A Model of Increased Female Engineering Persistence to Graduation

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Abstract

At Loyola University Chicago (LUC), the B.S. Engineering program graduates about 50% women annually. After receiving ABET accreditation in 2020, LUC began participating in the ASEE annual survey and was ranked #6 in 2020 (52%), #6 in 2021 (58%), and #5 in 2022 (54%) for Percentage Bachelor's Degrees Awarded to Women. The program graduates 20 to 30 students per year.

Based on internal student surveys, female students enroll because they are drawn to the collaborative environment of the program. Based on first- and second-year student completion of the Longitudinal Assessment of Engineering Self-Efficacy, women begin the program with lower levels of self-efficacy but stay in engineering at similar rates as men.

In this paper, program structural supports, particularly those administered during the first undergraduate semester, are described that mitigate the chilly climate of engineering as an unwelcome space for women. A new theoretical framework, the BELONG (Becoming Engineers Leading Our Next Generation) Conceptual Model of Engineering Persistence, is proposed that describes the program. The model is based on social cognitive career theory and incorporates program structural supports as model inputs and the sense of belonging construct as a precursor to engineering persistence.

As a first step towards model validation, six structured interviews with self-identified women of Color in the Class of 2028 were conducted to gain a nuanced understanding of their program experiences during their first semester. Researchers used emergent, focused, and thematic coding to eliminate inconsistent findings, search for patterns, and generate dominant themes. Subsequent analysis elucidated student experiences and understandings of engineering self-efficacy, outcome expectations, interests, experiences of program supports and sense of belonging, and helped to provide a more nuanced understanding of their engineering education experiences. Data from this study support the efficacy of the BELONG model, a structural solution that addresses the exclusion of women, in attracting and potentially retaining women and women of Color in engineering.

Introduction

Numerous organizations, from the National Academies to the President's Council of Advisors on Science and Technology, have alerted educators of the pressing need for an increase in BS engineering graduates for future national economic growth [1-7]. Obvious methods for addressing this issue are increasing engineering persistence [2] and increasing the participation of underrepresented populations that enter the engineering student pathway [6-8]. Although the annual number of total BS engineering graduates did increase over the last two decades, from 66,852 in 2002 to 139,482 in 2022 [9], an increase of 209%, this increase was primarily fueled

by the expansion of existing programs and the creation of new programs [10]. Thus, there is an opportunity to solve the engineering pathway issue by recruiting and retaining women.

Unfortunately, the push to increase BS engineering graduates over the last two decades has marginally affected the graduation percentages of underrepresented minorities, such as women, African Americans, and Hispanics. Since women make up half the population, why do U.S. engineering institutions continue to only graduate less than a quarter women engineers (Figure 1)? Further, how can this disparity be understood and eliminated?

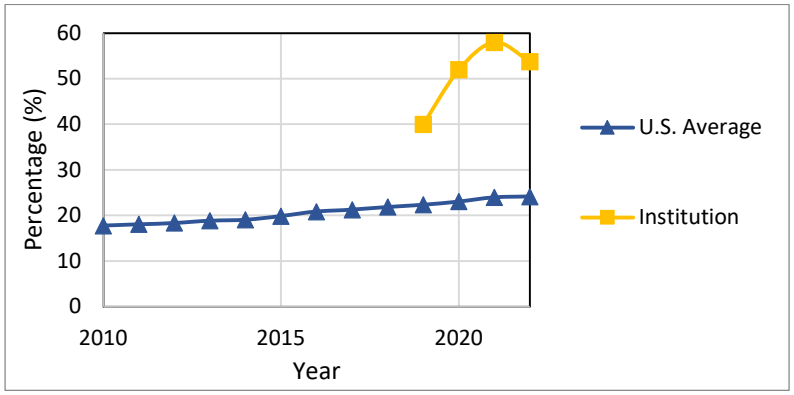

Figure 1. Percentage of engineering bachelor's degrees awarded to women [11].

Background

The Talking About Leaving studies are illustrative of engineering persistence. As the foundation for the original Talking About Leaving study, 810,794 undergraduates who entered a national sample of four-year institutions were followed from 1987 to 1991. Of engineering majors, 85.6% of males stayed in the original major or group, compared to only 14.4% of females. A sample of 335 science, math, and engineering students were then followed over a three-year period in the early 1990s. Each student had a mathematics score at or above 650 SAT or 28 ACT; 26% of the student sample were students of color, with almost equal numbers of women and men. Within this sample, 55% of juniors switched majors. The top three switching reasons for women were reasons for choice of STEM major proved inappropriate (91%), poor teaching by STEM faculty (89%), and inadequate advising or help with academic problems (84%) [12]. When a similar study, now called the Talking About Leaving Revisited Study, was conducted in 2012, the top three switching reasons for women were poor quality of STEM teaching (97%); difficult transition to college (89%); and competitive, unsupportive STEM culture makes it hard to belong (85%) [13].

The Chilly Climate

One way to understand this low rate of female persistence is that the "chilly climate" of engineering/STEM creates a hostile and unwelcoming space for women. The chilly climate for female higher education students, first identified and named by Hall and Sandler in 1982, refers to the subtle or overt ways in which "a chilling classroom climate puts women students at a significant education disadvantage" [14]. Such faculty classroom behaviors include overtly discriminatory comments to women, nonverbal and other cues such as less eye contact and less

attentiveness when women speak, class discussions conducted in a way that discourages women students, and assertive male speaking patterns being equated with intelligence and authority [14].

For example, the infamous resistor color code mnemonic, Bad Boys Rape Our Young Girls But Violet Gives Willingly [15], was still being taught in 1982 in an electronic circuits course the first author was required to take for her BS Electrical Engineering degree. In describing their college classroom observations over two decades of research grants in 1994, Sadker and Sadker stated that "men are twice as likely to monopolize class discussions, and women are twice as likely to be silent" [16]. In a longitudinal study of chemical engineering students (87 men, 34 women) who first enrolled in an introductory chemical engineering course in 1990, several women reported hearing disparaging remarks from engineering professors about female students [17]. Perceptions of an unwelcoming academic climate and bias and discrimination experiences can be detrimental to persistence [18].

Four decades later, the chilly climate continues. Instructors of engineering students are more likely to respond to students' gender expression through gender blindness (gender inequity is nonexistent or invisible) and gender acknowledgment (causes of gender inequity are outside instructor interactions with students), rather than through gender interventions (active intervention as part of teaching responsibilities) [19]. Male students may occupy classroom sonic space 1.6 times more than female students, as determined from 95 hours of observation of nine social science, humanities, and natural science courses over 80 course sessions in an Ivy League college [20]. Female STEM students still experience gender disparities due to masculine cultures and choices by men. Masculine defaults in masculine culture reward behaviors typically associated with men, such as self-promotion and teaching with masculine topics. Differential treatment in masculine culture results in women treated worse than men. Because men choose engineering as a major, they decrease the proportion of women in the classroom, increasing the likelihood of masculine cultures dominating [21, 22]. As subjects in the Talking About Leaving Revisited Study described during interviews, the competitive individualism by some male students to be recognized as the smartest in class undermines female students' sense of belonging and commitment to persist [23]. Sense of belonging may be defined according to Baumeister and Leary and Wilson and VanAntwerp as "frequent, positive, caring social bonds [24]" [25] that result in "feelings of inclusion and support" [25].

Individuals who exist at the intersection of multiple systems of oppression, exclusion, and underrepresentation experience even chillier environments. Black female engineering students face isolation; hypervisibility (discomfort for "being the only one"); and difficulty forming study groups, which can affect academic performance. Their exposure to microaggressions further decreases their sense of belonging [26, 27], due to delegitimization of skills and expertise and racialized and gendered encounters [28]. Similarly, Latine female engineering students experience gendered, racialized marginalization. They feel more disengaged from engineering than their white peers due to relational and gender-based barriers [29, 30].

The recognition of the immense time and energy expended to navigate and cope with the chilly climate sheds light on why women have reported losing interest and motivation [26, 31].

Ultimately, eliminating gendered systems in engineering environments requires interventions aimed at structural change [32].

Interventions To Address The Chilly Climate

Various interventions, from courses and skills training to counterspaces and faculty representation have been implemented to address the chilly climate.

Courses target a specific aspect of the chilly climate [33, 34]. For example, thirty years ago, Dr. Sheryl Sorby developed a course, which evolved into versions of software and a workbook, for supplementary training in 3-D spatial visualization [35]. Women are initially less skilled in 3-D spatial visualization than are men [36], and taking a graphics course during the first year in engineering may cause them to consider dropping out. Sorby and her collaborators demonstrated that spatial visualization training improves performance [37, 38] and persistence [39]. Training interventions within engineering courses teach skills that may enable female engineering students to better manage stress related to their learning environment [40] and to increase performance [41].

Counterspaces in STEM are physical or conceptual safe spaces for underrepresented groups. These counterspaces may mitigate the chilly climate by increasing sense of belonging; they provide a safe haven from isolation and microaggressions [26]. By interviewing 39 women of Color of different ethnic groups, career stages, and STEM disciplines, Ong et al. determined five types of counterspaces that interviewees had experienced: peer-to-peer relationships (74.4%), mentoring relationships (66.7%), national STEM diversity conferences (66.7%), STEM and non-STEM campus student groups (64.1%), and STEM departments (51.3%) [42]. At a large public, urban PhD-granting university with high research activity, participants in STEM intervention programs (SIPs) had 2.9 times higher odds of persisting in STEM majors (p=0.028), compared to non-SIP participants [43].

Faculty representation may mitigate the chilly climate by increasing the proportion of women in the classroom. By modeling the count of women of Color engineering faculty as a function of year, engineering department, institutional characteristics, departmental-level characteristics, and state residence for engineering departments in 345 ASEE member institutions from 2005 through 2016, Main et al. determined that engineering departments that award more bachelor's degrees to women undergraduate students were more likely to employ relatively more women faculty [44]. More recently, Erichsen et al. used augmented inverse probability weighting (AIPW) to model National Center for Education Statistics Integrated Postsecondary Data System (IPEDS) data from the 2000-01 and 2008-09 IPEDS reporting cycles, limited to U.S. institutions with a tenure system that offered STEM bachelor's degrees. Using this model, it was determined that either increasing the proportion of non-tenure-track women faculty or increasing the proportion of tenure-track women faculty by 5% did not significantly increase gender exposure among STEM undergraduates. However, increasing the proportion of tenured women faculty by 5% significantly increased gender exposure by 0.7% (p<0.05). These AIPW results imply that warming the chilly climate requires both hiring and granting tenure to more women faculty [45].

While all these interventions are substantial and well-intentioned, some are ultimately band-aids, rather than true solutions, because they do not address masculine defaults, differential

treatment, proportion of women in the classroom [22, 26] and/or sense of belonging [18, 26, 27].

LUC Program Structural Supports

In contrast, LUC Department of Engineering is addressing the chilly climate through program structural supports. "LUC's B.S. Engineering program is a general engineering program with specializations of biomedical, computer, and environmental engineering. Each specialization emphasizes a social justice application. For example, in biomedical engineering, students learn to design and test robust medical device software, in preparation for a medical device to be cleared or approved by the Food and Drug Administration. All patients should receive high-quality medical devices, regardless of their ability to pay. All Engineering courses are taught using a mandatory active learning style, which increases the retention of female students, students of color, and first-generation students [28-31]" [46].

Building on the social justice core curriculum already provided by the university, Engineering administers social justice case study projects within Engineering courses to teach about the social consequences of technology on others. "Four social justice case study projects are embedded in the Introduction to Engineering Design first-year course, Experiential Engineering sophomore course, Electronics Circuits and Devices sophomore course, and Capstone Design I senior course. Each case study project has a different format, and contains written, presentation, and discussion components" [47]. This program is the first in the United States to fully integrate social justice within its curriculum [48].

Numerous program structural supports address chilly climate issues (Table 1). By far, the most important new first-year student program structural support is the first Engineering course these students take, ENGR 101: Introduction to Engineering Design. This four-credit hour course is taught three times per week, for 100 minutes each course meeting, over three sections. A main instructor in each course section teaches three-credit hours on various topics, including 9 out of 41 course meetings devoted to SolidWorks. The chair teaches the fourth credit hour of each section, 13 out of 41 course meetings. During these 13 course meetings, engineering design, systems, and a social justice introduction are taught. Also, four guest lectures from engineers in industry are arranged, with a light dinner for the speakers and students after the presentations. Since an open-ended first-year design project is the most effective way to retain engineering students [49], students are assigned to groups of three to four students, with each group working to solve a problem for a sponsor on campus. Sponsors are all university employees, such as the Dean of Libraries, Nursing Professors from the Center for Simulation Education in the School of Nursing, an Emergency Medicine Professor in the School of Medicine, and/or a Sustainable Agricultural Manager in the School of Environmental Sustainability. To guarantee that the students solve their problems by the end of the course, each group is required to meet with the chair before each of three milestones (Project Requirement Specification, Progress Report, Final Presentation/Report) is due. More detailed information about how first-year design projects are conducted can be found in [50]. Key aspects of ENGR 101 address microaggressions, differential treatment, isolation, and gendered assignments (Table 1).

Table 1. Chilly Climate Issues [21, 22, 25] Addressed through Program Structural Supports.

Chilly Climate Issue Addressed	Program Structural Supports
Masculine Defaults	Microaggression Identification: During the second course meeting of the first ENGR course, within the social justice module, a table of common microaggressions [51] is presented. The PI then asks that one student tell a second student if he/she is hurt by a microaggression and also states that she would be glad to tell the second student if the first student is uncomfortable having this conversation. The Department of Engineering should be a safe space.
	Freshman design projects for the Loyola Libraries, Nursing Simulation Lab, Medical School, and School of Environmental Sustainability are not gender-based [50].
	Industry-sponsored, two-semester capstone projects are not gender-based.
Differential Treatment	Each bimonthly faculty meeting begins with fifteen minutes of student review, to ensure faculty members are aware of and can support all student needs.
	All course projects have accompanying rubrics, so grading is transparent.
	During freshman orientation, the PI shares statistics indicating lack of diversity in undergraduate engineering and explains why more diverse engineers are needed to design products used by the world.
	Teamwork is emphasized through CATME peer evaluations, short CATME dimension training videos, and meeting support tools [52] . The CATME adjustment factor without self is used to properly weigh each student's contribution to each project milestone grade.
Proportion of women in classroom	All Engineering courses are taught using a mandatory active learning style (problem-based learning [53-55] and collaborative learning), which increases the retention of female students, students of color, and first-generation students. Engineering course sections seat at most 24 students, to facilitate active learning. Collaboration, rather than competition, is emphasized.
	The Engineering faculty is diverse and models the gender and ethnic diversity Engineering wishes to see in its student population (Figure 2). The Chair of Engineering is an Asian female full professor.
	Faculty diversity also includes industry and academic experience, with these industry experiences informing the first-year, collaborative, and problem-based learning activities given in courses.
Sense of Belonging	Each freshman or capstone design group is constructed so a female student or student of color is not isolated within a group of 3-4 students. A typical freshman group construction is 2 female students plus 2 students of color.
	The combination classrooms/labs for Engineering courses are card-access only, for use by Engineering students, faculty, and staff. These dedicated spaces turn into study lounges at night, so it is easy to find other students working on the same homework.

This B.S. Engineering program graduates about 50% women annually. After receiving ABET accreditation in 2020, LUC began participating in the ASEE annual survey and was ranked #6 in 2020 (52%), #6 in 2021 (58%), and #5 in 2022 (54%) for Percentage Bachelor's Degrees Awarded to Women (Figure 1). The program graduates about 20 to 30 students per year.

Based on internal student surveys, female students enroll because they are drawn to the collaborative environment of the program. Based on first-year and sophomore student completion of the Longitudinal Assessment of Engineering Self-Efficacy, women begin the program with lower levels of self-efficacy, but stay in engineering at similar rates as men [56].

Figure 2. The LUC Engineering Faculty.

Theoretical Framework

Program structural supports are the inputs to the proposed BELONG (Becoming Engineers Leading Our Next Generation) Conceptual Model of Engineering Persistence, which is based on social cognitive career theory (SCCT) [57]. SCCT has garnished strong empirical support [58] as a framework for explaining the underlying psychological and social learning processes that translate engineering learning experiences into interest in and intent to persist in engineering among diverse student populations [59-63]. SCCT posits that students will develop interest in engineering when they hold strong beliefs about their ability to perform it (self-efficacy) and positive beliefs associated with pursuing it (outcome expectations). Together, self-efficacy, outcome expectations, and interests lead to an intent to perform the activity of engineering and persist in such endeavors in the face of barriers. "SCCT is particularly well-suited to help understand the underrepresentation of women in engineering, given that it takes into account the influence of external or contextual supports (e.g., inclusive program structures) and barriers (e.g., hostile and unwelcoming environment) on intent to persist in engineering. Greater contextual support will lead to stronger self-efficacy beliefs and outcome expectations and ultimately a stronger intent to persist in engineering in the future, whereas encounters with major barriers may inhibit the translation of self-efficacy and outcome expectations into interest and persistence" [64] (Figure 3).

The BELONG model also incorporates the well-established sense of belonging construct to explain how intrapersonal and environmental factors shape one's sense of belonging in a given academic field such as engineering [25, 27, 40, 65]. Inclusion of sense of belonging in the SCCT model is especially relevant when studying the impact of contextual/structural factors (e.g., chilly climate) that inhibit academic progress. The sense of belonging construct further incorporates social justice literature [66-68] that highlights the importance of structural change in promoting equity, as well as the utility of using SCCT as a framework to understand the development of social justice interest and commitment. Social justice research also highlights how experiences of injustice (e.g., sexism) can lead to commitment to social justice advocacy [69]. Therefore, because women may experience injustice, they may be more compelled to consider engineering if it is framed as a form of social justice advocacy.

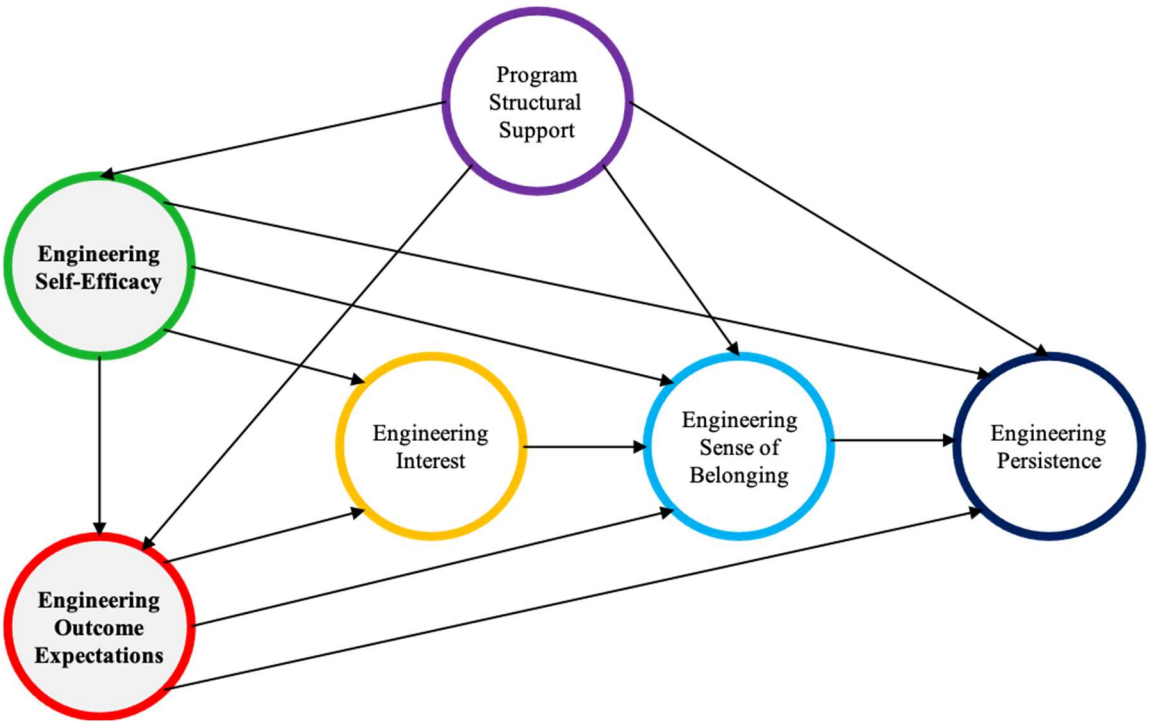

Figure 3. BELONG Conceptual Model of Engineering Persistence.

Research Questions

To understand the influences that lead to female engineering persistence at LUC, the following research questions were addressed:

- What influences first-year female engineering students of color to stay in engineering during their first year
    - What program characteristics and structural supports influence them?
    - What individual characteristics and experiences influence them?
- In what ways does the BELONG model represent the experiences of first-year female engineering students of color who persist in engineering?

Methodology

This study employs a qualitative research design utilizing individual interviews [70] to explore the experiences of self-identified women of Color in the LUC Engineering program.

Sampling

Using purposive sampling, participants who met the following criteria were selected: 1) enrolled in the LUC Engineering program during Fall 2024, which has program structures that support women of Color in Engineering; 2) self-identified as women of Color on university forms; 3) received grades of C- or higher in required classes for Engineering, including their ENGR 101: Introduction to Engineering Design course; and 4) enrolled in courses for Spring 2025, indicating their retention in the program.

During Fall 2024, 58 first-year students enrolled in the Engineering program, across three sections of ENGR 101. Of the Class of 2028, 26 were men (45%), and 15 out of 58 (26%) self-

identified as men of Color, based on demographic characteristics self-reported in their university-level academic records. Of the Class of 2028, 32 were women (55%), and 18 out of 58 (31%) self-identified as women of Color.

During the first month, one woman of Color announced she was going to switch programs; another woman of Color was dismissed from the program and encouraged to explore other majors due to two grades less than C- in required Engineering and science courses. Three women of Color received one grade lower than a C- in a required math or science course. Thus, 13 of 18 (72% women of Color) students were eligible for interviews, representing 22% of the first-year students. Out of these 13 students, six participants (42% eligible women of Color) completed interviews for this study and their findings are associated with pseudonyms. To protect anonymity in this small sample, there is no table of demographic information and pseudonyms are intentionally not used when sharing findings that include identifying information.

Data Collection Procedures

Per the IRB-approved protocol, the Engineering administrative assistant recruited female students of color in ENGR 101 after the final grades were posted. School of Education researchers then consented and interviewed study subjects. This process ensured that the program faculty and chair were not involved in recruitment and data collection to ensure participation was voluntary and students could share confidentially.

Six structured individual interviews were conducted over Zoom to understand their experiences during their first semester. The interviews lasted between 30-60 minutes. Participants were asked questions like "What has been beneficial in helping you succeed in the Engineering program?" and "In the last semester, tell us about any challenges that you encountered, and how you overcame them." Interviewers recorded, with transcriptions, the Zoom interviews and also took notes. Notes and audio recordings were used to ensure transcript accuracy.

Data Analysis

Researchers used emergent, focused, and thematic coding to eliminate inconsistent findings, search for patterns, and generate dominant themes [71]. First, interviewers completed initial open-coding, consisting of reading line-by-line attributing emergent codes to the data. Through this process, they identified and refined emergent themes. Next, interviewers compared these emergent themes to the BELONG model, identifying similarities and differences. Interviewers then did a second round of coding using the BELONG model as focused codes. Researchers then compared themes across interviews, identifying commonalities and differences. As necessary, individual interviewers were analyzed again for emergent themes that may not have been apparent in initial analyses. Throughout this process, the research team documented themes through memos and discussed preliminary findings and interpretations during team meetings. Participants reviewed findings via a member check to help validate findings.

Roles of the Researchers

The first author created most of the listed program structural supports and teaches the engineering design project portion of ENGR 101. She determined which students were eligible

to be interviewed from their academic records and gave a list of eligible students to the Engineering administrative assistant to recruit. The second author collaborated with the first author to develop the BELONG conceptual model of engineering persistence, based on well-established vocational psychology, sense of belonging, and social justice theories and empirical literature. The third author led the development of the qualitative research design, oversaw the interviews and assisted with analysis and representing findings. The fourth and fifth authors supported the qualitative research design, conducted the interviews and analyzed them.

Findings

The findings from the interviews with six students in the LUC Engineering program are organized based on the elements of the model, including sense of belonging, program supports, engineering interest, self-efficacy, and outcome expectancy. Prior to exploring alignment of students' experiences with these elements, the students' self-perceptions of their identities as women of Color and persistence, which were selection criteria for the study, were addressed.

Identities and Experiences as Women of Color

The students identified as women and mentioned how the Engineering program had a large percentage of women. They all noted diverse representation in the LUC Engineering program. Three participants recalled the chair of Engineering pointing this out at the beginning of the semester. Nadia (pseudonyms used to protect anonymity) remembered her experience during the program orientation which confirmed her decision to enroll at Loyola. "I saw a lot of females there, and it wasn't like other schools, (that were as) male dominated." These students acknowledged their identities as women in Engineering.

In their interview, four of the six students identified as women of Color. The two students that did not identify as women of Color focused on peers and faculty, in general, as supportive, welcoming and respectful, regardless of race. Nadia explained "it's not too important for me to address...as long as there is respect within my peers and professors." Across interviews, students told stories of experiencing a supportive environment.

In comparison, another student identified as Mexican, noting that she came into the program with impostor syndrome due to previous negative experiences associated with being the only Hispanic in a predominantly white high school. "When I went to the first dinner [within the Engineering program], I realized there wasn't many Hispanics. I just kind of got that feeling again." She spoke about overcoming imposter syndrome as one of the few challenges she faced her first semester. She described flipping her negative thinking into finding a positive with being one of the few Hispanic women within her Engineering class. "As soon as I got to my classes, I realized I was able to make other friends." Another student shared "There are instances where I can see differences between me and my classmates, whether it's like I'm like one of two Black women in my classes...it's just little stuff like that that you kinda are aware of. But it doesn't really—I don't allow it to deter me if that makes sense." Both women mentioned experiences of noting that they were minorities.

Similarly, Kaelyn identified as bi-racial. Although she reported not experiencing any microaggressions, she told a story of another student in the program who had experienced a

racial microaggression from another engineering student. She described how her identity as a woman was affirmed, while her racial identity was not. "At first I was a little bit afraid to go into engineering, because I thought it would be more male dominated. But I mean at Loyola, it's pretty 50/50, I would say. My biggest thing...I didn't expect...all the racism...I'm just gonna continue because I mean, it's like real life, too. There's gonna be people like that. I just have to learn how to navigate it." She saw representation for her identity as a woman but had a different experience with her racial identity. The four students that identified as women of Color all noted the racial and ethnic diversity within their cohort.

Persistence

In addition to meeting sampling criteria for ensuring persistence in their first year of the Engineering program, the six students described experiences and qualities that demonstrated their persistence. In addition to experiences overcoming feelings from imposter syndrome and navigating racial microaggressions described in the previous section, students spoke about course projects and teamwork as "challenging," and providing a sense of accomplishment from hard work and successfully completing projects. When describing their completed design project, Nadia explained, "I would say it was difficult to imagine… But as lessons went on, CAD became a little simpler to use and understand…we were able to do multiple puzzle pieces…we all kind of just added on, or had respectful thoughts of saying, 'Oh, what if we did this instead?'…I think towards finals week, it got a little difficult to maintain a deadline, but we managed." Students persisted at learning new content and soft skills.

The women emphasized confidence in their decisions to major in Engineering. Nadia and Aaliya explained how an Engineering degree, including their experiences in their first semester, supported their current career aspirations. Maria and Kaelyn shared stories of quickly switching majors at the beginning of their first year. They articulated why Engineering was a better fit than their initial choices due to the small, close-knit community and opportunities to build things. Elisa and Bette shared some feelings of uncertainty regarding being in the Engineering program. Elisa shared "I feel like when I started engineering, I wasn't too sure that...this is what I wanted to do. But then, after last semester, I feel like I made the right decisions...this is what I'm meant to do. This is what I want to do." Bette explained "...there were times where it'd be so challenging, and I would get so frustrated with myself, my classes, everything that I had to do...balancing...being in a new environment, plus having...tough classes...There were definitely times were I did want to quit...it's a 100% what I want to do with my career so there's no other option." Experiences during the first semester solidified students' choices to persist in the Engineering program, which we elaborate on through the remainder of the Findings section.

Factors Influencing Persistence

In this section, findings on students' experiences that influenced persistence are highlighted.

- Community and Sense of Belonging – The women described a sense of belonging in the program. Bette explained

> ...Going into a STEM field, as any woman is terrifying, and then as a woman of Color that just adds a whole other layer. I will say at Loyola Engineering there are a good amount of women of color...it's just not feeling completely alone. I definitely think that there is space to exist as a Black woman in

> the Loyola Engineering department. I really, really appreciate that it's definitely made me more comfortable. And even with speaking up in classes or just being willing to share my ideas seeing other people that look like me. It definitely helps.

Later in the interview, Bette told a story of struggling with her first SolidWorks assignment to make a V block. She called her mom, because she was not sure if she could complete the assignment, and then she realized there was another girl struggling with the same assignment nearby. She introduced herself and asked her if she would like to collaborate and help each other. "We ended up being able to complete the project using each other's help...this is what Engineering is about and this is why I'm in this program." Bette explained further "I have so many female engineering friends. I feel truly blessed to even be able to have more than 3 women that I can say 'Oh, yeah, we're going through this process together. But at Loyola, honestly...I never feel like I'm outnumbered or my voice won't be heard, or people are going to talk over me. I don't really worry about that." Similarly, Elisa explained "Loyola is really open, which I like. I feel like I don't need to be nervous, I guess, to be myself here." In general, these women felt a sense of belonging in the program.

The relationships they developed with other students in the program who provided support through academic support, microaffirmations, and friendships. Aaliya described how they consistently provided **microaffirmations** for their work in courses and their Engineering projects. "I feel like the students all kind of do that. We all cheer each other on…I try my best to keep morale high." Such affirmations also fostered relationship building.

Although four out of six women only shared positive feelings of belonging, two students had mixed experiences. Both women felt like they belonged as women but had heard about racial microaggressions other women of Color experienced within the program and consequently had some mixed feelings of belonging in relation to their racial identities. Another student explained "I feel like students that I was in, at least my engineering class, was a pretty diverse group. It wasn't just specifically one race. I feel like that helped." Among the four students that identified as women of Color, three of these students noted that racial and ethnic diversity within their cohort.

- <u>Program Supports that Fostered Community and Belonging</u> – Students described several program supports that fostered their development of community and sense of belonging. Although sometimes students explicitly discussed their awareness of these connections, more often, as researchers, the fourth and fifth authors noted these supports embedded in their experiences. As evident in the prior section, women of Color seeing representations of themselves in their cohort was an important source of support for them, which often takes intentional efforts with recruiting students.

  Although each student had distinct experiences, they all described building relationships, and even friendships, with the students on their team for their ENGR 101 design project. Maria explained, "So (our design project) did make us closer and closer together, especially because it was like a team-heavy project that you cannot do a lot of the stuff alone, that's what brought us together." Maria further explained "we all (got) along so well…and I just love them so much. I was even able to make friends with them by the end." Their

descriptions demonstrated how an intentional, rigorous team project also provided a positive relationship building experience, providing community and potential support to stay in the program.

The women described not only working together on their engineering projects but also forming study groups in the other math and physics classes that they shared. "I think having classes outside Engineering with my teammates was helpful to maintain a respectful space because we got to know each other…we would help each other with math and physics and being able to do that made it a more comfortable and respectful environment for us to prosper on our project" (Aaliya). While some students described getting to know almost everyone in the Engineering program, other students felt like the structure of the class based on Engineering team projects prevented them from getting to know others in their course.

All students mentioned the small class sizes, about 24 students, as also being critical for fostering these relationships, something that attracted them to the program, and a reason that they stayed. Illustrating how the small class size impacted her sense of community, Maria reflected, "I love that they do the classes that are smaller. And they actually put a lot more attention towards you. And it makes you (feel)...like a tight knit community, unlike other schools that are bigger. And they just have 50 to 100 students of engineering, in one classroom." Aaliya explained that having a small class size fosters close relationships between students. "I do enjoy having a smaller class size, where we get to interact with like the same few people, really build close relationships."

In addition to the small class sizes, Kaelyn and Bette emphasized the program curriculum that is rooted in active learning and collaborative learning that provided practical learning experiences. Both women also had a strong interest in Engineering due to opportunities to build things and work with their hands. For example, Kaelyn explained

> ...compared with other universities where it's mostly just lectures, here we actually work hands-on and have stuff that we've already done. I have a USB drive and it's full of stuff from SolidWorks and CAD that everybody's looking for...I think we're building a cardiograph...over the next four years...So if I can learn a lot and then apply it, I think that's just the best thing...you are building as you go in Engineering, so I'm going to use this for some ultimate project by the end of this year, next year, and so on. It makes it more exciting to me.

She also emphasized the value of group work in this context. "I think it's very helpful to have everything in groups. Five brains (are) definitely better than one, especially when it comes to making larger projects, or even just complex assignments." Even with positive collaborative learning experiences, she also noted "competition" and "tension" between students as a challenge that she had to overcome. In comparison to Kaelyn and Bette, Elisa described acclimating to active learning as a challenge that she had to overcome.

The physical space of the Flex Lab, which is a space that only Engineering students can access, even at late night hours, provided a dedicated space for students to work on team projects, study together, and build relationships. "(It) definitely helped me stay on track and focus" (Nadia). "Being with all my other fellow engineers we are able to help each other out and bounce ideas off of each other" (Bette). Students also reported accessing other

available supports at LUC, including tutoring and office hours, primarily for math and physics courses.

The women described opportunities for "positive role models in engineering...like Dr. Baura" (Bette). These positive role models varied for the women. Across the six women, they mentioned third and fourth year students, engineering faculty, faculty in other departments, guest lecturers, and project sponsors. In addition to building relationships with first year engineering students, three of the six students spoke about interactions and developing relationships with third- and fourth-year students in the Engineering program through an ice cream social, as well as other informal interactions.

Although the students had similar experiences with peer-support fostered through the program's design, the students described varied relationships with faculty. Three students described overcoming apprehension to talk with faculty members and seek out support. Maria explained, "If you just try talking with them, it might be scary at first, you need to for sure make an effort…It does make you see them more than 'Oh, they just give my papers,' but they're also there for you and everything." One student discussed getting to know faculty outside Engineering better than the Engineering faculty. Another student described already being comfortable having conversations with Dr. Baura, even though she recognized most of her peers would not agree at this point. Another student described faculty, in general as "super nice, helpful, very approachable." In general, the women viewed faculty as supportive and were still in the process of building relationships and becoming comfortable using faculty as a resource.

In addition, two students recalled guest lecturers who were women and women of Color, which helped them envision their future careers. Two other students reported favorable interactions with sponsors with whom they were collaborating through the ENGR 101 design project. Nadia commented on the value of these interactions. "I would say from Dr. [faculty name] about our engineering design project and our sponsor, especially when we would often meet and check in with them. They would critique us sometimes, but they would also compliment us for our work, but it was more like a team compliment." These interactions speak to the role models, mentoring and relations within their design projects.

While students identified several program-level supports that fostered their sense of belonging and persistence, four of the six students also attributed their persistence to sources of familial support.

- Engineering Interest – Women attributed their interest in engineering to a variety of elements of the field, including problem solving, fixing and building things [72], math and physics, and the humanity aspect. For example, Elisa shared "I really enjoy learning, especially math and physics...It's challenging but it's really cool to be able to understand how things work in the world, like projectiles or soundwaves...when I am out and about being able to think this works because of some physics concepts, it's really cool." Also, Bette explained that "...engineering scratches an itch in my brain, being able to solve other people's problems...(it) gives me a purpose and a meaning to life." The women mentioned these interests in the

context of overcoming challenges; thus, they return to these interests to affirm their decisions to stay in Engineering.

Some students discussed these interests developing prior to starting the LUC Engineering program. For example, Nadia mentioned that she took robotics courses in high school. "I was on a Vex robotics team for two years in high school, and I really enjoyed it. And I know a lot of engineering has those principles of Vex robotics. And I've just thought it'd be nice to do that. And biomedical specifically, because before that, I wanted to do something in medicine, and I feel like this combines the best of both worlds." Although the women mentioned their interests in Engineering, this construct was not emphasized throughout the interviews in the same manner as community and sense of belonging and program supports.

- Self-Efficacy – Students exemplified various qualities of self-efficacy. Bette described how she reframes her thinking when she gets a problem to solve and does not know how to approach it or what the first step might be. "Well, if I can't even get the first step down, do I belong here? Can I continue in this program?...The farther you go the harder it gets...but I think what is great is that everybody else is feeling the exact same way, because like an engineering problem you probably have never seen it before...every time it's a new experience and with new experiences come hardships, but they also offer the opportunity to really grow and challenge yourself...you can grow with other people by forming such a collaborative environment and helping each other out." Throughout the interview, Bette also referred to collaborating with other students, faculty women of Color role models, putting in hard work and extra time, and her interests in Engineering as supporting her self-efficacy to continue in the Engineering program.

  Nadia indicated that working in the collaborative project fostered her leadership and self-efficacy skills as she learned how to lead the group. "I just felt the need to do it...It was nobody's reasoning, but a little bit from everywhere, seeing how other people are, seeing how my professors teach and seeing how they interact, and also observing the other engineering groups and seeing their dynamics as who is leader and how they navigated that, I guess, picking up behavior from around the department." Nadia had an opportunity to learn and apply leadership skills, developing new confidence in her leadership. Other students described similar experiences learning skills in collaboration and teamwork. Although students mentioned content-related skills, such as learning to use SolidWorks, the majority of their experiences developing self-efficacy related to learning soft skills. All students demonstrated confidence in their academic studies, seeking out resources, such as tutoring, study groups and Khan Academy, to support their learning.

- Outcome Expectations – In contrast to other elements of the model, in these interviews, five students did not explicitly address outcome expectations. Students still seemed to be developing an understanding of what an engineering career may be and whether they would be engineers. Some students did appreciate learning about the connection of social justice to engineering. Elise described being interested in environmental engineering, and then pursuing a masters in civil engineering and getting licensed as an engineer. Amid describing these goals she also explained "I think a key part of environmental engineering is an aspect

of public health. You are worried about what is exactly happening with people. You're not just worried about the engineering aspect. There is a huge humanity aspect to it." In general, students wanted to learn more about engineering careers, and perhaps this element of the model may be more evident in subsequent years within their degree program.

Discussion

The findings from interviews with six women of Color in the LUC Engineering program demonstrate their persistence in engineering after their first semester. The women shared extensively about their experiences with developing community and sense of belonging. Their stories also demonstrated how several program level supports helped foster these experiences, most notably, developing new relationships and friendships with peers through group projects, study groups, small class sizes, and using a common physical space, the Flex Lab. The women also mentioned interactions with faculty, third- and fourth-year students, guest lecturers, and project sponsors as beneficial for support and role models. In addition, for some students, elements of the curricular design, including active learning, team-based projects, and social justice implications, supported their interest in Engineering and sense of belonging.

The women described overcoming challenges, including learning new content, successfully completing design projects, and navigating imposter syndrome, microaggressions and tension in relationships. After their first semester, most women did not have a clear sense of outcome expectations for being an Engineering major, which we anticipate may become a more salient element of their experiences later in their undergraduate training. Similarly, they reported some interest in Engineering, but we anticipate this interest will further develop in subsequent years of their program. For these reasons, longitudinal research on these women's experiences across their undergraduate program is critical for understanding the fit of the proposed model for supporting women of Color.

By focusing on women of Color, we also identified distinct experiences from intersecting racial and gender identities. Their strong sense of belonging as women in the LUC Engineering program demonstrates the importance of representation of women within a cohort of students and faculty. Given that LUC is a predominately White institution, it is not surprising that some women of Color experienced imposture syndrome and racial microaggressions.

The chilly (i.e., hostile) climate is a commonly recognized explanation for the exclusion and underrepresentation of women and racial minorities in engineering. It is important to note that a program climate reflects structural realities. As such, chilly climates that exclude women are not solved by teaching women how to navigate a hostile environment. We believe that chilly climates are solved by structural solutions. Data from this study support the efficacy of the BELONG model, a structural solution that addresses the exclusion of women, in attracting and potentially retaining women and women of Color in engineering.

The BELONG model addresses the chilly climate at the structural and program level with programing dedicated to understanding gender discrimination and microaggressions, social justice advocacy case study assignments, and creation of an environment where gender equity and gender microaggressions are discussed openly and at the start of training. Participant

responses highlighted how these structural solutions along with adequate representation of women and people of color among the BELONG program faculty had a meaningful impact on student experiences while enrolled in the program. For example, one participant discussed how their decision to enroll at LUC was affirmed during the Engineering orientation programming once she noticed the representation of women in the program and could recall the chair of the Engineering program discussing women in engineering months after the event. We believe this is compelling evidence of the importance and impact of structural solutions to the problem of the hostile environment.

It is also important to note that participant responses highlighted the ways in which the BELONG model also facilitated the creation of a sense of community among student participants. In fact, the BELONG model structures learning experiences (e.g., class projects, access to shared lab space after hours) in such a way as to foster learning in community/small groups. Participants noted how these community building aspects were embedded in their engineering training. Participant responses related to self-efficacy also seemed to highlight the ways in which individual and collective self-efficacy were fostered through group-based learning experiences. Collective efficacy [73], or the confidence of a group to work toward a common goal, may be of particular importance in the context of women (and other historically excluded communities due to hostile climates) in engineering. Ultimately, it is possible that BELONG learning experiences foster individual and collective self-efficacy, which then produces and deepens one's sense of belonging in the BELONG program and in the field of engineering in general.

Present findings should be considered in light of a number of study limitations. First, although the BELONG model makes causal claims about the role of self-efficacy, outcome expectations, interests, program supports, and sense of community on student engineering persistence, the present study's use of qualitative inquiry is not suited for testing causal claims. Rather, the present study elucidated student experiences and understandings of engineering self-efficacy, outcome expectations, interests, experiences of program supports and sense of belonging and helped to provide a more nuanced understanding of their engineering education experiences. Also, whereas the BELONG models addresses engineering persistence over time, the present results reflect one cross-section of time and are not able to address how these experiences and processes may evolve longitudinally. Studies interested in testing causal or temporal hypotheses could use experimental and longitudinal methods in the future.

Further, a complete analysis of engineering persistence would examine enrollment as well as retention. LUC Engineering first-year female enrollment over ten years has varied from 34 to 57%, which is atypical. Based on first- and second-year student completion of the Longitudinal Assessment of Engineering Self-Efficacy, LUC women begin the program with lower levels of self-efficacy, but stay in Engineering at similar rates as men [56], which is also atypical. In the LUC Engineering program over nine years, the majority of students who did not persist to the third semester failed Calculus I, College Physics I, Calculus II, and/or College Physics II. In this tenth year of the program, a record 90% of the Class of 2028 has persisted to the second semester. In analyzing engineering persistence, it is essential to consider how the enrollment

of students who are STEM proficient is influenced by financial aid administration, targeted marketing, and other enrollment strategies.

Moving forward, Class of 2028 study participants will continue to be interviewed annually to obtain longitudinal data as they progress through the Engineering program. Members of the Classes of 2029 and 2030 will also be interviewed annually. Quantitative methods will be used to test temporal and/or causal relationships (e.g., examining the utility of self-efficacy, outcome expectations, interest, and sense of belonging in explaining engineering persistence). Enrollment data will also be analyzed to understand how first year enrollment is shaped. Once the most effective program structural supports and enrollment strategies for female engineering persistence are identified, they will be disseminated so that they can be adopted by other programs.

In summary, a new theoretical framework, the BELONG (Becoming Engineers Leading Our Next Generation) Conceptual Model of Engineering Persistence, is proposed that describes the LUC Engineering program's ability to graduate about 50% annually. The model is based on social cognitive career theory, and incorporates program structural supports as model inputs and the sense of belonging construct as a precursor to engineering persistence. As a first step towards model validation, six structured interviews with self-identified women of Color in the Class of 2028 were conducted to gain a nuanced understanding of their program experiences during their first semester. Researchers used emergent, focused, and thematic coding to eliminate inconsistent findings, search for patterns, and generate dominant themes. Subsequent analysis elucidated student experiences and understandings of engineering self-efficacy, outcome expectations, interests, experiences of program supports and sense of belonging, and helped to provide a more nuanced understanding of their engineering education experiences. Data from this study support the efficacy of the BELONG model, a structural solution that addresses the exclusion of women, in attracting and potentially retaining women and women of Color in engineering.

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