Sense of Belonging within an Undergraduate First-Year Engineering Program: Comparison Across Different Levels of Math Readiness and URM Status

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Introduction

The significance of a sense of belonging in influencing students' success and engagement is widely acknowledged [1]. The relationship between a sense of belonging and academic persistence has been both theoretically and empirically substantiated by scholars such as Astin [2] and Pascarella & Terenzini [3]. Notably, within the context of engineering education, scholars have underscored the critical role of a sense of belonging in influencing students' persistence [4], [5]. While a positive sense of belonging contributes to students' persistence, it is crucial to recognize the potential hindrance posed by a lack of mathematical skills [6]. Alarming statistics from 2002 reveal that only 34% of high school graduates possessed the necessary skills for college. This concern is exacerbated when considering the disparities among Underrepresented Minorities (URM), with only 34% of Black or African American and 20% of Latino/Hispanic students deemed college-ready, compared to 40% readiness among white students [7]. Furthermore, students with low math readiness are identified as being at-risk in college [8]. While existing literature has extensively addressed the sense of belonging at the macro level [9] and underscored the significance of math readiness [10], a noticeable gap exists in the micro-level exploration of students' sense of belonging in engineering and their individual levels of math readiness.

In light of the critical role that a sense of belonging plays in shaping students' academic experiences and success, it is imperative to focus on the intricate interplay between this sense of belonging and students' readiness in mathematics. A special emphasis must be placed on fostering a sense of belonging among Underrepresented Minority (URM) students, recognizing the unique challenges they may face. In response to this imperative, our research endeavors to explore the nuanced perceptions of students concerning their sense of belonging within the context of engineering education. The research questions that lead this inquiry are:

> *RQ1: How do students with different levels of math readiness rate their engineering program sense of belonging?*
> *RQ2: How do URM and non-URM students report level of belonging in engineering?*
> *RQ3: How do Non-White math-ready students rate their engineering program sense of belonging in comparison to White students?*

By investigating these research questions, we aim to explore the diverse ways in which first-year general engineering students, particularly those with varying levels of math readiness and from Underrepresented Minority backgrounds, perceive their sense of belonging within the dynamic landscape of engineering education. The significance of this research lies in the recognition of the interconnectedness of belonging, math readiness, and identity. These relationships call for a thorough examination to inform the development of strategies that not only enhance both the sense of belonging and math readiness but also contribute to the overall success of students in the dynamic setting of engineering education. Our study seeks to contribute valuable insights that

can inform educational practices, policies, and support structures to create an inclusive and conducive environment for the diverse student population in the field of engineering.

Literature review

Belonging, identified as a fundamental human motivation by psychologists [11], serves as a central hub with far-reaching positive implications [12]. In the collegiate setting, a profound sense of belonging not only encourages students to immerse themselves more deeply in their studies but also correlates with greater persistence and academic success [13], [14], [15]. This connection to belonging prompts students to actively seek campus resources, fostering an environment conducive to their future success [16] and positively impacting their mental health by reducing stress [11]. However, this sense of belonging is not uniform across students. Factors such as academic discipline [17], math readiness, and being part of Underrepresented Racial-Ethnic Minorities can influence students' perceptions [18].

In the field of engineering, a sense of belonging has proven pivotal in shaping students' engineering identity and sustaining their efforts [19]. Given the inherently challenging nature of engineering programs, recruiting and retaining students, especially in their first year, poses a considerable challenge [20]. Therefore, it becomes crucial for administrators, including faculty, to scrutinize students' perceptions of motivation and engineering identification during the critical first-year stage [21]. Importantly, engineering sense of belonging not only aligns with future career aspirations [22] but is also intricately linked to academic satisfaction, grades, interests, and outcome expectations [23], [24], [25].

There has been a significant body of literature exploring how different aspects of identity, such as racial, gender, nationality, socioeconomic status, or sexual preferences have influenced a students' sense of belonging, and how that sense of belonging subsequently influences persistence and achievement [26], [27], [28], [29], [30],[31] . Large and ongoing efforts have been initiated to address specific shortcomings of academic cultures to address problems in a sense of belonging for many of these identities and intersectionalities [32], [33], [34]. In addition to institutional support programs and structures, individuals who identify with visible minority groups will often seek to foster social networks to bolster their sense of belonging [35].

There has been a recent decline in ACT and SAT scores nationwide, pointing to a pervasive decline in math readiness in the United States [36]. Research indicates that this factor significantly impacts their academic journey [6], [37], [38]. The roots of students' challenges in college-level mathematics may be traced back to their high school experiences [39], [40]. Given that mathematical skills are often used to assess job applicants across various careers [41], math readiness becomes a critical determinant for college admissions [42] and subsequent degree attainment [43], [44]. While some studies have delved into disparities in math readiness, others have explored variations based on racial and ethnic minorities [45].

The perception of integration and emotional connection during the first year, often referred to as the sense of community [46], has been shown to have a substantial influence on students' academic achievement [47]. This emphasizes the pivotal role that a sense of belonging plays in shaping the academic experiences of students as they embark on their college journey. Notably, failure to integrate into both the social and academic systems can lead to students leaving

college, a phenomenon well-documented in the literature [48]. This departure poses a significant challenge, and its impact is particularly noticeable for underrepresented minority (URM) students [49]. The unique challenges faced by URM students in navigating cultural and social identities underscore the importance of addressing their nuanced experiences of oppression. To foster a sense of connection to the academic environment, URM students may require specific support mechanisms [50]. Given that a sense of belonging is deeply rooted in cultural and social identities, it is imperative to recognize that URM students may encounter distinct obstacles that necessitate tailored strategies for fostering integration. Consequently, there is a pressing need to implement special measures to provide an equitable and supportive environment for students from this group. These strategies should be designed to address the unique challenges and enhance the sense of community for underrepresented minority students, promoting their retention and success within the academic setting.

Method

In the initial week of their enrollment in the Virginia Tech engineering program, spanning from the Fall of 2015 to the Spring of 2020, a substantial cohort of 8,727 undergraduate students participated in a survey. The survey was administered to all students in the first year General Engineering Foundations of Engineering course sequence. The survey, administered electronically as a mandatory, for-credit homework assignment, was based largely on the MUSIC model (eMpowerment, Usefulness, Success, Interest, Caring) [51] and was designed to gather comprehensive information encompassing individual characteristics, student identification numbers, and their perception of belonging within the engineering program Subsequent to the data collection phase, the authors liaised with the registrar's office to cross-reference the student identification numbers with their corresponding demographic information and to determine their math readiness level. In the context of this study, math readiness was determined by the highest level of mathematics credit that the students had attained prior to completing the survey, as discussed later in this paper.

Engineering Program Belonging

To answer our research questions, we selected a subset of the questions on the survey that pertain to sense of belonging within an academic program. The items in the engineering program belonging instrument are adapted from the Psychological Sense of School Membership scale [52]. This instrument was refined by Jones [53] specifically for undergraduate engineering students. Six items were selected for this study to measure various perceptions of engineering and the sense of belonging of students. The items were administered to measure the level of agreement on the six-point Likert scale from 1- “completely disagree” to 6- “completely agree.” The reliability score of these items was a = 0.73. Table 1 displays the items that were used in this research.

Table 1: Engineering Program Belonging

No.	Item
1	I feel like a real part of the General Engineering program.
2	Sometimes I feel as if I don't belong in the General Engineering program.

3	I feel very different from most other students in the General Engineering program.
4	I wish I were in a major other than engineering.
5	I feel proud of belonging in the General Engineering program.
6	The amount of effort it takes to do well in my engineering program is worthwhile to me.

Analysis and Results

The sample demographics reveal a predominantly white student population (n=5379, 61.6%), followed by 1065 Asian students (12.2%), 567 Latino/a/x/Hispanic students, and a smaller representation of 265 Black or African American students (3.9%). In terms of gender distribution, the majority identified as male (n=6713, 76.9%), with females constituting 22.9% (n=2001). Additionally, students were asked to self-report their Underrepresented Minority (URM) status, with 11.6% identifying as URM (n=1008), while 88.4% were non-URM students (n=7719). The self-reported data also highlighted that 9.4% of participants were first-generation students. In terms of math readiness, 6.1% (n=528) were not math ready (only passing pre-calculus), nearly half (49.8%, n=4347) had completed calculus I, and 44.1% (n=3853) had completed calculus II or post-calculus II. The demographic data and math readiness are presented in Table 2.

Table 2. Demographic information

	N-(%)[2]	
Race/ethnicity		
Asian	1065	12.2
Black or African American	265	3.9
Latino/-a/-x/ or Hispanic	567	6.5
Two or more races	412	4.7
White	5379	61.6
Nonresident Alien	794	9.1
American Indian/Alaska Native	6	.1
Native Hawaiian/Pacific Islander	8	.1
Not Reported	231	2.6
Gender identity		
Women	2001	22.9
Men	6713	76.9
Other	13	.1
Groups		
First-Gen	821	9.4
Non-First-Gen	6243	71.5
URM	1008	11.6
Non-URM	7719	88.4
Math Readiness		

No Math/Pre Calc	528	6.1
Calc I	4347	49.8
Calc II/Post Calc II	3852	44.1
Total	8727	100.0

Math Readiness and Sense of Belonging

In classifying participants based on their math readiness levels, we established three distinct groups. The first group (NM) comprised students without math readiness, denoting those who had not yet completed Calculus 1. The second group (M) included students with standard math readiness, indicating their successful completion of Calculus I. Lastly, the third group (HM) consisted of students with high math readiness, signifying their passage of Calculus II or post-calculus II.

For within-group comparative analysis, we employed the Kruskal-Wallis H test [54], [55], [56], recognized as an omnibus test and alternatively referred to as a non-parametric one-way ANOVA due to the non-parametric distribution of the collected data. To conduct between-group comparisons, we opted for the Games-Howell post hoc test [57], [58], given the unequal sample sizes in each group. It is important to note that constructs 2, 3, and 4 were recoded due to their negative wording.

Table 3. Comparison analysis within and between groups based on their level of math readiness.

Items		Sense of Belonging Constructs				
		(M±SD)	Mean Rank	H-test	Games-Howell (Mean Differences)	
					NM	M
1. Real Part	NM	4.58±0.94	4243.54			
	M	4.67±0.86	4447.42	11.36**		
	HM	4.61±0.87	4283.04			.056*
2. Don't Belong	NM	4.22±1.35	4011.5			
	M	4.37±1.22	4253.58	39.49***	-.155*	
	HM	4.52±1.15	4533.45		-.31***	-.151***
3. Feel Different	NM	3.86±1.41	3971.31			
	M	4.06±1.31	4297.16	27.27***	-.196**	
	HM	4.18±1.24	4489.81		-.312***	-.12***
4. Other Major	NM	5.07±1.1	4166.93			
	M	5.17±0.96	4304.68	12.47**		
	HM	5.23±0.92	4454.51		-.17**	-.06**
5. Feel Proud	NM	5.3±0.84	4392.85			
	M	5.35±0.8	4523.22	46.29***		
	HM	5.23±0.85	4177.09			-.12***
6. Effort	NM	5.22±0.94	4392.13			
	M	5.27±0.81	4433.58	9.36**		
	HM	5.23±0.81	4278.28			.05*

*Note: ***,**, and * denote the significance levels .001, .01, and .05 respectively.*

Table 3 depicts the results of the comparative analysis within and between groups. The Kruskal-Wallis H test indicated a statistically significant difference in students' sense of belonging constructs among three groups based on math readiness. Specifically, the Games-Howell post hoc test brought to light that math-ready students exhibited a significantly higher sense of belonging, feeling like a real part of the general engineering community (4.67±0.86, $p<.05$), in comparison to students with high math readiness levels (4.61±0.87). A parallel trend emerged in the amount of effort construct, where math-ready students demonstrated a significantly higher sense of belonging (5.27±0.81, $p<.05$) than their high math-ready counterparts (5.23±0.81).

Moreover, the post hoc test illuminated that students with no math readiness reported a significantly lower sense of belonging in the second construct, "Sometimes I feel as if I don't belong in the General Engineering program" (4.22±1.35, $p<.05$) compared to both math-ready students (4.37±1.22) and high math-ready students (4.52±1.15, $p<.001$). Additionally, a significant difference in the second construct was observed between math-ready students and high math-ready students. This trend persisted in the third construct, where students perceived feeling different from other students in general engineering.

In the fourth construct, which gauges students' agreement with the statement "I wish I were in a major other than engineering," students with high math readiness exhibited a significantly greater sense of belonging (5.23±0.92, $p<.01$) compared to math-ready students (5.17±0.96) and those without math readiness (5.07±1.1). Interestingly, in the fifth construct—"I feel proud of belonging in the General Engineering program"—students with high math readiness perceived a statistically lower sense of belonging (5.23±0.85, $p<.001$) compared to math-ready students (5.35±0.8).

URM and non-URM sense of belonging

In self-reported URM status, 1008 students (11.6%) acknowledged their affiliation with underrepresented racial-ethnic minorities. Among these URM students, the breakdown by race/ethnicity revealed a diverse composition, with over 56% identifying as Latino/a/x/Hispanic (n=567), 26.3% as Black or African American (n=265), 16.1% belonging to two or more races (n=162), 0.8% as Native Hawaiian/Pacific Islander (n=8), and 0.6% as American Indian/Alaska Native (n=6). In terms of gender, the majority of URM students identified as male (76.7%, n=773), while 23.2% identified as female (n=234). Furthermore, 18% of URM students reported being first-generation students (n=181).

To examine potential disparities in their perceptions of engineering sense of belonging, we employed a student t-test and Welch's t-test [59] to account for unequal sample size to compare URM and non-URM groups. The analysis revealed statistically significant differences between these groups in specific constructs.

Table 4. Difference in the sense of belonging across URM and non-URM students.

Student Support Construct	Mean Comparison Across Non-URM and URM Students				
	Non-URM (M±SD)	URM (M±SD)	t-stat	Corrected p-value	Cohen's d
1. Real Part	4.63±0.88	4.67±0.86	-1.22	.22	

2. Don’t Belong	4.44±1.19	4.35±1.27	2.15	.041*	1.19
3. Feel Different	4.13±1.27	3.86±1.4	6.36	<.001***	1.29
4. Other Major	5.19±0.95	5.16±0.98	1.06	.29	
5. Feel Proud	5.29±0.83	5.35±0.81	-2.09	.036*	.83
6. Effort	5.24±0.82	5.32±0.81	-2.89	.004**	.82

*Note: ***,**, and * denote the significance levels .001, .01, and .05 respectively.*

As depicted in Table 4, URM students reported a significantly lower sense of belonging in the second construct, "Sometimes I feel as if I don't belong in the General Engineering program" (4.35±1.27), compared to non-URM students (4.44±1.19, p<.041). This trend persisted in the third construct, "I feel very different from most other students in the General Engineering program," where URM students perceived a significantly lower sense of belonging (3.86±1.4) compared to non-URM students (4.13±1.27, p<.001).

Contrastingly, in the fifth construct, "I feel proud of belonging in the General Engineering program," URM students reported a significantly higher sense of belonging (5.35±0.81) compared to non-URM students (5.29±0.83, p<.036). This pattern continued in the sixth construct, "The amount of effort it takes to do well in my engineering program is worthwhile to me," where URM students perceived a significantly higher sense of belonging (5.32±0.81) compared to non-URM students (5.24±0.82, p<.004).

Math-Ready Non-White and White Students

To explore disparities between students from minoritized groups and white students, we specifically focused on those who self-reported passing Calculus I. It's important to clarify that the category "Non-White" encompasses all racial groups except White, and students reported as Nonresident Alien were excluded from this analysis. The selected participants were then categorized into Non-White and White students for the purpose of conducting the comparison analysis. A total of 3,697 students were included in this analysis, with 2,612 reported as White and 1,067 as Non-White.

Table 5. Difference in the sense of belonging across math-ready Non-White and White students.

Student Support Construct	Mean Comparison Across math-ready Non-White and Non-White Students				
	Non-White (M±SD)	White (M±SD)	t-stat	Corrected p-value	Cohen’s d
1. Real Part	4.65±0.91	4.64±0.83	.355	.722	
2. Don’t Belong	4.31±1.26	4.37±1.18	-1.27	.204	
3. Feel Different	3.88±1.37	4.13±1.27	-5.393	<.001***	1.29
4. Other Major	5.09±1.02	5.24±0.85	-4.628	<.001***	.903
5. Feel Proud	5.35±0.84	5.38±0.76	-1.112	.266	
6. Effort	5.27±0.84	5.29±0.78	-.701	.483	

*Note: *** denote the significance levels .001*

As depicted in Table 5, the t-test comparative analysis showed that Non-White students reported a significantly higher sense of feeling different from other students (4.37±1.18, $p<.001$) compared to White students (3.88±1.37). This trend was similarly observed in Non-White students (5.24±0.85, $p<.001$) who expressed a desire to be in a major other than engineering, indicating significantly higher scores than White students (5.09±1.02). Conversely, we noted a reverse pattern in Non-White students' sense of belonging, specifically in feeling proud and finding their efforts worthwhile. Although these differences were higher in Non-White students, they did not reach statistical significance.

Limitations

Our research focuses primarily on examining the impact of math readiness on students' sense of belonging. This study primarily relies on statistical differences to analyze and interpret aspects of student perceptions. Further exploration of qualitative aspects could provide a fuller understanding of students' experiences and perspectives and potential interdependent contributors.

The findings discussed may be limited in their applicability across diverse academic settings and student demographics. While our research provides insights into the relationship that potentially exists between math readiness and students' sense of belonging, these limitations indicate the need for future studies. Specifically, future studies can further explore the qualitative aspects of this phenomenon to include a broader spectrum of intersecting factors and to assess translation across diverse academic settings. Through these explorations, we can better understand the student experiences and more effectively develop strategies to support student success in various engineering educational contexts.

Discussion and Conclusion

While there are statistically significant differences across the groups in all of the six questions that we analyzed, we see the smallest mean difference between students' perception that they are a real part of the program, that they are proud to be in the program, and that they feel the effort of the engineering program is reasonable (see Table 3). The largest mean differences emerge when students compare themselves to their peers who are math ready and find themselves different. The difference in math readiness directly translates into a reduced sense of belonging for these students. In contrast, when examining the sense of belonging for non-white students and white students who are math ready, we see that while non-white students report a large and significant sense of difference between themselves and other students, we do not see a reduced sense of belonging in these students.

Students with a reduced sense of belonging are less likely to engage in help-seeking [60], [61]. Whereas student sense of belonging tends to decrease over the course of an academic year, there are interventions that can bolster that sense of belonging and increase a student's likelihood to persist in an academic program [62]. Interventions aimed at increasing student's sense of awareness reported not only increases in persistence, but increased grade point averages, and increases in overall student mental and physical health [63]. Success in interventions has been reported for first-generation students and ethnic and racial minority students [64], [65], [66].

Recent work in diversity, equity, and inclusion (DEI) programs nationwide has resulted in the recognition of differences between students while reducing any stigma associated with these differences. The messaging in DEI programs encourages students to celebrate their differences as valued contributions to the diversity of teams and programs in which they participate. Despite their differences, students show a high sense of belonging that encourages help-seeking and support structure development in these groups. It is important to recognize the reduced sense of belonging that is associated with a potentially stigmatized aspect of a student's academic career in their incoming math readiness level in STEM fields. To increase persistence and success rates among students who are not math-ready, it is imperative to develop interventions that can destigmatize math readiness as a deficiency and bolster a sense of belonging among these groups.

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