer science and engineering courses."

For the analyses, agreement with this statement was recorded as a binary outcome: 1= total sense of belonging (agree/strongly agree) vs. 0= partial or no sense of belonging (from somewhat agree to disagree strongly). This approach allows one to focus on a critical point of difference: experiencing a complete sense of belonging or not (rather than on a gradual increase on a scale that assumes, for example, a meaningful difference between "agree" and "strongly agree").

We found significant differences in the sense of belonging based on gender and race/ethnicity: relatively few women (24-27%) and students of color (44-47%) reported a complete sense of belonging at the beginning and end of the course compared to men (55-58%) and White students (68-70%). These perceptions of belonging remained relatively stable for half of the students. A quarter of students experienced at least some improvement, and a quarter experienced some decline; 11% more reported a complete sense of belonging at the end of the course.

3.3 Social Expectations of Success

To measure students' expectations of success for students in their identity group (based on gender and race/ethnicity), students were asked the following questions.

Question: To what extent do these statements describe your experience in computer science and engineering courses? A 6-point scale: Strongly disagree (1) to Strongly agree (6).

- *Students of my racial/ethnic background are expected to do well in computer science and engineering courses.*
- *Students of my gender are expected to do well in computer science and engineering courses.*

For the analyses, agreement with these statements was recorded as a binary outcome: 1= fully agree (agree/strongly agree) vs. 0= partial or no agreement (from somewhat agree to disagree strongly). We found significant differences in how students perceive social expectations of their own identity groups. Specifically, fewer women, Hispanic/LatinX, and African American students thought that students of their identity group were expected to do well in computer science and engineering courses compared to men, Asian American, or White/non-Hispanic students. These perceptions remained relatively stable (14% more reported a complete agreement that students of their gender could succeed when asked at the end of the course).

3.4 Multivariate Logistic Regression Models

Our models included gender (women vs. men students) and race/ethnicity (four groups: African American/Black, Asian American, Hispanic/LatinX, and White). Six different models have been developed to understand the impact of mathematics and programming preparation entering the course on the sense of belonging and perceived social expectations for students from different race/ethnicity and gender identity groups.

Model A-Begin. Impact of *Gender* and *Race/ethnicity* on students' sense of belonging regardless of prior mathematics and programming knowledge at the beginning of the course.

Model A-End. Impact of *Gender* and *Race/ethnicity* on students' sense of belonging regardless of prior mathematics and programming knowledge at the end of the course.

Model B-Begin. Impact of *gendered social expectations* on students' sense of belonging at the beginning of the course.

Model B-End. Impact of *gendered social expectations* on students' sense of belonging at the end of the course.

Model C-Begin. Impact of *race/ethnicity-based social expectations* on students' sense of belonging at the beginning of the course.

Model C-End. Impact of *race/ethnicity-based social expectations* on students' sense of belonging at the end of the course.

Table 5 shows B-coefficients and odds ratios for all six models. The summary of findings is described in the following sections.

4 RESULTS

The models A-Begin/A-End are used to find the impact of the dynamics of students' intersecting identities and their sense of belonging at the course's beginning and end (RQ1 and RQ2). We also use models B-Begin/B-End and C-Begin/C-End to identify influential factors in the changes in students' sense of belonging between the beginning and end of the course (RQ3).

[6] $^{***}\ p \leq 0.001$, $^{**}\ p \leq 0.01$, $^{*}\ p \leq 0.05$, $\dagger\ p < 0.1$.

Table 5: Summary of logistic regression models A-Begin, A-End, B-Begin, B-End, C-Begin, and C-End.[6]

B-coefficient (odds ratio)	Model A-Begin	Model A-End	Model B-Begin	Model B-End	Model C-Begin	Model C-End
Women vs. Men	-1.494^{***} (0.225)	-1.129^{***} (0.323)	-1.165^{***} (0.312)	-0.464 (0.629)	-1.544^{***} (0.213)	-1.097^{***} (0.334)
Hispanic/LatinX vs. White	$-0.655\dagger$ (0.519)	-0.839^{*} (0.432)	$-0.657\dagger$ (0.519)	$-0.730\dagger$ (0.482)	-0.434 (0.648)	-0.523 (0.593)
Asian American vs. White	-0.866^{**} (0.420)	-1.202^{***} (0.301)	-0.914^{**} (0.401)	-1.205^{***} (0.300)	-1.180^{***} (0.307)	-1.608^{***} (0.200)
African American/Black vs. White	$-1.174\dagger$ (0.309)	-1.396^{*} (0.247)	-1.343^{*} (0.261)	$-1.653\dagger$ (0.191)	-1.045 (0.352)	$-1.437\dagger$ (0.238)
Mathematics Preparation	1.133^{***} (3.105)	0.813^{**} (2.255)	1.067^{***} (2.906)	0.855^{**} (2.352)	1.060^{***} (2.886)	0.904^{***} (2.470)
High school programming courses	0.489^{*} (1.631)	0.359 (1.431)	$0.445\dagger$ (1.561)	0.320 (1.377)	$0.424\dagger$ (1.527)	0.287 (1.332)
Expectations about same gender identity			0.762^{**} (2.185)	1.265^{***} (3.544)		
Expectations about same racial/ethnic identity					0.928^{***} (2.529)	1.409^{***} (4.090)
Constant	0.415 (1.515)	0.678^{*} (1.970)	0.105 (1.111)	-0.73 (0.929)	0.179 (1.196)	0.169 (1.184)
Number of samples	373	342	370	342	370	342
Cox-snell R-squared	0.17	0.14	0.19	0.19	0.20	0.20

4.1 Students' Intersecting Identities and Sense of Belonging (RQ1 & RQ2)

Gender significantly impacts a sense of belonging even when controlling for race/ethnicity, mathematics, and programming background. Women constitute 21% of the class (and are a minority within each ethnic group). Across all ethnic groups, women reported a significantly lower sense of belonging than men at the beginning and end of the course. In other words, there is a significant difference in the sense of belonging of men and women within any of the ethnic/racial groups.

Differences in the sense of belonging were found between White students and students of color at the beginning and end of the course, regardless of preparation in mathematics and programming. White students, who constitute 22% of the class, reported a significantly higher sense of belonging than Asian American students, who constitute 57% of the class. A high percentage (68-70%) of White students reported a complete sense of belonging at the beginning and end of the course, compared to 38-47% for Hispanic/LatinX, African American/Black, and Asian American students.

Additionally (not shown in Table 5), we found using multivariate modeling that being a first-generation college student has a relatively weak negative effect on a sense of belonging, irrespective of students' ethnicity or gender. Having parents or guardians who have knowledge of CS or engineering or encourage students to pursue CS or engineering does not significantly affect the sense of belonging.

4.2 Influential Factors on Sense of Belonging (RQ2 & RQ3)

We analyzed the impact of factors such as programming and mathematics knowledge entering the course, social expectations of success, and academic performance measured through the final course grade on the changes in the sense of belonging. Identifying high-impact factors is essential in designing interventions to improve students' sense of belonging.

4.2.1 Mathematics and Programming Knowledge. The impact of mathematics on the sense of belonging does not seem to be affected by students' prior programming preparation or social expectations of the success of their identity group (discussed below) at either beginning or end of the course (Models B-Begin and B-End). In other words, students with the same level of programming preparation would have a stronger sense of belonging if they had mathematics knowledge.

Additionally, we examined the impact of exposure/preparation in programming on students' sense of belonging. The results indicate that high school exposure/preparation in programming has a more substantial positive impact on the sense of belonging at the beginning of the course ($p < 0.03$) than at the end (see Models A-Begin and A-End). As such, programming knowledge is shown to be relevant to the sense of belonging but not as strongly as mathematics knowledge. Additional findings while studying the impact of mathematics and programming knowledge on the sense of belonging include:

- Having a course about programming in high school (e.g., AP Computer Science) has a significant impact on students' sense of belonging.

- First-generation students are significantly less likely to have high (3-5) AP CS scores than their peers (28% vs. 43%), so we included programming background in the models instead of first-generation status because it captured the impact of first-generation status on students' sense of belonging.
- Level of high school preparation in Mathematics (measured by types of last mathematics class completed and standardized test scores) has no impact on the sense of belonging.

4.2.2 Social Expectations of Success. We found that the gap in expectations of women and men about whether students of their gender could succeed in computer science and engineering courses is even wider (40-50%) than in the sense of belonging (about 30%).

Gendered expectations of success significantly positively affect students' sense of belonging (among both men and women) at the beginning of the course (Model B-Begin). At the end of the course, these gendered expectations grow in importance and seem to reduce gender differences in the sense of belonging (they become statistically insignificant) (Model B-End). Students who think that students of their gender are expected to do well have a stronger sense of belonging regardless of their gender (or ethnicity), mathematics knowledge, or CS coursework in high school.

The racial/ethnic perceptions of success vary across the groups and gain more importance in explaining the differences in the sense of belonging at the end of the course (models C-Begin and C-End). Asian American students, in particular, are deferentially affected by the perception of success of their group compared to other students. Unlike their peers, many Asian American students fully agree that students of their race/ethnicity are expected to do well (66-70%), yet fewer of them feel a complete sense of belonging (less than half). All other groups, including women and racially underrepresented students, report the opposite: more students feel they belong than feel their identity group is expected to do well.

4.2.3 Course Grade. Course grades have a significant but not particularly strong effect on the sense of belonging (the overall correlation is $r = 0.25$). Women reported a much stronger relationship between their grades and belonging ($r = 0.37$) compared to men ($r = 0.18$). Racially underrepresented, White, and Asian American students were similar in this regard, meaning their sense of belonging was not more impacted by course grades at the end of the course than other students.

Also important to note that course grade was not a predictor of whether a student would improve to feel a complete sense of belonging during the course. This suggests that improvement was not limited to students who received high grades in the class. What mattered was whether students believed they had mastered the topics covered in the class, while their gender or race/ethnicity identity did not have a substantial impact.

4.3 Discussion

We found significant differences in the sense of belonging related to gender and race/ethnicity identity regardless of whether students have taken computer science courses in high school or have knowledge of mathematics. In other words, differences in the sense of belonging cannot be explained by differences in students' preparation (see Models A-Begin and B-Begin).

When we included students' opinions about whether students of their gender were expected to do well or not, the gender differences in the sense of belonging were present in the entry survey (Model B-Begin). At the end of the course, gender differences were present (Model B-End) unless we included students' perceptions of how students of their gender are expected to perform. This means that the sense of belonging in women was directly affected by the (low) expectations they think other students or teachers have for the performance of students of their gender (and vice versa for men students). These perceptions seemed to be aligned with their initially low sense of belonging after taking this course (Model A-End). Looking into the race/ethnicity-based expectations, they show an increase in importance at the end of the course and have varying impacts on students from different racial/ethnic groups (Models C-Begin and C-End). Asian American students, in particular, show a lower sense of belonging at the end of the course while demonstrating a strong belief that Asian American students are expected to do well in computing courses. These observations are insightful in understanding the dynamics of students' sense of belonging in a gateway computing course and designing interventions that can eliminate the equity gap by focusing on the specific needs of students from different identity groups. This research further highlights the impact of raising awareness about cultural stereotypes through stereotype threat workshops and guest speaker series for promoting students' expectations of success for their identity group.

Additionally, the final course grade does not seem to substantially impact students' sense of belonging except for showing a moderate correlation for women ($r = 0.37$). This suggests that equity in the sense of belonging can be improved by emphasizing mastery of topics and conducting frequent and lower-stake assessments.

5 CONCLUSION

In this paper, we studied the sense of belonging in a gateway programming course from the perspective of intersecting students' gender and racial identity, academic preparation entering the course, gendered and racial/ethnic-based expectations of success, and course grades at the beginning and end of the course. Through this study, we observed that:

Gender and Race/Ethnicity Gender significantly impacts the sense of belonging for all ethnic groups (even for women students who are racially represented). White students demonstrated a higher sense of belonging irrespective of self-reported mathematics and programming knowledge.

Prior Knowledge Mathematics knowledge impacts the sense of belonging more than programming knowledge in the assembly course.

Social Expectations Gendered expectations of success significantly affect the sense of belonging to the extent that it reduces the impact of gender by itself. The impact of racial/ethnic-based expectations varies for different groups and is shown to negatively impact Asian American students.

Academic Performance Course grade impacts the sense of belonging only moderately.

The proposed framework considers students' intersecting identities for understanding and promoting the sense of belonging in a gateway computing course.

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