Undergraduate Engineering Education: Creating Space for Multiply Marginalized Students

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Abstract
Research regarding systemic inequalities in the science field has uncovered scarce opportunities and insufficient support for underrepresented groups. This research provides evidence of inequalities related to multiply marginalized students. The work in this research is to address the intersectionality in these multiple identities in an effort to provide inclusion for the affected marginalized groups. Intersectionality framework considers how multiple characteristics—in this research, race and gender affect an individual socially in contrast to separating the characteristics for individual examination. Minorities, specifically Black females, continue to contribute significantly to the underrepresented in science, technology, engineering, and math (STEM) in academia and in the workforce, particularly electrical engineering. The barriers indicated in this representation often lean toward interest, gender biases, preparedness, and the invisibility of self-identification in mentors. Using mixed methods including literature reviews and questionnaires, this paper examined those methods and compared them to existing social and balanced identity theories and interventions to address identity formation as a notable developmental challenge, resilience, and resistance of Black females in the engineering field. In this research undergraduate engineering students (N = 58) responded to a questionnaire measuring STEM-inclusivity, identity, preparedness, assessed the scholar's perspective on their involvement in STEM, and psychological effects the students endured during enrollment in a STEM program. Additionally, from this investigation, this paper suggests methods for creating space for multiply marginalized students to broaden participation in undergraduate engineering.

Background
For decades males have dominated engineering in academia and the workplace. Asian and Caucasian men established the status quo for demographics in engineering years ago [1]. According to Pew Research Center, employment statistics for STEM job clusters (defined STEM jobs specific to the applicable industry), Caucasians, Asians, Blacks, and Hispanics represent 67%, 13%, 9%, and 8% respectively of STEM jobs—Caucasians and Asians are overrepresented in engineering and architect jobs at 71% and 13%, respectively—Blacks and Hispanics are underrepresented at 5%, and 9% respectively [2]. The increase of women in engineering academia or the workplace has been slow to non-existent over decades. In a survey posted by the U.S. Census Bureau, decennial census 1970-2000 and American Community Survey public use microdata 2010 & 2021 reported a slow incline of female representation in engineering in the workplace from 3% in 1970 to 15% in 2021 [3]. U.S. Census Bureau, American Community Survey in 2021, Titled: “Occupation with the smallest share of women workers” there were 9.4% females working specifically in electrical and electronic engineering. Figure 1 displays the disparity in female engineering employees vs male engineers over decades.

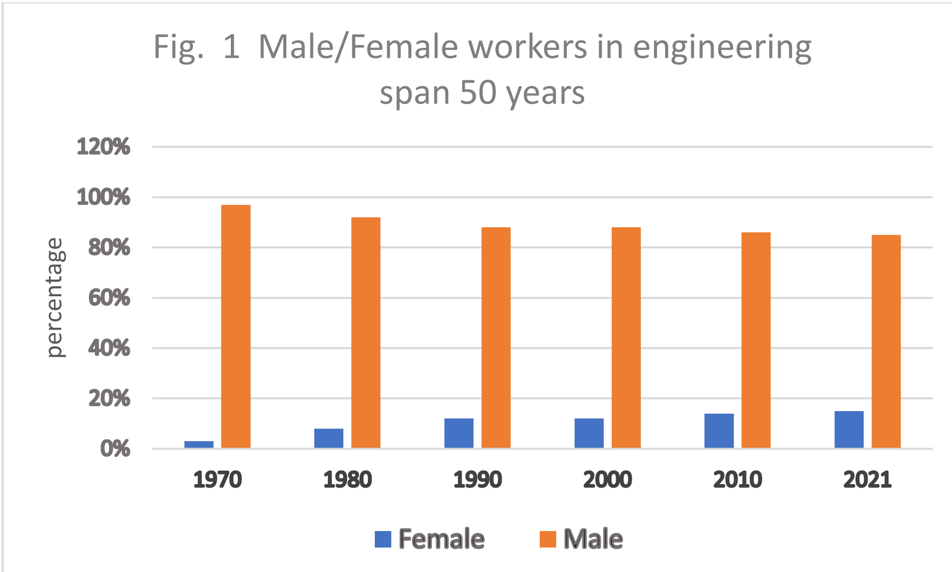

Fig. 1 Male/Female Employees in Engineering Last 50 Years

The National Science Foundation (NSF) issued data for race in comparison to STEM degrees conferred in higher education. NSF reports a percentage of high school students enter the STEM workforce without pursing a college degree; however, the STEM industry relies on workforce members with college degrees [4]. Figure 2 graphically displays the data [4] pulled from the NSF report.

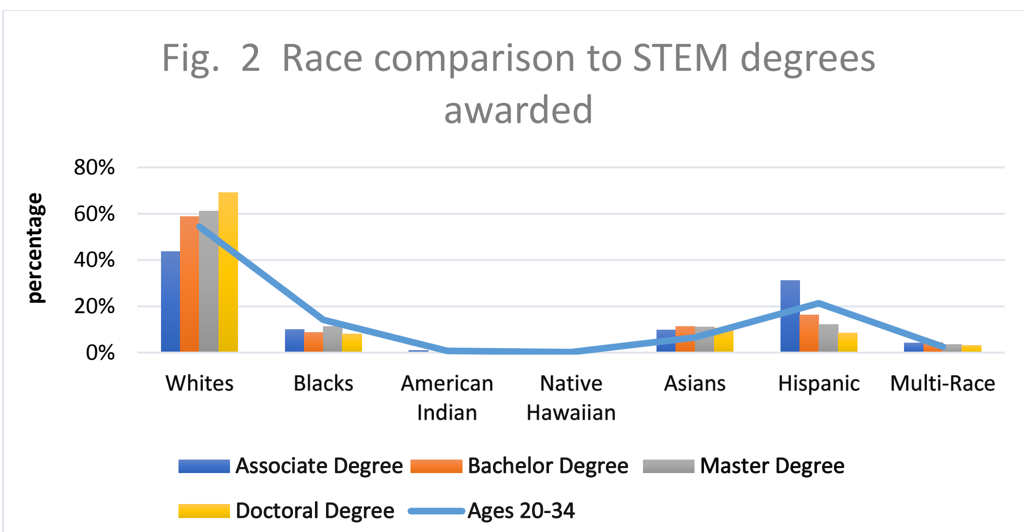

Fig. 2 Race Comparison to Earned STEM Degrees

It is important to the scope of this paper to emphasize one underrepresented group depicted in figure 2—Blacks received a low percentage of degrees across the board. With Figure 3 gender disparities are further analyzed. Figure 3 displays data from the electrical engineering (EE) departments at Morgan State University (MSU), Texas Southern University (TSU), Jackson

State University (JSU), and North Carolina A&T (NC A&T) that reveals the gender gap in the electrical engineering discipline. The demographic data depicted in this graph was retrieved from the Offices of Institutional Research at NC A & T, MSU, and JSU and the from the Office of Institutional Assessment, Planning and Effectiveness at TSU. The graph conveys this disparity through the enrollment numbers for each gender. NC A&T has a sizable number of EE students, 166; however, the enrollment for females—18% is still considerably lower in comparison to its male students—82%. The enrollment of female students vs males students at MSU is 13.05% and 86.15%, respectively, TSU is 16.67% and 83.33%, respectively and JSU is 14.9% and 85.07%, respectively.

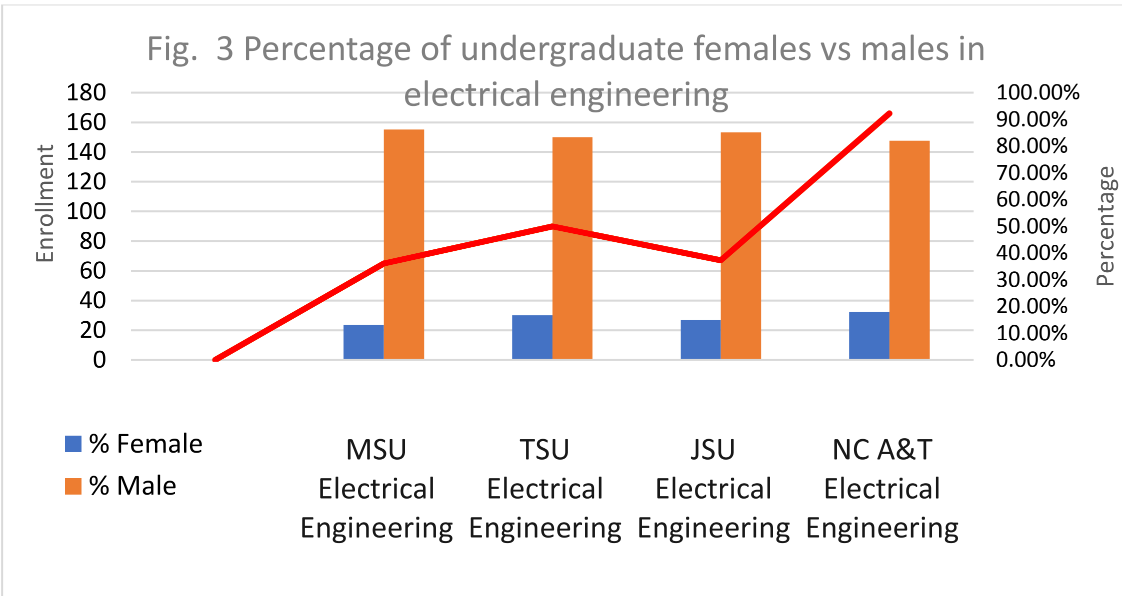

Fig. 3 Percentage of Female vs Male Undergraduate Electrical Engineering Students at MSU, TSU, JSU, and NC A&T

Although barriers are revealed for young adults at the collegiate level to entering the workforce a study from the American Psychological Association (APA) suggest disparities are initiated during early childhood development years [5]. Educational disparities associated with race and gender regarding underrepresented groups in undergraduate engineering focuses mostly on assisting students once enrolled. Early Childhood Education (ECE) and K-12 education plays a significant role in preparing students for a collegiate path. Early exposure to mentorship as shown in [6], tutelage, resilience tools, engineering concepts, and advanced math have been empirically proven beneficial [7]. Additionally, intervention or implementation of social determinants of health, such as education, socioeconomics, community, and health care have substantive value in fostering environments facilitating a student's work ethic and retention.

Females enrolled in STEM programs, particularly electrical engineering, often do not complete the program. The sense of unbelonging in electrical engineering is more prevalent among underrepresented groups. These students change programs during the second or third semesters after enrollment [8-9]. Academic and workplace environments in engineering are not always welcoming to female counterparts, leaving females with a sense of unbelonging [10-11]. With paucity of encouragement from educators for females to enroll or express interest in science or math during primary through secondary levels of education subsequently resign females entering the collegiate level with undiscovered interest and deficient skills required for engineering programs [12-15]. Current research on math-gender misconceptions that lend toward this level of encouragement do not confirm the misconceptions but more so raise questions of how the applications of the misconceptions psychologically affect the student [13]. Forms of gender misconceptions play key roles in female representation in STEM and also impact identity formation [16-21].

Introduction

Identity Theory

Research on identity has been prevalent in theoretical and experimental development in psychological studies [22-26]. The continued curiosity in the theory of identity is attributed to the significance of understanding an individual in social settings and how they appear in society.
Identity theory proposes individuals have several identities framed in hierarchal order. Commonly, identity is considered as categories used to establish the societal role for an individual. A core objective of identity theory is to indicate how the categories associated to an individual's different identities are assigned and controlled during interactions. In the late 60's Erik Erikson posited identity formation essential to the development of an adolescent. Erikson's framing of identity considers a process dually positioned in the core of an individual and community culture [27]. Erikson's identity theories ignited the investigation of different forms of identity and submitted to the complication of this process. Particularly, in STEM—research on identity suggest individuals begin to form their identities, additionally, establish thoughts concerning career aspirations early as elementary [28-34].

Role Identity/STEM identity

Developing and establishing a STEM identity has influential significance in educational and career aspirations for an individual [35-37]. Conversely, history demonstrates STEM identity development for marginalized students has been laden by a representation deficit in STEM—academia and the workplace. Positions in these areas are predominantly comprised of Caucasian males [1, 38]. Research proposes identity formation for career aspirations—such as becoming an engineer as the student's role identity. There is little research investigating the student's role identity in STEM careers [39]. However, it is well documented that establishing a student's role identity can possibly contribute to the interest of a career in STEM [40-43]. Research has also demonstrated exposure to role models that individuals can self-identify with—same gender and race, could intensify the development of a STEM identity [44-45]. In particularly, the STEM identity development in undergraduate females [45].

Racial Identity

Racial identity has been extensively researched to better understand the psychological effects on the lives of Blacks [46]. Racial identity in Blacks is a complex phenomenon. Therefore, the necessity of a multidimensional evaluation of racial identity is required. The Multidimensional Model of Racial Identity (MMRI) and investigation on identity theory share many parallels [47-48]. MMRI, similar to identity theory surmises Blacks have many identities also framed in hierarchal order. Race is counted as one of those identities. The MMRI method for examining racial identity in Blacks considers the impact race had historically and ethnically on the lives of Blacks. This consideration adds another layer to the research in identity theory. Racial identity has been linked with several attributes—such as self-esteem [49-51], scholastic measurements [52-54], self-identification in mentors [55-56], and career ambitions [57-58]. Examining the intersectionality of these social groups—gender, identity and race are prevalent in our research efforts to assist in broadening participation in engineering for Black female students.

Intersectionality

The latest theoretical research advances suggest the development of identity occurs as adolescents mature combined with their environmental and social perspectives in relation to diversity within those spaces [59]. Scholars have exercised intersectionality to examine the experiences of persons belonging to multiple disenfranchised groups. Research suggest that developmental studies would benefit from Crenshaw's design of intersectionality. Crenshaw's theory states disenfranchisement comprises of systematic disparities and interwoven structures of oppression [60]. Spencer's phenomenological variant of ecological systems theory (PVEST) integrated this component into its framework. PVEST was formulated to assess theories that disregarded inequality issues experienced within multiple layers of life.

In this research we address inequalities that hinder multiply marginalized students from pursuing and/or completing an undergraduate engineering degree. Our study addressed the intersectionality in these multiple identities in an effort to provide inclusion for the affected marginalized groups. Intersectionality framework considers how multiple characteristics—in this research, race and gender affect an individual socially in contrast to separating the characteristics for individual examination. Minorities, specifically Black females, continue to contribute significantly to the underrepresented STEM in academia and in the workforce, particularly EE. The barriers indicated in this representation often lean toward interest, gender biases, preparedness, and the invisibility of self- identification in mentors. Using mixed methods including literature reviews and questionnaires, this paper examined those methods and compared them to existing social and balanced identity theories and interventions to address identity formation as a notable developmental challenge, resilience, and resistance of Black females in the engineering field.

Methods

In this research undergraduate engineering students responded to questionnaires measuring STEM-inclusivity, identity, preparedness, assessed the scholar's perspective on their involvement in STEM, and psychological effects the students endured during enrollment in a STEM program.

The Black females attending a MSI was the focus of this research. As noted in figure 3 the percentage of females enrolled in EE at MSIs is considerably low. Examining the high percentage of females enrolled in other STEM disciplines—biology, chemistry, and math vs EE at MSIs is one of the motivations for this research. Table 1 displays the percentages of females vs males in STEM disciplines at four different HBCUs. The data was collected from each school's website. The websites had interactive tools enabling filtering options to gather specific enrollment information for discipline, gender, and race/ethnicity—TSU (Home - TSU Enrollment Data -

Texas Southern University), JSU (https://www.jsums.edu/institutionalresearch/data/student-data/enrollment/), MSU (Interactive Fall Cohorts by Major, Gender, and Race/Ethnicity (morgan.edu)), and NC A&T (Enrollment (ncat.edu)).

Table 1
Comparison of Females in STEM Disciplines

Institution	Gender	Chemistry	Biology	Math	EE
TSU	Female	3.31%	40.33%	1.16%	1.24%
	Male	1.32%	8.84%	0.83%	6.2%
MSU	Female	7.84%	43.13%	.49%	8.11%
	Male	.49%	9.31%	0%	50.45%
JSU	Female	4.42%	33.27%	.75%	.63%
	Male	.75%	7.63%	.25%	3.59%
NC A&T	Female	4.54%	31.06%	2.27%	1.55%
	Male	1.07%	6.01%	1.76%	6.86%

At TSU, the females enrolled in chemistry—3.31% compared to males at 1.32%, biology 40.33% compared to males at 8.84%, math 1.16% compared to 0.83%. The percentage of females in EE decline compared to those enrolled in biology, chemistry, and math to 1.24% compared to males at 6.2%. The enrollment numbers for females in chemistry, biology, and math far outweigh the number of females enrolled in EE—this enrollment comparison is the same for each HBCU. Figure 4 gives a graphical presentation of the percentages from the four HBCUs. It allows for a quick synopsis of the differentiation between these numbers.

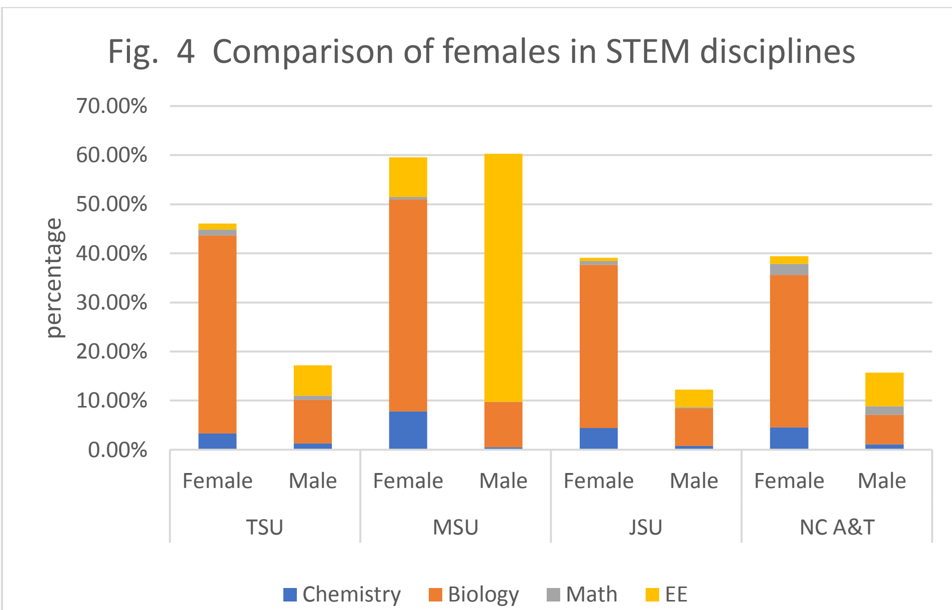

Fig. 4 Comparison of Females in STEM Disciplines at TSU, MSU, JSU, and NC A&T

The EE numbers highlighted in yellow are clearly visible for the male students at each HBCU, notably at MSU. These numbers show the males enrolled outnumber the females enrolled in EE.

Why the decrease in the female enrollment numbers for EE? The total percentage of females enrolled at these institutions is reasonable—overall females at MSU is 63.23% of the student body; however, once the enrolled are dispersed into specific disciplines the number of females enrolled in EE is significantly less. Our research questions are:

Q1. Why are females underrepresented in the EE discipline
Q2. Why are black females not enrolling in EE disciplines when they are enrolling in other STEM disciplines at MSIs
Q3. Are the student's experiences affecting them psychologically

Procedures

Questionnaires were emailed to the entire student body of undergraduate engineering students in the School of Engineering at MSU. The instructions on the questionnaire advised the following to the potential responders: "Thank you for volunteering to participate in this data gathering process. Your responses will help inform the experiences of minorities in undergraduate engineering education." The eligibility criteria to complete the questionnaire required the participants to have undergraduate status as an engineering student at MSU. The questionnaires were administered during fall 2023 and spring 2024 semesters. The questionnaires included 152 total items measuring the students' identity role in engineering, belonging, acceptance into STEM, assessment of the students' perception of their role/value in STEM, assessed any psychological effects experienced during enrollment in STEM, and demographics. A total of 58 undergraduate engineering students attending the HBCU responded. A small percentage of the responders identified as female, 26.8% and 73.2% were male. We filtered for EE Black female students—the percentage decreased to 23.2%.

In combination with other questionnaires identity questions from [61] were used to survey the undergraduate engineering students. We investigated how the undergraduate engineering students view their identity role in engineering and belonging [62]. The questionnaire questions were derived from research gathered from relevant literature and tools used to measure acceptance into STEM [63-64], assessment of the students' perception of their role/value in STEM [64-66], identity [61, 64-66] and assessed any psychological effects multiply marginalized students experienced during enrollment in STEM [67-69]. Two questionnaires were administered. The results were measured by the Engineering stress culture (http://creativecommons.org/licenses/by/4.0/) and subscales from the MMRI [70] instruments.

Results

We referenced the thematic analysis described in [71] to identify the emergent themes. The analysis of the collected data resulted in the identification of five themes: (1) contribution to the choice of engineering, (2) difficulty of preparation for engineering, (3) support systems along the education pathway, (4) expectations and aspirations, and (5) accessibility to mentoring on campus. The themes, definitions, and sub-themes are presented in Table 2.

Table 2: Identified themes depicting the impact of factors on the participation and persistence of females in EE

Theme	Definition	Sub-codes
Contributions to the choice of engineering	Factors that influenced choice and contributed to an increased interest in engineering	Family or relatives, STEM awareness or engagement, curiosity or interest, strength in engineering, teacher or mentor, motivation, engineering capability, early exposure, engineering society or opportunity and internship
Contributions to difficulty of preparation for engineering	Factors that contributed to the difficulty encountered during your academics	Lack of opportunities, classroom and extra-curricular learning, technology, family, pandemic, difficult faculty, lack of motivation or planning, tutor or mentor, isolation
Contributes to support in the education pathway	People, event, experience, or program enabled you to overcome the challenges	Campus opportunities, family or relatives, professors or faculty, peers, personal development, early exposure
Expectations and aspirations	Aspirations during or after study.	Community development or service, job in the industry, graduate studies
Accessibility to mentors	Utilization of mentoring services at institution and role mentors played in persistence in the field and career pursuits	Yes or No (Uninhibited mentor-mentee relationship, Lack of mentoring opportunities, mentoring services not utilized)

Contributions to the choice of engineering

The first theme to emerge was choice of engineering. The responders, 9%, conveyed the need to be part of the engineering community discussion in initial stages of study to avoid isolation and making alternate discipline choices. The need to study engineering and develop personal satisfaction doing engineering activity at an early age measured at 3%. Figure 5 13% of the students chose engineering due to curiosity or interest in engineering. Some students, 26%, stated they were influenced by relatives and family members while 11% of the respondents stated a strong background in engineering. None of the participants were influenced by high school mentors to pursue engineering. The responders, 18%, were motivated to pursue engineering through interaction with college engineering students and exposure to engineering professionals.

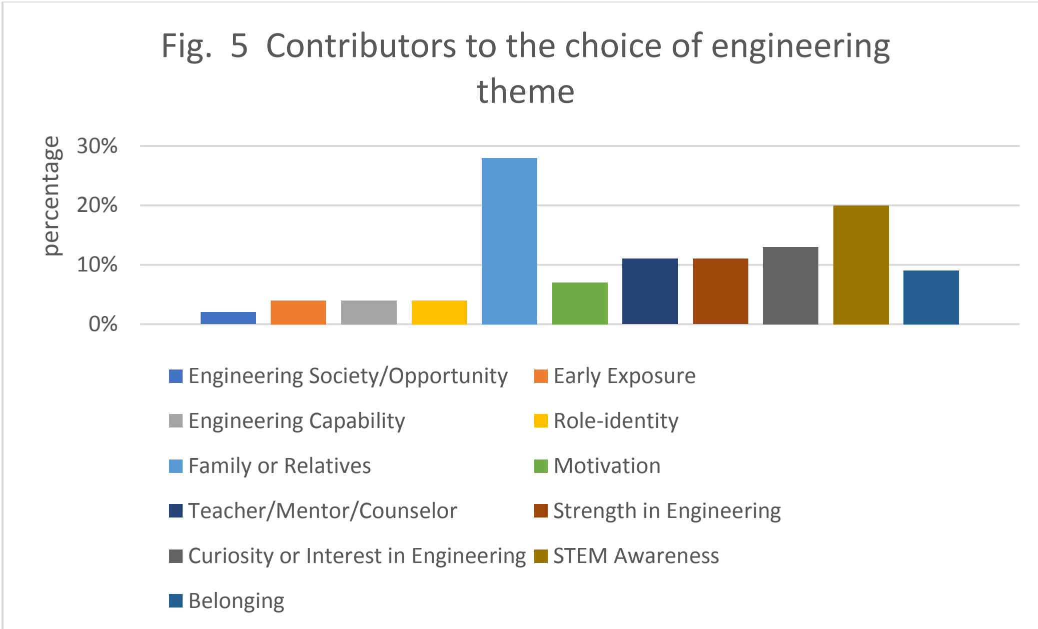

Fig. 5 Contributions to the choice of engineering theme

Contributions to difficulty of preparation for engineering

During the pandemic students experienced significant issues being outside the classroom. Figure 6 shows 21 % indicated they were left behind and experienced a drop in motivation to study due to the lack of in-class instruction. Poor grades were attributed to difficulty in learning concepts related to their EE courses and poorly taught preparatory courses. Some students reported at 12% a lack of motivation, anxiety, and isolation. The students felt these contributors had a psychological effect on their performance in EE subjects. While slightly under 10% of students stated they had no challenges, the same percentage indicated issues as a result of poor faculty communications and teaching deficiencies at the high school level. A reported 6% conveyed a lack of research and internship opportunities on campus and industry, and 3 % indicated financial challenges contributed to the difficulty faced during their study. All the respondents are familiar with the use of technology and tools for learning within their reach.

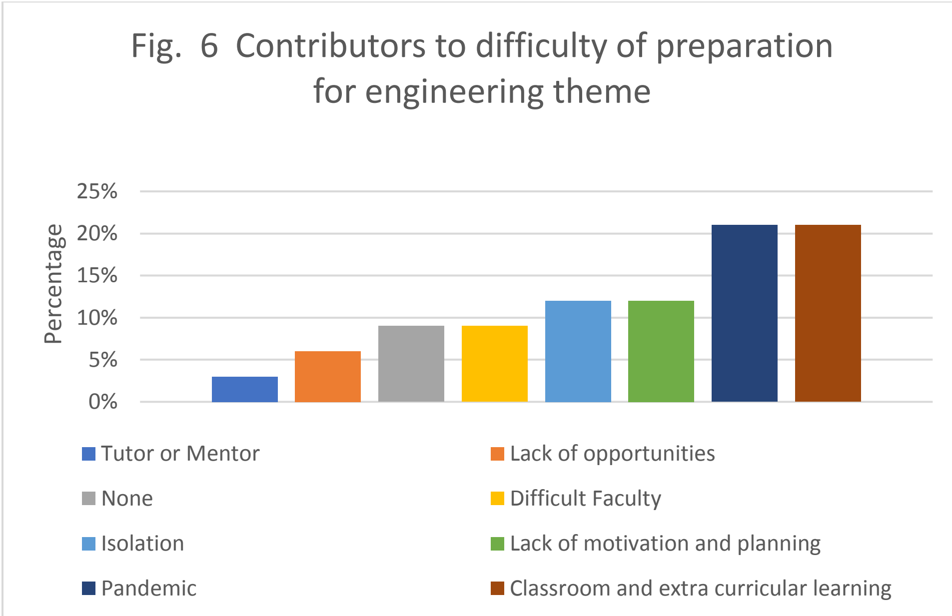

Fig. 6 Contributors to difficulty of preparation for engineering theme

Contributes to support in the education pathway

The journey through engineering can be challenging for students without adequate support systems. Figure 7 indicates that faculty at institutions can play a crucial role in students' successful pursuit of engineering education and beyond. A reported 27% of the respondents indicated that close academic advising, research opportunities seminars, and timely intervention of faculty helped their progress. A reported 22% stated involvement in mentoring groups through friendship and positive rapport with peers helped with psychological and academic development. Others (15%) found campus opportunities such as jobs, seminars and conferences opportunities were a positive factor in their persistence. A reported 12% indicated that personal growth and self-efficacy was significant to their success. At 10% the students conveyed that family support at home and the same percentage indicated that company outreach on campus and internships fostered their continued interest. A reported 6.7% stated that they demonstrated passion for engineering at an early age.

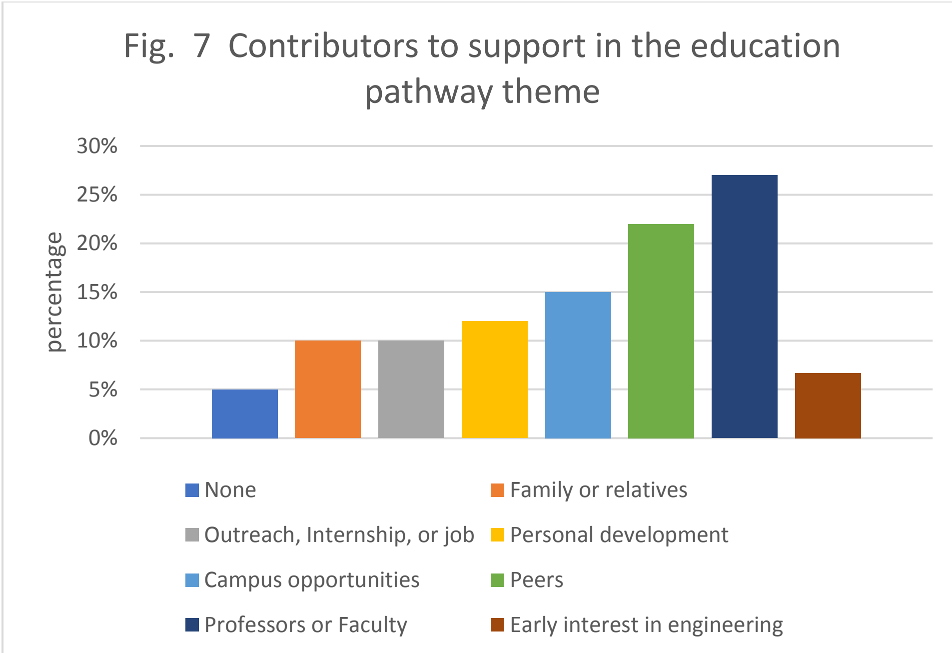

Fig. 7 Contributors to support in the education pathway theme

Contributors to the expectations and aspirations theme

Supporting underrepresented groups require understanding a students' engineering career aspirations. According to the survey conducted, 49% of the students responded they are confident in the pursuance of employment in the industry immediately after graduation. Furthermore, 34% hope to continue their education at the graduate level depending on funding and support available. Less than 6% stated they will engage in a business start-up, pursue a second degree, or prepare for certifications (see Figure 8).

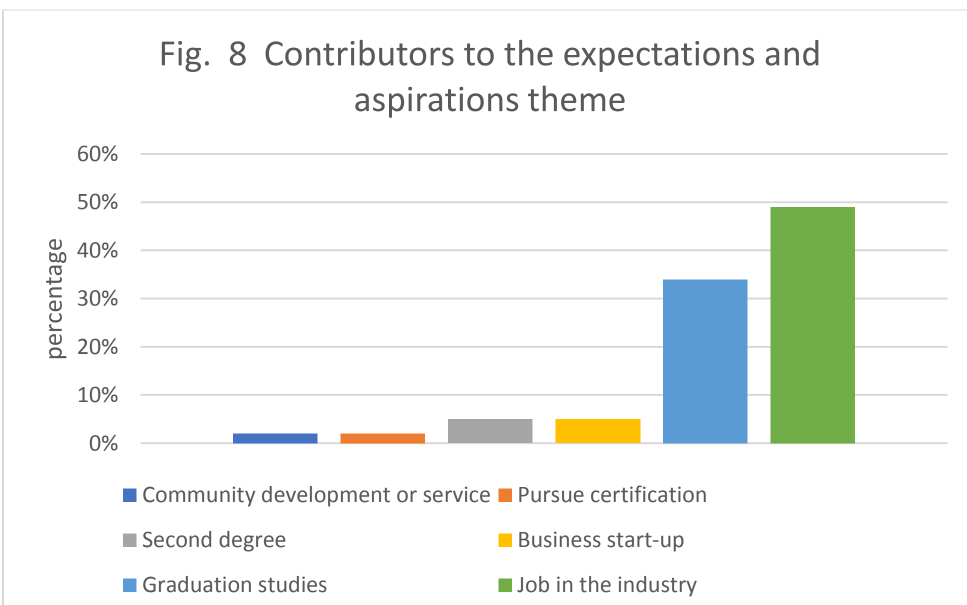

Fig. 8 Contributors to the expectations and aspirations theme

Contributors to the accessibility to mentors and mentoring opportunities at institutions to assist academic success and career development theme

According to the survey, students who answered "yes" stated at least one professor, faculty or staff member has initiated a conversation with them about their career options. These groups expressed feelings of career readiness. Figure 9 also shows 58% of those students responded they are confident in graduating with the knowledge and skills needed for success in the engineering workplace.

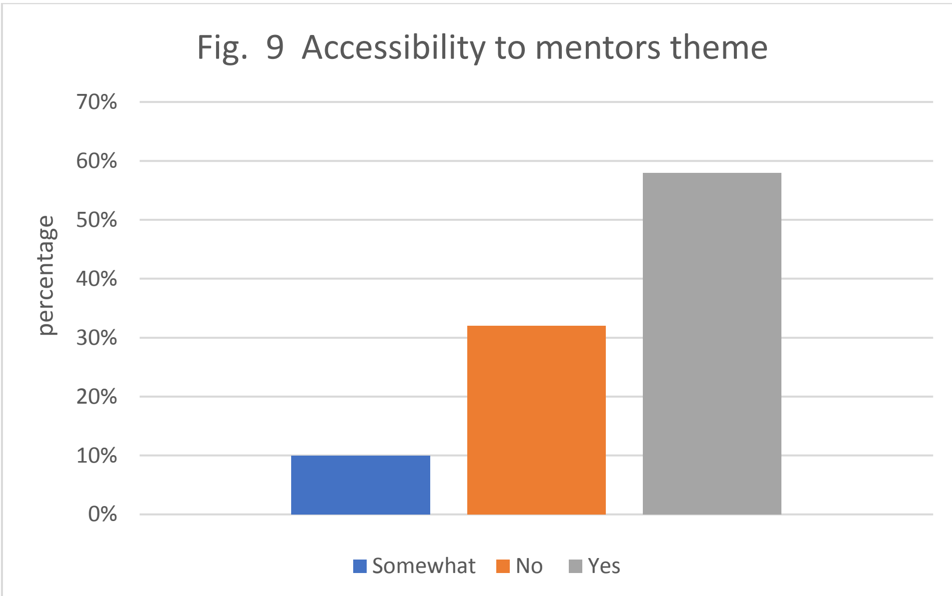

Fig. 9 Accessibility to mentors

We are still collecting data on whether the student's experiences affected them psychologically. Figure 10 demonstrates some of the sample questions.

Fig. 10 Sample questions for experiences affecting the students psychologically

I found it hard to wind down. ______________________

○ Yes ○ No ○ Sometimes

Females are treated fairly in this department. __________

○ Strongly Disagree ○ Disagree ○ Neutral ○ Agree ○ Strongly agree

Fig. 10 Sample questions for experiences affecting the students psychologically [70]

We have collected some preliminary results due to overlap questions posed on the different questionnaires. Preliminary results indicate a substantial percentage of the undergraduate engineering students reported an increase of stress and apprehension during enrollment. There were also significant numbers indicating signs of developing depression. We discovered connections with mental-health, role-identity, and sense of belonging. The data also supported the reason for the research—underrepresentation of female students.

We are developing a Broadening Participation Model shown in table 3 to facilitate the increase and support of underrepresented females in EE based on the results from the questionnaires, the engineering stress culture, and subscales from the MMRI instruments. The model will address reaching students during the elementary level to dispel misconceptions and support the development of role-identity in EE, creating inclusion programs to support belongingness, and create gender/identity student-mentor match networks, all to increase the engineering education pipeline from education to the workforce.

Table 3.
Preliminary Building Blocks for the Broadening Participation Model

Sample Item	**Broaden Participation Component**
Interest in Electrical Engineering (EE)	Identify Interest Early [32]
Belongingness in EE	Create Inclusion and Support Programs [67]
Self-Identify with Mentors	Create gender/identity match mentor program [6-7]
Role-Identity in EE	Diversify the teachers/professors [34]
Misconception of Mathematical Skills	Provide preservice training dispelling ideals [72]

Discussion

Building engineering awareness

The students' responses suggest the value of increasing awareness of engineering and the work engineers perform during earlier stages of education would increase the number of students who pursue and attain engineering degrees, and their technical literacy. Most engineering outreach activities have focused on introducing elementary and middle school students to engineering but have low outcomes on affirming student's interest and preparing them to pursue an engineering degree. There is a need for adequate preparation of students at the K-12 level through activities and programs that prepare them to pursue engineering degrees. This will require more in-depth knowledge about K-12 education and blending engineering content into age-appropriate activities to reinforce or supplement curricular material.

Effective and inclusive mentoring

From the survey results it was interpreted the students valued various mentoring opportunities available on campus. From the results it was also determined the need for mentorship programs to consider the intellect, social, and professional development needs of the students. Encompassing these factors in mentorship will help encourage students, particularly underrepresented groups, to pursue careers in engineering. One aspect of mentorship that needs improvement is increasing the presence of industrial mentors during K-12 education. Although there are high school mentorship programs that help refine skills such as problem-solving, people skills and critical thinking, the involvement of industrial mentors can help bring in the missing piece of the critical need in communities. This can help enlighten more students to pursue engineering careers, understand networking and real-world expectations, and strengthen bonds with the community at an early age.

Role models and their representations

The feeling of isolation, balancing an engineering career with family life, academic dissatisfaction, and lack of minority role models on campuses can reduce representation. There is a need for equitable access of students to role models of similar gender and race. Most females indicated that encouragement and validation from someone like them can help build their engineering confidence and level of self-efficacy. College administrators should seek diverse faculty to reflect the student body and to encourage/motivate an increase in female representation.

Quality Teachers with engineering knowledge

The participating students emphasized the need for early exposure to engineering via clubs and outreach programs from the industry. The students also noted the importance of identifying diversity in the field, requesting early exposure to engineers from underrepresented groups at the K-12 level. This can involve outreach to elementary, middle, and high schools to highlight inspiring engineering projects from the industry and academics, exposure through field trips, more internships opportunities, and job shadowing to engineering companies or facilities. The inability to identify or connect with practicing engineers is a concern. Addressing this will partially alleviate concern some students have with the lack of understanding real-world relevance of engineering.

Conclusion

This is a work in progress. We are hoping our final results from this research will aid in and encourage broadening participation efforts for the engineering discipline. Our preliminary results suggest student awareness regarding inclusion and role-identity in EE play a significant role in the student’s mental well-being. This also confirms the significance of creating inclusive environments in EE. Results also indicate there is a need for mental health support for multiply marginalized undergraduate engineering students attending MSIs.

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