Educating Engineering Students Innovatively: A Model for Improving Retention and Academic Performance of Black Upper-Level Students

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A. Introduction

In a study of the Florida A&M University-Florida State University College of Engineering pre-engineering program, almost 700 engineering students were analyzed that were enrolled through the HBCU (FAMU) partner of the joint college [1]. Of the students who completed the pre-engineering program, 72% eventually graduated from the university with a degree in engineering. Therefore, students who finished the pre-engineering program were highly likely to persist to graduation. Although the results were encouraging, the analysis revealed that less than 1 in 4 FAMU students completed the pre-engineering program successfully. A deduction can be made that completion of the pre-engineering program is a good predictor for persistence to an engineering degree completion. Based on this information, it was determined that by significantly increasing the percentage of students who complete the pre-engineering program, there could be an increase in students that persist to graduation. The problem arose of how to increase the number of black students that persist through the engineering curriculum.

A recent Lumina Foundation-Gallup State of Higher Education study that surveyed over 12,000 people introduced an eye-opening phenomenon that uncovered the psychological, physical, and financial barriers that black students face when attempting to obtain a bachelor's degree [2]. This study provides some insight into why black students have a lower six-year graduation rate (50.2%) than any other racial or ethnic group [3]. The study investigates people currently enrolled in college, enrolled in a certificate program, had some college experience, and never enrolled in college. Of the currently enrolled students, 1,106 were non-Hispanic Blacks, of which 317 were in a bachelor's degree program [2]. The report unveils the inequities in college for black students. Of the students currently enrolled in colleges with a low number of racially diverse students, 21% of black students felt discriminated against and disrespected while also feeling physically or psychologically unsafe. Couple that phenomenon with the study uncovering that 36% (more than a third) of black students have outside factors that are major priorities, such as being caregivers and/or holding full-time jobs, which is twice as much as their non-black counterparts. This means that some black students not only have to navigate the rigors of their college curriculum, but competing life priorities and responsibilities that many non-black students do not have to navigate to complete their degree programs. Nearly 46% of the black students with these obligations have considered leaving college. Black students in the study mention the importance of financial aid, scholarships, increased personal income, and support from college staff to ensure they persist.

In 2017, a comprehensive student support program called Educating Engineering Students Innovatively (EESI) was created. The program directly addresses some of the issues outlined in the above study that black students may face in completing their pre-engineering program. The

program builds on an Engineering Living Learning Community (LLC), which provides social structures that create a safe shared community incorporating a supportive academic and co-curricular environment [4]. These types of support programs increase a student's sense of belonging in college [5]. However, EESI takes things one step further by incorporating experiential learning opportunities coupled with financial support, which changes students' personal income and builds an engineering identity. These factors not only create support in areas that alleviate external barriers, which assist black students' retention in college, but the program opens up opportunities to better prepare students once they graduate college to be ready for the STEM workforce and/or graduate school.

Some studies show that experiential learning can positively impact participants, but few focus on black students and even less on a Historically Black College and University (HBCU). Consequently, this research highlights the impact of a structured community experiential learning experience on underrepresented minority engineering students, majority black. This study will focus on students who participate in experiential learning held at an HBCU to determine the program's impact on their persistence from sophomore to senior year. It also provides insight for Predominantly White Institutions (PWIs) and other institutions to learn and model best practices for retaining black students beyond their freshman year.

B. Overview

After successfully retaining students from their freshman year to their sophomore year with an Engineering LLC, in 2017, Florida A&M University (FAMU) introduced an experiential learning program titled Educating Engineering Students Innovatively (EESI, pronounced "easy") that expanded on the freshman support program to retain underrepresented minority students from sophomore year through senior year. The EESI cohorts consist of a subset of students that actively participated in the Engineering LLC. The primary purpose of the EESI program was designed to: (1) inspire and motivate undergraduate students to practice engineering, (2) provide community engagement, and (3) reinforce their fundamental engineering knowledge in an environment designed to foster a better college experience. Ultimately, creating a safe space that includes support structures that aim to retain students in engineering, heighten their interest in engineering, and provide the tools necessary to excel in college and later in the STEM workforce and/or graduate school.

The main goals of the Educating Engineering Students Innovatively program is to

1. Remove some of the external barriers of black college students that make them leave college
2. Have students successfully complete the pre-engineering curriculum
3. Assist with second and third-year retention and equip students with the knowledge to persist in engineering
4. Build students' technical skills and engineering design capacities to make them attractive in the STEM workforce and/or graduate school

5. Incorporate professional development to ensure the scholars are ready for the STEM workforce and/or graduate school
6. Develop students' character and accountability
7. Impart a sense of pride and confidence to create an engineering identity

Components of the Educating Engineering Students Innovatively

Currently, the college has two student support programs designed to assist freshmen students in transitioning from high school to a university: the Engineering Concepts Institute (ECI) Summer Bridge Program [6] and the Engineering Living Learning Community (LLC) [4]. These two freshmen programs have shown that active student support of underrepresented minority engineering students can ensure they are retained to their sophomore year. However, before 2017 there was not the same level of intentional support at the college to encourage sophomore or second-year pre-engineering students to continue until graduation. The EESI program is designed to fill that gap, building upon the prior ECI and Engineering LLC successes to engage students from sophomore to senior year, ensuring an "easy" journey.

Student Selection

Because the students are selected from a pool of students that participated in the Engineering LLC program, there is a wide variety of demographic of students, which allows for an inclusive environment. The decision creates a larger pool of applicants instead of eliminating particular groups. As presented later in Table 1, the student demographics are similar for each group analyzed.

During students' freshman academic year, they are evaluated during their participation in general meetings, team-building activities, and community service. The requirements for entry into EESI is active participation in the Engineering LLC and an application that includes an essay. The students are not reviewed on their academics, but on their motivation to become an engineer and their active participation in the Engineering LLC. This means the program focuses on the whole student, not just their academics.

Essay Prompts in Application
Why are you interested in an engineering degree, and what are your plans once you earn that engineering degree?
What lessons have you personally learned from Engineering Concepts Institute and/or the Engineering LLC program?

Program Elements

The Educating Engineering Students Innovatively program, which spans the fall and spring semesters of the academic year, allows sophomores to seniors the ability to participate in one of four different tracks: Entrepreneurship and Innovation, Industry, Research, or Engineering Projects in Community Service (EPICS). Students spend one day a week in meetings learning general topics: user-centered engineering design, engineering ethics, project management, teamwork, technical presentations, etc. Depending on the track students select, they would participate in additional technical skill sessions to assist with their specific projects. The sessions are designed to provide instruction in various technical topics directly related to their project or interest. Student groups meet outside of the normal meetings to work on their projects as a team and/or with their faculty lead. Below are several components of the EESI program.

a. *Group Meetings:* Students work in groups on a track that interests them for a semester. Below is a description of each of the tracks.
    a. *Entrepreneurship and Innovation*: More and more Gen Zers have no intention of working for a company after graduation. As such, there has been a push to create an engineering curriculum incorporating innovation and entrepreneurship as early as students' sophomore year [7]. In this track, students form groups to develop an innovative concept to compete in entrepreneurship and innovation competitions. They determine major pain points that plague certain users. As a result, the students develop a potential solution and/or prototype considering the market and user in the engineering design process.
    b. *Industry*: Similar to a senior design capstone project, an industry-sponsored project allows underclassmen to engage early in the engineering design process. Each project has milestones that the students must complete throughout the year. There is an industry technical advisor that meets with each group, as well as a technical lead at the school to ensure deliverables are met. The advantage to this track over senior design projects is that because not all students are seniors, companies can introduce multi-year projects that better align with real-world conditions.
    c. *Research*: There have been focus groups on underrepresented minority science students that show those participating in a structured research program take on a "science identity" and are more likely to persist in their major [8]. Similar to other structured research programs, EESI students work in laboratories with faculty on the latest cutting-edge technology. However, the faculty are selected to ensure they have a passion for underrepresented minority student success and that their lab extends the safe space concept.
    d. *Engineering Projects and Community Service (EPICS)*: This track is a program created at Purdue University where students participate in engineering service-learning projects. Service learning (sometimes called community engagement)

has students solve problems related to social impact. These types of projects have shown a great deal of improved retention, especially for female engineering students [9]. They allow students to experience first-hand how engineers benefit mankind.

b. *Technical Skill Sessions:* Since the program starts with sophomores, some students have not started taking engineering-level coursework. Introducing technical skill sessions allows students to confidently work on their respective projects while building their technical toolbox for the after-college workforce. These sessions can also bring key engineering terms into context that students learn in their core coursework. Sample topics include MATLAB, Python, material science, and entrepreneurship sessions.
c. *General Sessions:* Students spend time each week as a cohort, no matter their project, on general topics: professional development, engineering ethics, project management, teamwork, technical presentations, etc.
d. *Mentorship:* Students are matched with a mentor from either academia or industry. These mentors are evaluated to determine if they will be a good fit for their mentees. The mentors also go through training at the beginning of the year.
e. *Study Sessions:* Students participate in sessions for their respective science and math courses. Upper-level students are hired to lead the study sessions. Students utilize active learning techniques to communicate math and science concepts. This component of the program provides academic support.

Demographics of EESI Students

Between 2018 - 2021, the EESI program has had about 20 unique students participate in each academic year. This paper will analyze three (3) groups of sophomore students. The first group, the general engineering students (180), participated in no structured engineering support program during their time at Florida A&M. As defined in this paper, the Engineering LLC students (69) are the ones that only participated in the structured engineering freshman support program and did not participate in a support programs any of their latter years. The EESI students (76) are those that participated in the Engineering LLC freshman year program and at least one year of the structured upperclassman support program their sophomore year. To summarize, general engineering students have zero (0) years of structured student support, Engineering LLC one (1) year, and EESI at least two (2) years of structured support. As depicted in Table 1, the EESI students are comparable to other sophomore FAMU engineering students. This table shows that not just the "best" students were selected for the EESI sophomore-year support program.

The data in Table 1 shows sophomore engineering students (new cohort) entering FAMU, between 2017 and 2020, as first-time in college freshmen (original cohort). There are a few differences between the three groups. A higher percentage of female engineering students participate in the EESI program. Additionally, there is slightly a higher percentage of Pell grant eligible, first-generation, and instate residency students in the general population student cohort. The aspect that is similar in the three groups is the high percentage of underrepresented

minorities (> 95%). There are comparable high school GPAs (Δ1) and both the math ACT (Δ1) and SAT (Δ7) test scores. The groups have similar high school profiles, but both EESI and Engineering LLC students have higher first-semester freshmen GPAs and ALEKS math assessment scores. This can be expected since both groups participated in freshmen support programs, while the General Engineering Students did not [4]. The common high school preparation allows for unique analysis, since it has been long believed that high school performance and/or first-term GPAs are good predictors of persistence. Since the high school preparation is similar for all three of the groups and the first-semester college GPA is similar for two of the groups, the only varying factor is the level of structured support provided throughout students' college years. Hence, it allows for a study with a distinct control group and two variable groups that only vary in the experiential learning sophomore program.

Table 1. Comparison of EESI, Engineering LLC and General Population Engineering Students Demographics and High School and College Performance Profile, 2018-2021.

	EESI Students	Engineering LLC Students	General Engineering Students
	Cohort Size		
Original Cohort (FTIC [2017-2020])	157		351
New Cohort (Sophomore [2018-2021])	76	69	180
	Demographics		
Gender (Female)	40%	28%	31%
Race (Black)	95%	90%	91%
Race (Hispanic)	3%	6%	4%
Pell Grant Eligible	45%	52%	57%
First Generation	14%	13%	22%
In-State Residency	61%	65%	79%
	Performance Profile		
1st Semester College GPA	3.4	3.2	2.7
High School GPA	3.3	3.1	3.2
SAT Math	570	563	564
ACT Math	23	22	22
ALEKS (Highest)	63	62	51

C. Results

The outcome of the EESI program components creates a safe environment that produces good academic performance.

Second Semester GPAs

The second-term average GPAs of the cohorts between 2018 and 2021 were compared among the three groups. As shown in the demographics section, all three groups start with similar high school preparation. However, with the freshman student support programming described [4], the EESI and Engineering LLC students outperform the general engineering students in their first term GPA by nearly 25%. Figure 1 shows the sophomore (fall semester) GPA of the students retained in engineering. Please note that students that were in engineering their freshman year and switched out of engineering are not included in Figure 1. This study only investigates students in their sophomore year (2018-2021), but each group has students that did not persist to year two. Table 1 shows that the general engineering student group has nearly a 50% reduction in the cohort size of students retained in engineering, from freshman year to sophomore year, while the Engineering LLC and EESI group kept over 92% of their cohort size. This is provided for benchmark purposes only. The freshman year will not be analyzed in this paper, because a previous study detailed some of the factors that lead to discrepancy in first-year retention [4]. Figure 1 shows that the average GPA of Engineering LLC and general population students are never higher than the average GPA of the EESI students. The average sophomore-year GPA of general students is similar to that of Engineering LLC students who did not have sophomore student support. Still, a larger percentage of freshmen Engineering LLC students were retained in the engineering major than General Population engineering students, which could have left students in their sophomore year with higher GPAs in the engineering major.

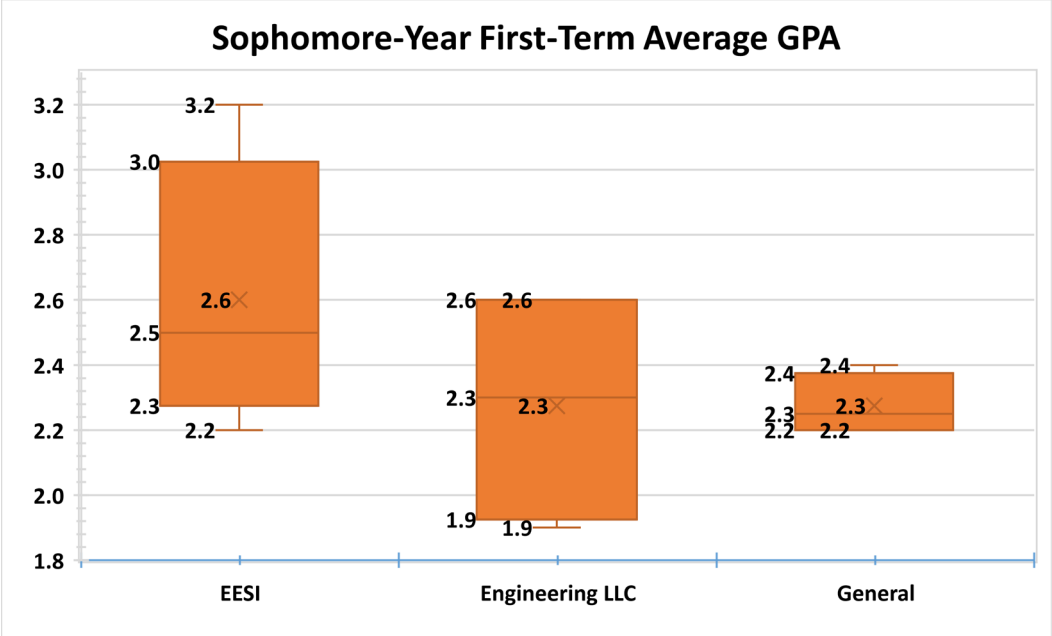

Figure 1: The sophomore year first-term average GPA of engineering students

Pre-Engineering Course Completion

At this university, all first-time students are granted entry into the FAMU-FSU College of Engineering as pre-engineering majors. The college created the pre-engineering program requirements based on courses in all engineering students' curriculum: First Year Engineering Lab (FYEL), Calculus I, Calculus II, and General Physics I (or General Chemistry I). After passing all four (4) pre-engineering required courses, students become engineering majors depending on their major. Students can only fail one class two times or two courses. In this case, the students can be considered for entry with other course evaluations. However, if a student fails three times and/or three courses, they must choose another non-engineering major. A previous university study found that only 10% of freshmen that do not start in the freshman support program (General Students) start in Calculus I, and 27% of students that participate in the freshman support program (Engineering LLC and EESI) start in Calculus I [6]. As such, it takes over 70% of incoming freshmen more than two semesters to fully complete the pre-engineering curriculum and declare their engineering major. A previous study determined that students who can get through the pre-engineering curriculum are more likely to graduate in one of the engineering majors [1].

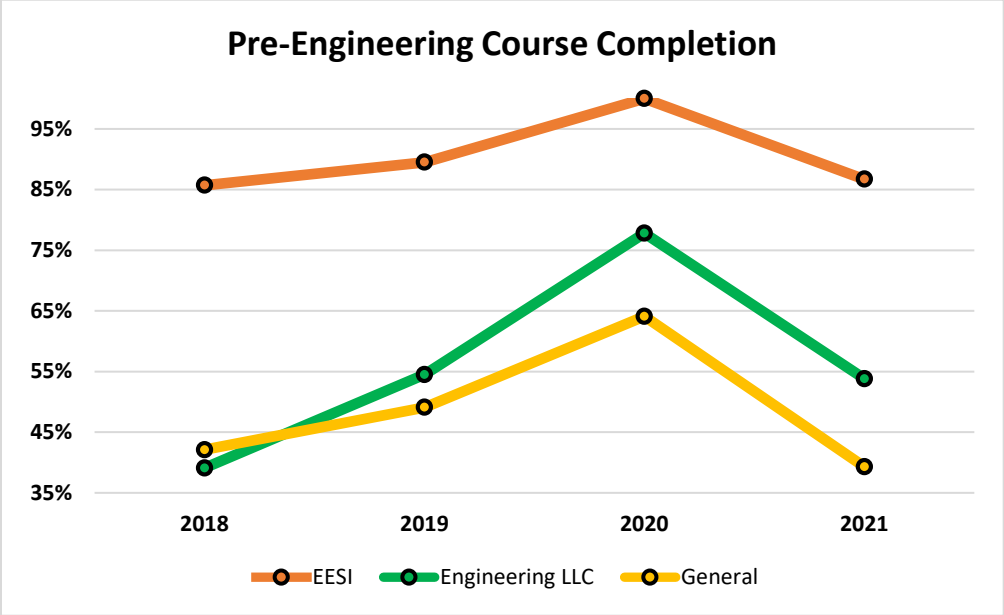

Figure 2: Pre-Engineering course completion between 2018-2021 cohorts

Based on this previous study, a key purpose of the EESI sophomore student support program was built around getting the students through the pre-engineering curriculum. Figure 2 shows the percentage of students in each cohort that successfully finished the pre-engineering curriculum and were granted permission into the engineering program. On average, students who participated in EESI have a pre-engineering completion rate of 88% over the four-year span. In

comparison, both Engineering LLC and General Engineering students have less than 57% average pre-engineering completion rate. In the year with the highest deviation, 2018, there is nearly a 50 percentage point difference in the completion. Please note that because it takes some students more than one year to complete the pre-engineering curriculum, the 2021 cohort's percentage can become potentially higher for each group since students are still matriculating.

Retention

The next comparison of academic performance is student retention from fall to fall. For example, a student in the 2018 cohort is considered a successful retention if they are enrolled in school in fall 2019 by the 5th day of classes. In Figure 3, the first tier (orange) are students retained in engineering majors offered at the FAMU-FSU College of Engineering (COE). Those majors include electrical, computer, mechanical, industrial, civil, environmental, chemical, and biomedical engineering. The second tier (yellow) are students retained in STEM majors other than those offered at the FAMU-FSU COE, such as computer science, engineering technology, and biological agricultural systems engineering, etc. The combination of tier 1 (orange) and tier 2 (yellow) is the retention of students in a STEM major. The third tier (green) are students enrolled at FAMU, but in a non-STEM major. The total of all three tier colors is the percentage of students retained at FAMU in any major.

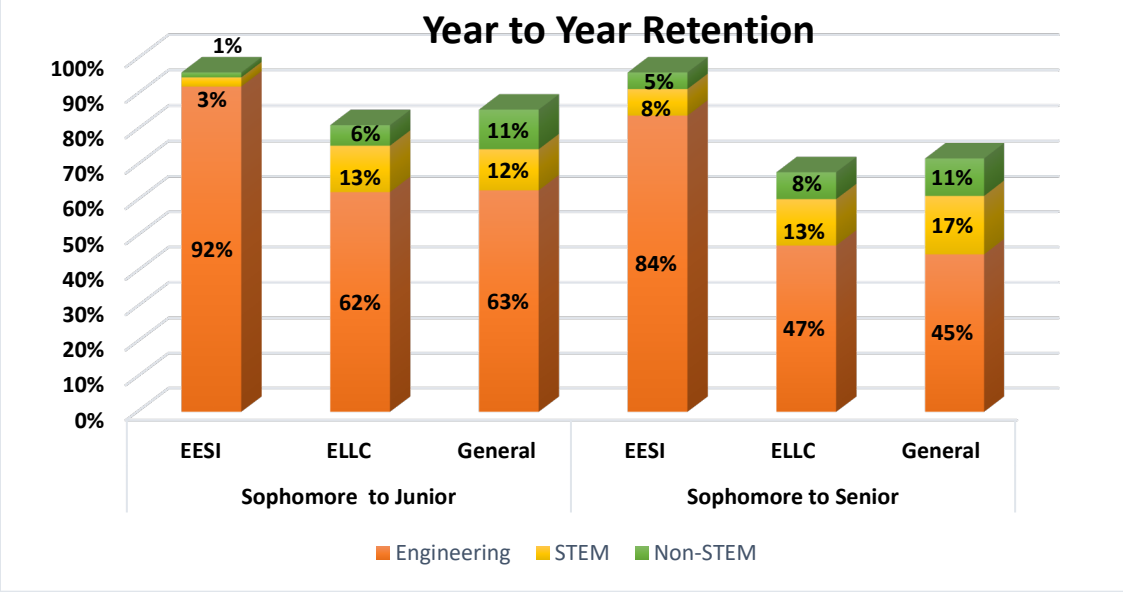

Figure 3: Fall-to-Fall Retention of Engineering Students

This study investigates students retained to sophomore year in engineering and tracks them to their junior and senior years. There is a noticeable difference in the second-year to third-year

retention of both the Engineering LLC students and general population students. Going from sophomores to juniors, about 60% of students are retained in engineering for both groups, roughly a 30 percentage point difference from EESI. Then, from sophomore to senior year, a little over 45% of the students remain in engineering for both groups, roughly half the percentage points than EESI. This shows that experiential learning experiences provide a substantial difference in upper-level retention.

In order to further determine the impact the experiential learning program had on students, a Bayesian statistical analysis was performed to estimate the probability of being retained in an engineering major from the sophomore to the junior and senior years by the program. The analysis utilized a binomial distribution model and measured the 95% Highest Density Credibility Interval (HDI) [10]. HDI plots for the retention probabilities are given in Figures 4 and 5. Non-overlapping HDIs imply that the difference in outcomes can be considered statistically significant [11]. The "dot" on each plot indicates the most likely retention probability. The figures provide the HDI of all three (3) cohorts of engineering students. Only the EESI (orange) group has no overlap with any other group. As such, the students participating in the EESI program were more likely (statistically significant) to be retained in their junior (0.9) and senior (0.65) years compared to the other two programs. In contrast, there was not a statistically significant difference between Engineering LLC students and general population students. The model predicts that students in either of these programs were just as likely to be retained into their junior and senior years.

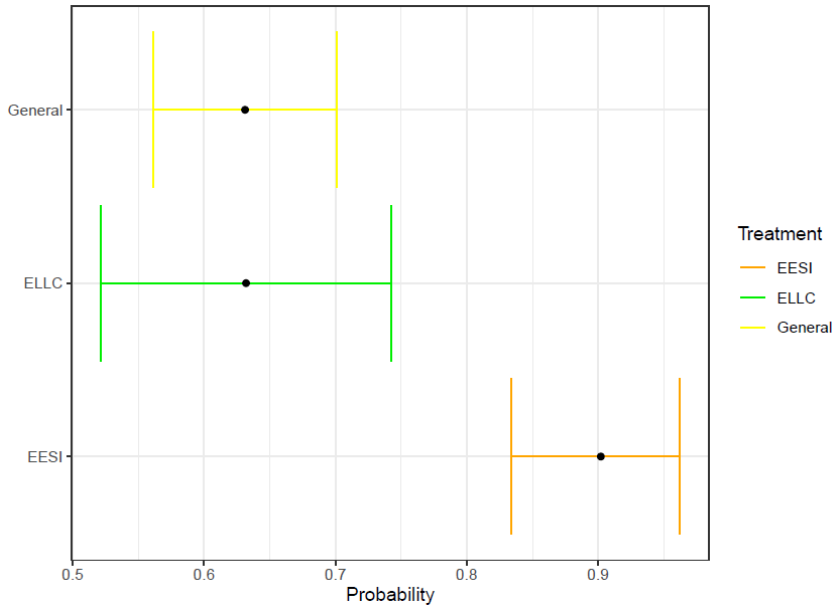

Figure 4: Probability of Retention in Engineering From Sophomore to Junior Year

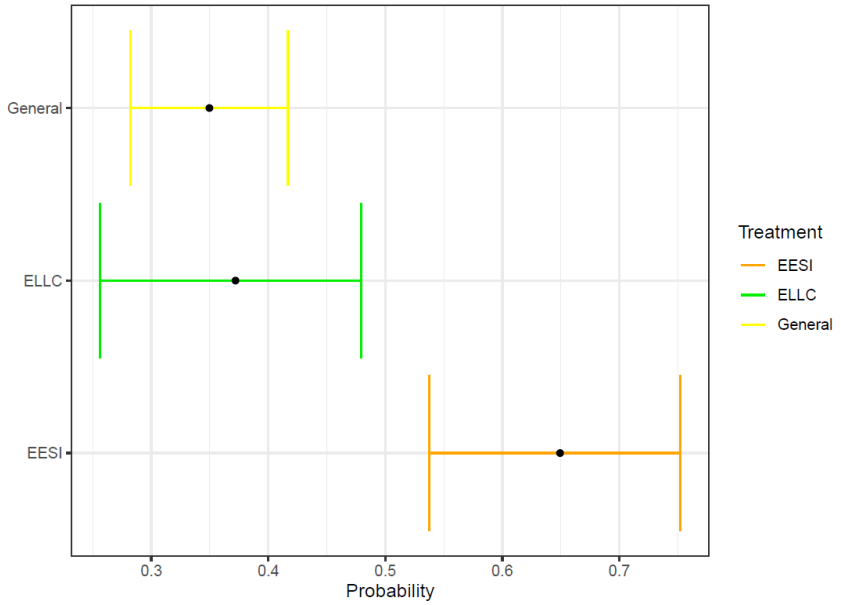

Figure 5: Probability of Retention in Engineering From Sophomore to Senior Year

D. Discussion

There are some key takeaways from the EESI program. First, experiential learning intertwined with academic support is necessary for this demographic of students. Introducing projects that interest the students and actively scaffolding them through the engineering design process builds their confidence and vision of life after graduation. At the same time, academic support increases students' math and sciences aptitude for students that did not come to college "engineering ready" as defined in [4]. By keeping the cohort together from their freshman year to graduation, the program ensures a safe space where students can encourage and motivate each other. Additionally, only faculty, staff and industry partners that are trusted allies engage with the students creating a community where students flourish.

Several elements of the EESI program are beneficial to engineering students. Presently, most engineering curricula provide students with fundamental knowledge and skills to become engineers. However, the concepts are taught in seclusion, which makes the material difficult for students to understand the relationship between various engineering topics. Studies have shown that individuals learn best when actively participating in the learning process [12]. The EESI program is designed to bring some clarity to students by actively demonstrating how various course material "fits together." The students learn skill sets to make them marketable in today's workforce: teamwork, critical thinking and communication. Additionally, the program introduces new concepts and topics students will need to be successful in future engineering courses.

Usually, active undergraduate student engagement/participation programs focus on one area. The problem with most of those types of programs, for instance, research experience for

undergraduates (REU), is that only a small percentage of students are interested in research and/or a limited number of spots are available in a research lab for undergraduates. For universities where an REU or undergraduate research is the only option for active learning, this could lead to students not participating in any research or participating and having a disappointing experience. On the other hand, the Educating Engineering Students Innovatively program allows students to take control of their engineering college experience. At the same time, faculty can engage more students and easily scale up the number of students that can participate.

The precursor to EESI was an independent studies course. At that time, there was no funding available, and students participated voluntarily. By 2018, the official start of the EESI program, there was one company that provided both funding and an industry project. This allowed students to receive funding, so it reduced the number of students that had to seek employment outside of FAMU. Moreover, by 2020, a federal NSF S-STEM grant was acquired in addition to other industry partnerships that provided additional funding and the ability to ensure no students had to work outside of FAMU, which reduced students' financial needs and heavily increased retention and average GPAs.

E. Conclusion

The EESI program has varied over the years with the change of funding offered, which led to the ability to meet goal (1) of the program. However, the core concept of incorporating experiential learning with academic support has been the same to ensure that the seven (7) program goals are met. The quantitative results in this study show that the EESI students are retained at a higher rate than the other two groups, meeting goal (3), along with goal (2) of the pre-engineering program completion. It can be expected that the EESI program participants have a higher retention rate since the study shows they have a higher number of students that completed the pre-engineering program, while a previous study showed that those that make it through the pre-engineering program have a higher likelihood to graduate. It should be noted that both the EESI students and the Engineering LLC students started in a living-learning community their freshman year, which was able to help students persist to their sophomore year in a shared living space that created a sense of shared struggle and “family” environment in ways that the general engineering population did not experience. Still, only the EESI students that obtained experiential learning experiences, along with financial and academic support, weaved in with professional development, were able to navigate to their senior year in large numbers.

The quantitative data shows how the EESI program impacts participants academically compared to students who only participate in the freshman support or general engineering population. The EESI program assists with retaining students in engineering by using their passion as a catalyst to learn about engineering. The program makes the most significant impact on the retention of students in the second year of the “pre-engineering” program. The program has some positive

effects on student retention. However, the program can improve by increasing the academic support beyond the pre-engineering courses, potentially improving the second-term GPAs to be higher than a 3.0 GPA. This will make the students more marketable for the STEM workforce and/or graduate school after graduation.

It should be noted that even though Engineering LLC and EESI students only made up 31% of the first time in college freshmen in the original cohorts, Table 1, by the sophomore year (new cohort), they made up 45% of the universities engineering student population and 50% of the population by junior year and 55% by senior year. This further shows how the program has affected the total number of black students graduating from the university when a program that services a smaller subset of the population in the freshmen year ends up being the majority population by the senior year.

Even though, goals (4), (5), (6), and (7) are currently incorporated into the EESI program. For the next steps, a study will be introduced to evaluate how effective the program is at accomplishing them. Interviews and survey data will be analyzed to determine which factors, such as students' EESI track selection (i.e., entrepreneurship, industry, research, EPICS), affect their post-graduation path and the student's beliefs in how prepared they are to enter the workforce. Additionally, interviews will be conducted with students to determine the aspects of the program that directly impacts the other goals, such as accountability, creating character and engineering identity.

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