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Board 339: NSF S-STEM: Educating Engineering Undergraduates to be Intrapreneurs

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NSF S-STEM: Educating Engineering Undergraduates to be Intrapreneurs

abstract

The Tech Intrapreneurs Program (TIP) program focused on developing intrapreneurship skills and competencies in undergraduate Engineering students. Intrapreneurship is the practice of developing a new venture, product, or service within an existing organization. Engineering-focused companies require a diverse workforce that is capable of innovation and many students will not join these types of firms in as their first employer post-college. Intrapreneurial skills have been shown to facilitate career progression and improve managerial skills and opportunities. In order to address the need for more STEM workers to have intrapreneurial skills, TIP recruited and enrolled academically talented and diverse electrical and computer engineering undergraduate students. TIP provided a multi-faceted approach to improve entrepreneurship skills. Specifically, the program combined faculty and industry mentorship, workforce development seminars, an industrial internship, entrepreneurship programs, and scholarships (provided by NSF and an industry partner) to produce graduates with intrapreneurship competencies. A total of 68 scholars in four cohorts were admitted to TIP. Scholars, hiring managers, and mentors were surveyed on topics to reveal the efficacy of the program. Both qualitative and quantitative data were collected. This paper presents data on the growth in intrapreneurship competencies for each of the cohorts of students, data on mentoring practices that were integral to the TIP experience, as well as student and mentor perception data on the benefits of the program.

introduction

This paper examines the outcomes of a National Science Foundation sponsored Scholarships in STEM (S-STEM) program. This S-STEM program (TIP) was designed to produce intrapreneurial graduates, many from traditionally underrepresented groups, who were prepared to be innovators and managers in industry. An intrapreneur is someone who is entrepreneurial within an existing organization. The combination of faculty and industry mentorship, workforce development seminars, an industrial internship, entrepreneurship programs, and scholarships produced graduates who were sought after by various engineering sectors. Industrial partners provided mentorship, funding, and employment to the scholars.

The project incorporated evidence-based practices and previous research that had shown that:

1. Mentoring is vital to foster underrepresented groups' retention in undergrad courses, graduate school, and the professional workforce [1]. [2]
2. Student persistence is facilitated by mentors [3], [4], [5], [6], rigorous curriculum, and multiple opportunities to engage in real-world work contexts.
3. STEM identity is created through real-world experience in and connections to the STEM workforce; STEM identity is a strong and leading indicator of retention and advancement in the STEM workforce [7].
4. Experience with STEM innovation as an undergrad fosters entrepreneurship and innovation after graduation [8].

5. International experience as an undergrad facilitates preparation for the global STEM workforce [9].

project context

TIP enrolled undergraduate students in the Electrical and Computer Engineering Department (ECE) at Texas Tech University (TTU). Funding from the National Science Foundation Scholarships in STEM (S-STEM) program and financial gifts from a semiconductor company funded the student scholarships and other project costs. TTU is a public university in Lubbock, TX which has a total enrollment of ~40,000 students. ECE has approximately 600 undergraduate students classified as either Electrical Engineering or Computer Engineering majors. Table I lists the ethnicity for the Fall 2022 semester in ECE. Female students are ~ 15% of the ECE undergraduate enrollment.

TABLE I. Ethnicity of all ECE Students (Fall 2022)

Ethnicity	Count	%
White	253	43.2
Hispanic	124	21.2
Black or African American	39	6.7
Non-Resident International	105	17.9
Two or more races	26	4.4
Asian	33	5.6
Other	6	1.0
	586	100

recruiting diverse cohorts

A multifaceted approach was taken to ensure that every eligible ECE undergraduate student was made aware of the program. The multi-pronged recruitment approach included posting fliers, emailing the fliers to every student that met the eligibility criteria, faculty presentations, peer recruitment, and information provided one-on-one by the ECE undergraduate advisor.

TABLE II. Ethnicity and Gender of Cohorts

	Cohort 1	Cohort 2	Cohort 3	Cohort 4	TOTAL	%
Hispanic Female	4	2	2	4	12	18.1
Hispanic Male	3	1	5	1	10	16.7
Black Female	1	1	1	0	3	4.5
Black Male	0	1	4	3	8	12.1
White Female	3	6	1	2	12	18.1
White Male	5	4	3	3	15	22.7
Asian Female	0	0	0	1	1	1.5
Asian Male	0	3	1	1	5	7.6
TOTAL	**16**	**18**	**19**	**15**	**68**	**100**
Graduated	15	14	8	2	39	57.4
Active	0	0	6	11	17	25.0
Left Program	1	4	5	2	12	17.6

In total, TIP scholars were ~42% female compared to 15% in the ECE department. ~35% were Hispanic compared to ~21% in the department, ~21% Black compared to 6.7% in the department, and ~9% were Asian compared to 5.6% in the department.

components of the program

The program combined scholarships, with faculty and industry mentorship, workforce development seminars, an industrial internship, and participation in entrepreneurship programs. We will discuss observations and outcomes for each of these areas. The following discourse analysis methods were used.

Open coding (Blair, 2015; Hennessey *et al.*, 2020; Huber and Froehlich, 2020) was conducted to comb through the thank you notes and the mentoring reports. Each text was read multiple times, and themes were generated across each grouping of reports or thank you notes. For example, all the mentoring reports from Cohort 1 in Spring, 2020, were read as a group, coded, and then themes were generated using that grouping of texts, and that grouping alone. Thus, there were different themes that were developed in the thank you notes from Cohort 1 versus the mentoring reports from Cohort 1. Likewise, there were different themes from the mentoring reports from Fall, 2020 from Cohort 1 versus Cohort 2. We believe it is important to separate both the types of texts (mentoring reports and thank you notes) as well as the cohorts and timeframes to access possible differences among cohorts and semesters when the conversations occurred.

Thematic Coding (Gibbs, 2007; Vaughn and Turner, 2016) was then done by taking the themes (created from codes) for each set, and then re-analyzing each set using the themes as a lens to re-examine the text. Repetitive analysis allowed us to hone the codes even further. After that process, the text was analyzed to count how many discrete times the code emerged in each of the reports or thank you notes within a given set.

Thematic Occurrence Counting (Ryan and Bernard, 2003) allowed us to generate the data that were used for the analysis.

a. scholarship

NSF supported students were awarded up to a $10,000/year scholarship based on their need as determined by FAFSA and the financial aid office. COVID related loss-of income for some scholar's families caused higher financial need which was not reflected in FAFSA. The average need for NSF supported students: Cohort 1 ~$18,750; Cohort 2: ~$24,000; Cohort 3: ~$24,000; Cohort 4: ~$30,500.

As can be seen from the need values, there was substantial need in each of the cohorts that rose dramatically over the four cohorts, in part due to loss of financial opportunities for participating students and their families. The students submit a thank you note that frequently spells out how important the scholarship is to their ability to continue on in school, graduate, and get a well-paying engineering position. Below are some excerpts from the thank you notes describing what the scholarship has meant to the students.

> *"When I was younger my dad died when my mom was only making $7 an hour. Seeing my mom go through so much stress and have to basically give her all to*

make sure her two children succeeded and never went hungry. My mom juggled numerous jobs from being a healthcare administrator and caregiver whilst also running a side cleaning business to ensure she never missed a major bill. Seeing my mom go through all that showed me that money is not something to be taken lightly. My mom has had to tackle numerous hospital bills whilst attempting to put 2 children through college which is not a soft feat. Seeing my mom work 2x as hard just to make sure we were even able to make it paycheck to paycheck opened my eyes. The scholarship I've been given gives tremendous help to my family and especially me. I'm forever grateful for every penny that has been given towards my cause." – Cohort 4 Student

"Being a college student living independently means expenses can be high and that sometimes it can be challenging to make ends meet despite working as much as I can. The Tech Intrapreneurship Scholarship has greatly helped me with affording monthly expenses, which in turn means that I don't have to worry so much about my finances and I can focus more on my academics." – Cohort 4 Student

"I am a first-generation student, due to my parents not graduating high school and not attending college. It is not a family tradition to attend a university, but I hope to change that to push future generations of our family to attend college. An internship allowed me to save during the summer to help me pay for my tuition, books, and necessities. Without this scholarship, I would not be able to afford tuition because I rely on scholarships to attend college, since my parents cannot afford the tuition. I am incredibly grateful for this scholarship because it has helped my family not to have to worry about more financial responsibilities. I still must work, but I am able to work fewer hours due to this scholarship. I can focus on my studies more because of this scholarship opportunity." – Cohort 4 Student

It is quite clear from these letters that the scholarships are fulfilling their intent and allowing under-resourced students to persist in their studies, while being in a better position to take advantage of academic and research opportunities.

b. mentorship

Students enrolled in the program were required to have both a faculty mentor and an industry mentor. Each month, students submitted a written report that summarize the discussions that occurred during their mentor meetings. Students were only given general suggestions on what to discuss during the meetings. The mentors were not provided with any stipulations, although some asked for suggestions on what to discuss. Thus, the direction and content of the conversations was open to the personal interests and concerns of the student and mentor (naturalistic inquiry method). Discourse analysis of the reports was used to better understand, over time, the nature of students concerns, how attitudes and expectations about internships progressed, and what the mentor advised to better prepare the student for internships and permanent employment.

mentoring from the student's perspective

i. faculty mentors

Students were very appreciative of being given the opportunity to be mentored by a faculty member. Before being admitted into the S-STEM program, the majority of the students did not have strong interactions with any of the faculty. The engineering college has a common first year that is not taught by ECE faculty, so many underclassman in the program had very limited exposure to faculty and really didn't know many of them in a personal way. Many of the students were interested in understanding how their faculty mentors managed their schedules and what type of communication strategies were most useful for students when a student was struggling in a class.

Other topics of discussion with faculty mentors included:

- Finding time management strategies that were more effective for students.
- Achieving some career-life balance in their futures.
- Communication strategies with faculty (and advisors on campus).

When female students were being mentored by a female, the topic of low numbers of females in the ECE program and engineering workforce came up, in some cases many times. In male or mixed teams', gender related issues did not seem to come up as a topic.

A number of the students have gone to work in the research labs of their mentors which has led to more interest in doing graduate research and being better positioned to obtain an internship at a national lab. In all cases, it was the students' initiative, not a program requirement, to seek undergraduate research opportunities.

ii. industry mentors

Industry mentors were asked to explain their current roles within their company, as well as former roles and education background. This provided an opportunity for students to learn about how the mentor progressed and was promoted throughout their career. It also provided a chance for mentees to ask about the skills and training needed to go into management roles. Other topics included time management and how to handle difficult bosses. Other discussions were about technologies being developed at their respective companies and how these projects are organized and executed.

> "*My mentors that I have had during this program helped me tremendously by guiding me through challenging times during the semester and providing insight as to how I should move forward with my future.*" – Cohort 4 Student

The first two cohorts were most strongly affected by COVID-19 related issues. Thus, a primary theme that emerged from mentor reports was the effects of COVID-19; mostly how students thought about their coursework and how their industry mentors thought about their jobs. Although there was deep concern about the short and long-term impacts of COVID-19, the students expressed a sense of growth and learning in spite of the effects of the virus. Students self-reported that the S-STEM experience was still highly beneficial, even as much of the coursework and mentoring for the latter half of the Spring 2020 semester had to be moved online.

iii. mentoring from the mentor's perspective

Survey results showed that mentors frequently talked about working as part of a team and the general challenges of collaborative work. Mentors often discussed coursework recommendation, as well as work prospects and expectations within the engineering workforce.

When mentors were asked to reflect on the mentoring process, they focused on the types of actions and experiences that lead to a good mentoring relationship. The following are a few excerpts from those reflections.

> *"I think learning about a student's motivation on what they want to do and why they want to do, leads to a positive and engaging mentoring experience. It's a learning experience for me and it also helps to mentor student in a certain way rather than generic questions and answers. Different people have different life motivations and struggles and it's nice to know these to further help the students, or in certain cases help them avoid any misconceptions they have. Often time removing any mental barrier and giving them confidence in doing the right things is enough for really smart students."* – Industry Mentor

> *"I believe the students benefit from having a someone to bounce ideas off of. In my opinion, students have a lot of misunderstandings about the things that are expected of them from professors as well as industry. As an example, I have encountered countless students who are terrified of completing a master's degree, or are terrified of taking a certain job, because they feel that it is a lifetime commitment to that field. I hear things like, "If I take that job, I will have to work on embedded systems the rest of my life". Moreover, I think just forcing the student to take the time and formulate thoughts and arguments for their life-plan is invaluable. I feel like many of our engineering students get bogged down in their regular academic work to a point that they are not appropriately planning their future."* – Industry Mentor

When asked about whether or not they felt that these mentoring sessions were successful, there was an overwhelming belief that these sessions *were* not just successful but invaluable. Many reflected on the fact that these types of mentoring experiences should be much more common. Excerpts from the mentors' reflections are below.

> *"These mentoring experiences have been successful for students."* – Industry Mentor

> *"I do think they are successful. I think it's beneficial for students to see women (especially alumni) have engineering careers and offer advice and encouragement."* – Industry Mentor

The responses from the mentors strongly indicate that these mentoring experiences are vital for students to feel like they are becoming part of a larger community. Additionally, it was interesting to note how often the mentors talked about feeling validated or getting insights into their own careers or experiences by talking with these students.

workforce development seminars

The kick-off event for each cohort included a presentation by Dr. Larry Hornbeck, the inventor of the Digital Micromirror Device (DMD) which is produced by Texas Instruments and found in every cinema projector worldwide and most business projectors. Dr. Hornbeck served as the prime example of what it means to be an intrapreneur. He conceived the idea and started developing it while working on other projects at Texas Instruments. Because of his inspiration and hard work over three decades, the DMD has led to over $10,000,000,000 in cumulative sales for Texas Instruments. Dr. Hornbeck has won an Academy Award, Emmy, and many other technical achievement awards in addition to being inducted into the National Academy of Engineering. His presentation includes a detailed history of the development of the DMD and other associated technologies. Students receive a first-hand example of how challenging it was to be an intrapreneur and what it takes to bring a brand-new technology to market within an established company.

Weekly S-STEM seminars were an opportunity for the students to hear from engineering professionals about specific companies, job roles, and preparation required for job fairs. Each semester, speakers discuss a variety of topics that enhance the students’ understanding of engineering related industries. Engineers from Texas Instruments were frequent presenters, speaking on professionalism topics that included crafting a resume, interview techniques, and salary negotiation. Technical presentations included explaining the many roles within the semiconductor industry that rely on individuals with electrical and computer engineering training. Most students enter the program knowing that electrical and computer engineers are employed in large numbers by semiconductor companies, but do not understand the details of the various roles. Direct interaction with industry professionals is crucial for them to develop the understanding that will help guide the path they want to take into the semiconductor of some other engineering-heavy industry. Engineers from X-Fab, Burns and McDonnell, and other technology companies expanded the students’ knowledge of other job roles that require electrical or compute engineering training. Other presentations included an eclectic mix of ethics training, interpretation of artistic images (one of the student’s favorite discussions), and giving better presentation. The students especially enjoyed discussion topics that were much different than normal engineering classes. There was typically above average student participation in these classes.

c. industrial internship

Industrial internships can be a vital part of a student’s education. One of the main goals of the program was to strongly prepare students to compete for engineering internship opportunities. Students noted that the resume critiques, mock interviews, and discussions with hiring managers gave them extensive preparation. Unfortunately, the COVID-19 epidemic significantly curtailed internship opportunities, especially Summer 2020, and even through Summer 2021. Furthermore, the TTU College of Engineering had imposed a mandatory study-abroad program that further limited summer opportunities for internships. Many students were forced to choose to study-abroad, rather than take a paid internship. Although many students had a positive and beneficial study-abroad experience, the cost of the experience, coupled with a loss in summer income, negatively affected student finances on top of missing a possible internship opportunity.

Fewer than half the students who were Cohorts 1 and 2 were able to intern, but all program graduates in these Cohorts gained full-time employment or enrolled in a graduate program. The internship rate for Cohorts 3 and 4 is above 50% with most students in Cohort 4 having secured internships for Summer 2024. The remaining Cohort 3 students will graduate in May.

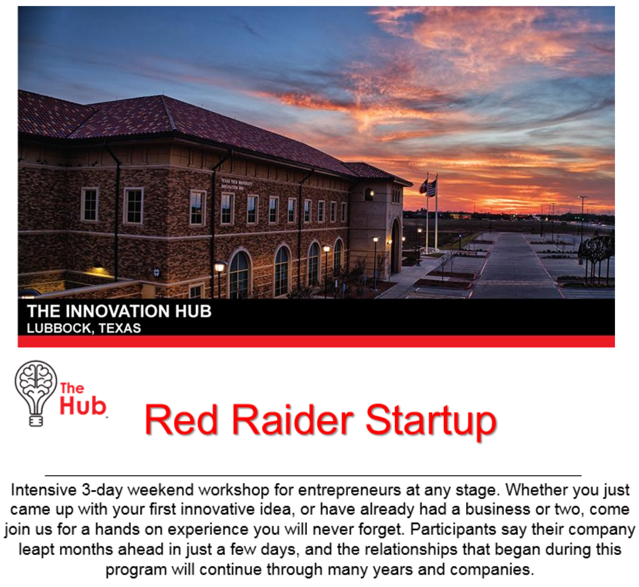

Figure 1. Innovation Hub and Red Raider Startup

d. entrepreneurship programs

Texas Tech's Innovation Hub (Figure 1.) provides a number of entrepreneurship programs that can be as short as a weekend (Red Raider Startup) or last a year (Accelerator). Each S-STEM student participated in at least one Red Raider Startup. The event is held over one weekend and involves entrepreneurship training sessions, ideation, team formation, customer discovery, and pitch presentations. NSF I-CORP materials, including the Business Model Canvas, are taught. Two times, TIP student-led teams won first place in the pitch contest. Below are some comments from the participating students.

> *"Attending Red Raider Startup was a good experience that helped build my teamwork, time management, and entrepreneurial skills."* - Cohort 4 Student
>
> *"Red Raider Startup always reminds me how hard it is to start an entrepreneurship alone but with the help of the innovation hub & by participating in their activities, they lift some of the weight off of you."* - Cohort 4 Student
>
> *"As always, Red Raider Startup was a really fun experience and allowed me to think outside the box and embrace the entrepreneur pathway."* - Cohort 4 Student

Although RRS is a long time commitment for one weekend, there has been a general consensus that it is an important activity to experience, especially if one has considered being an entrepreneur one day.

survey results

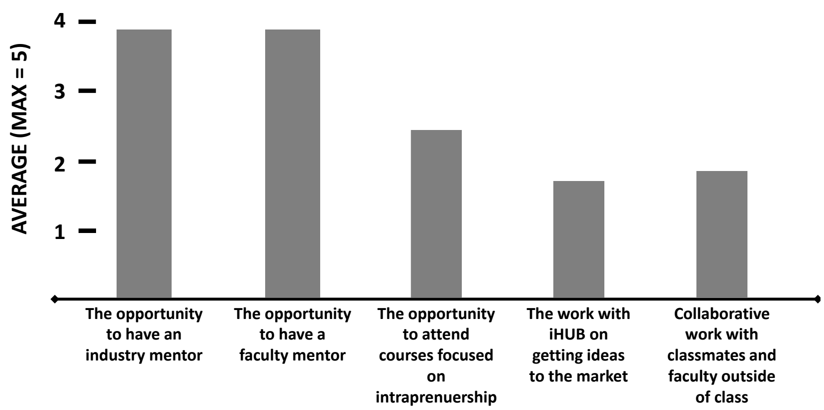

Figure 2. Graduates rating the importance of program components.

Graduates of the program were asked to complete a survey that asks them to rate which aspects of the program were most beneficial to them, provide open-ended responses to how the program benefitted them, and suggested areas to be improved or enhanced. To date, 15 students have responded to the survey. Graduates were asked to rank five aspects of the program. As shown in Figure 2 [10], having an industry and faculty member were noted as the most important aspect of the program. Collaborative work with classmates and working with the university's innovation hub were deemed the least important with courses focused on intrapreneurship falling in the middle.

Open-ended responses included the following

> *"As a cohort, we have participated in Red Raider Startup, the EOC Job Fair, as well as mentorships in industry. In seminars, we have guest speakers who tell us about the engineering field and intrapreneurship. All these experiences have been fantastic for my development and understanding of engineering and the engineering industry."* - TIP Student

> *"TIP has granted me so many opportunities with school and has even helped me set up an internship for the summer. This was due to the many connections I got to get with and also the mentor program that allowed us to look for a industry employee. This program taught me anything is possible and has given me an opportunity that I do not want to be taken away."* - TIP Student

Figure 3 [10] shows the extent graduates agreed that various aspects of the program were beneficial. All agreed that the scholarship was beneficial, which is of course no surprise. Many were in agreement with the other statements. Fewer than half of the graduates attained an internship, with COVID being a principal reason why there were limited internship opportunities. Most students believed that they had a better sense of the field of engineering as a whole as a result of the program. The majority noted that the program helped them complete the degree in a timely manner.

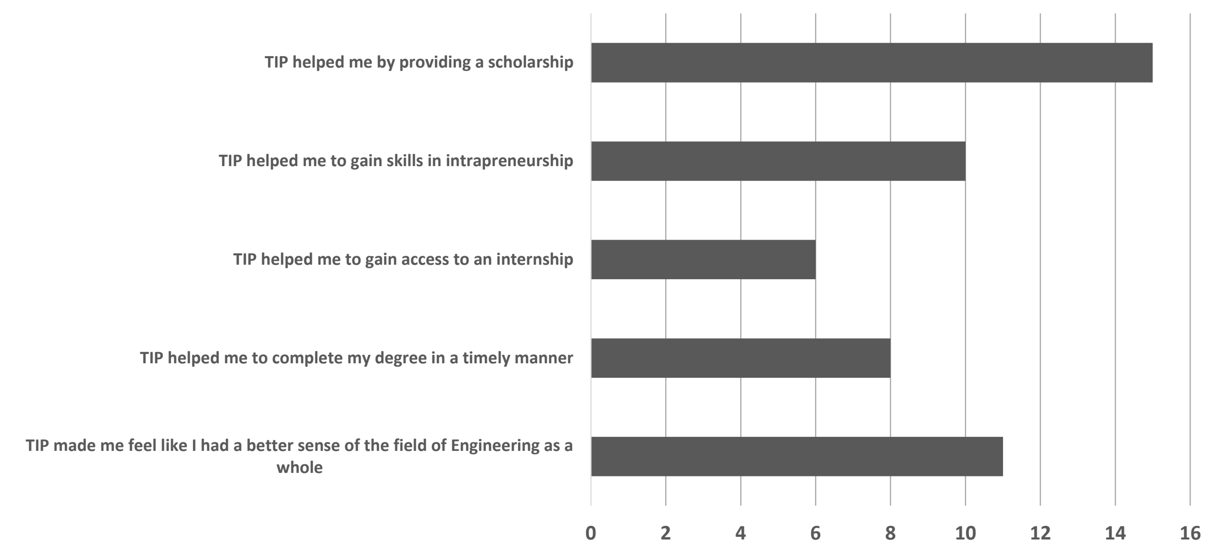

Figure 3. Survey of graduates who agreed with the statements.

Figure 4 [10] shows the responses of the graduates when asked to rate the importance of various outcomes of the program including engagement with the field of engineering, timely progression towards degree, access to internships, and gain intrapreneurial skills. Overall, engagement and connection was deemed the most important. Timely completion of degree varied in importance.

intrapreneurship tendencies

Each semester, students were asked to fill out the "Intrapreneurial Competencies Measurement Scale" (ICMS) survey by Vargas-Halabi *et al*.[11] at the beginning and at the end. The survey was used to measure and evaluate the development of intrapreneurial competencies, which include: (1) Opportunity promoter, (2) Proactivity, (3) Flexibility, (4) Drive, and (5) Risk-taking. Each of the categories of the ICMS is divided into 3-9 sub-categories to assess skill and mindset in the five general categories. In answering the questions on the ICMS test, students evaluated their proficiency in each of the areas. The survey questions are provided in the Appendix. Figure 5 shows the results of the survey for January, May, September, and December of Cohorts 3 and 4. The values reported are the average responses to each question.

The results show that there is a noticeable increase in intrapreneurial competencies

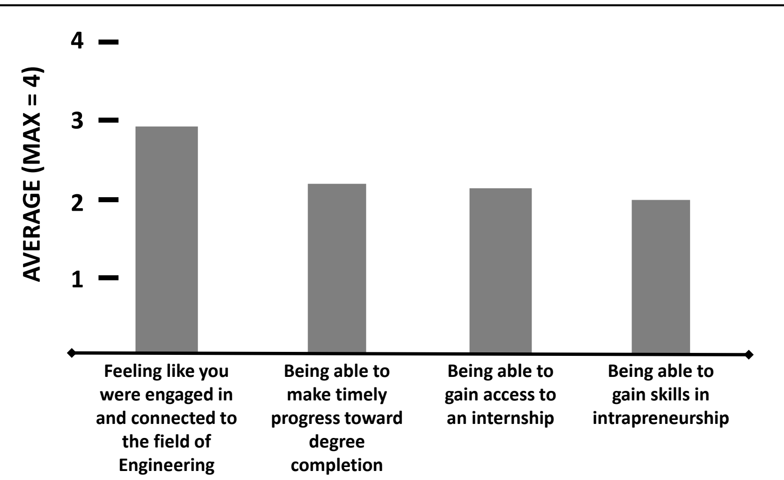

Figure 4. Student rating the importance of various outcomes of the program.

from January to December, but it does dip in the May and September responses. Additional work is being done to better understand the temporary decreases, but we speculate that it could be due to students going through a maturation process that includes gaining a deeper understanding of intrapreneurialism that leads them to question their own capabilities, before regaining confidence through internships and additional academic experiences.

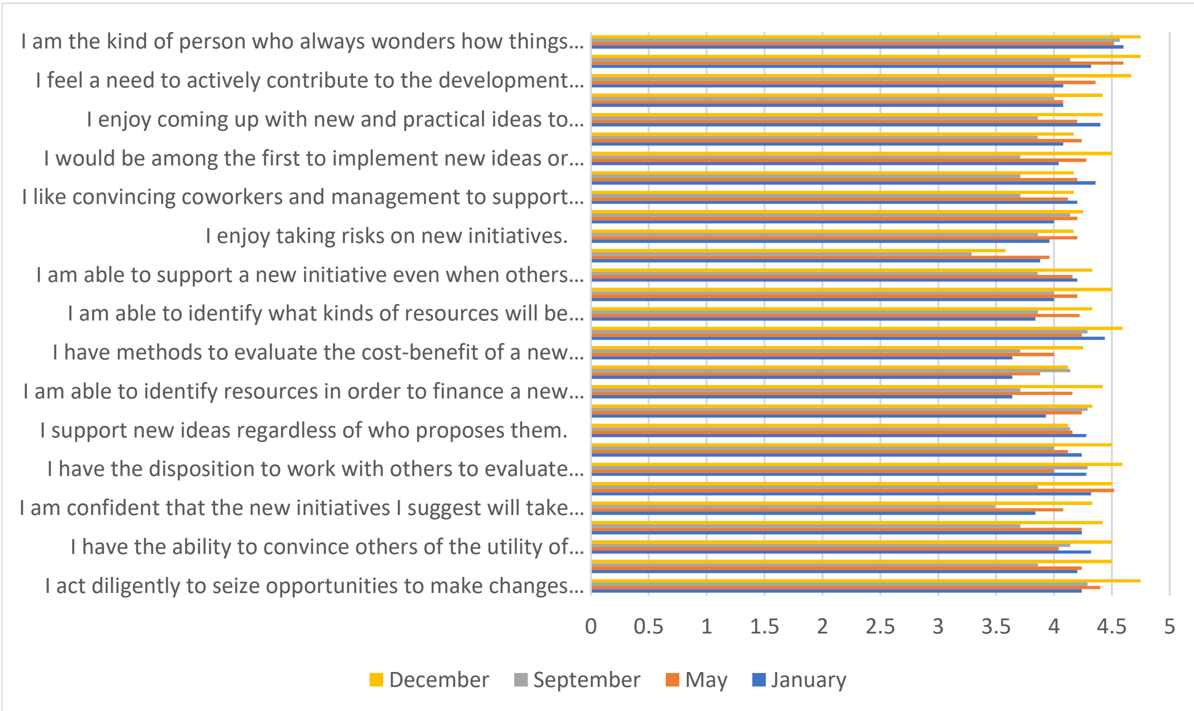

Figure 5. (ICMS) survey results for 2023.

conclusion

The Tech Intrapreneurship Program included four diverse cohorts of students. A concerted effort by advising staff, faculty, and students was needed to make this happen. Given the overall ethnic/racial and gender demographics of the electrical and computer engineering department and the field, the percentage of women and under-represented minorities in the program was very good. The surveys, mentoring reports, and thank you note responses of the students demonstrate that the program has been very worthwhile and has made significant contributions to the students' college careers and beyond. Mentorship by faculty and industry personnel were deemed as the most important aspect of the program, not including the scholarship. The generous scholarships provided by NSF and TI were the difference maker for student's being able to progress through their degree in a timely manner, gain research experience, and obtaining internships. According to student surveys, the program has increased entrepreneurial tendencies. Future work will include surveying more graduates after the 2024 academic year concludes, and more follow up surveys with mentors and hiring managers.

Appendix

Opportunity Promotor. *Please circle the answer that best matches your experience.*	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I act diligently to seize opportunities to make changes or generate new initiatives.	1	2	3	4	5
I ask questions that challenge how things are done.	1	2	3	4	5
I have the ability to convince others of the utility of carrying out new initiatives.	1	2	3	4	5
I have the ability to turn opportunities into manageable initiatives.	1	2	3	4	5
I am confident that the new initiatives I suggest will take place.	1	2	3	4	5
I promote enthusiasm in others during the execution of new initiatives.	1	2	3	4	5
Proactivity. *Please circle the answer that best matches your experience.*	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I have the disposition to work with others to evaluate any new opportunity that presents itself.	1	2	3	4	5
I carry out actions aimed at joining efforts between entities to implement new initiatives.	1	2	3	4	5
I support new ideas regardless of who proposes them.	1	2	3	4	5
Flexibility. *Please circle the answer that best matches your experience.*	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I have a well-defined scheme or way of thinking in order to recognize opportunities and generate new initiatives.	1	2	3	4	5
I am able to *identify* resources in order to finance a new initiative.	1	2	3	4	5
I recognize how to *obtain* the resources to finance a new initiative.	1	2	3	4	5
I have methods to evaluate the cost-benefit of a new initiative.	1	2	3	4	5
Compeller. *Please circle the answer that best matches your experience.*	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I am excited by the idea of monitoring the progress of a new initiative	1	2	3	4	5
I am able to identify what kinds of resources will be needed to start and sustain a new initiative.	1	2	3	4	5
I am able to clarify to my superiors what a new initiative means.	1	2	3	4	5
I am able to support a new initiative even when others say it can't be done	1	2	3	4	5
Risk Assumption.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

Please circle the answer that best matches your experience.					
I lean more towards new high-risk initiatives.	1	2	3	4	5
I enjoy taking risks on new initiatives.	1	2	3	4	5
I am willing to take a chance on new initiatives with uncertain results	1	2	3	4	5

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