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Scaffolding Student Success: Developing a Culturally Responsive Approach to Support Underrepresented Minorities in Engineering Undergraduate Research

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In this research study, a scaffolding technique is implemented in undergraduate research to cultivate and enhance engineering related aptitudes and stimulate additional experience that will allow underrepresented minority students to fully engage in communication and leadership roles post-graduation. Developing and supporting the growth of underrepresented minorities as leaders who make significant innovative contributions to the global and interconnected scientific society requires awareness of contextual issues that shape their educational experiences and a commitment to enact on a framework that blends technical, communication, and leadership skills in undergraduate engineering education. In the context of this four year study, a total of sixteen engineering students conducting undergraduate research participated. The faculty advisor served as the 'more knowledgeable other' who strategically implemented five technical aspects or 'scaffolds' to enhance technical knowledge, leadership, cognitive and communication skills: literature review, design, implementation, testing, and research. In this regard, student enhance their technical knowledge by applying engineering principles and developing new methods to solve research problems, whereas leadership, cognitive, and communication skills are instilled through character adaptability between team members, decision-making, team management, and collaboration. Results indicate that students developed in the following areas: establishing commitments, constant communication, managing tasks simultaneously, working with a range of ideas, and sharing responsibilities.

I. BACKGROUND AND MOTIVATION

Engineering disciplines have been established to educate its practitioners in finding innovative solutions to improve the human environment. Finding such innovative solutions requires applying knowledge in physics related topics to ensure that designed products are durable, functional, affordable, and safe. Thus, it takes a collaborative effort between teams to have ideas evolve from research proposals to developmental phases. This indicates that communication, technical, and leadership skills are an essential set of tools embedded within groups to execute and maintain the focus of innovative ideas. Thus, it is demonstrated that role of the practicing engineer is more than finding solutions to technical problems. It may include managing projects, working in team settings, communicating, decision-making, preparing technical reports, organizing events, scheduling meetings, or proposing new methods of solving problems.

These roles and duties, despite being essential for the success of a practicing engineer, are not cultivated in undergraduate engineering curricula which are focused on strengthening and nurturing areas in physics and mathematics. Unfortunately, engineering disciplines are technical in nature and grounded in societal values and practices that make communication and leadership skills a secondary focal point, or of minimal interest. There are several institutions, nonetheless, that have integrated writing centers or Leadership programs with the intention of promoting and enhancing technical communication and leadership skills. However, given the extensivity of engineering curricula, it becomes burdensome for undergraduate students to participate and take advantage of such venues.

This trend has gained considerable attention from national, state, and local agencies about reassessing the landscape of STEM education and developing proactive measures to enhance

STEM education quality, access, and outcomes. Several factors drive the need for STEM education reform. Among those factors are: the shift to a knowledge economy, a competitive global market, and the United States' international academic standing. These factors have catalyzed policymakers to prioritize STEM education as a cornerstone of educational reform efforts. Seen as vital to nurturing a strong, healthy national economy, STEM related occupations have increased dramatically over the past decade. According to the Pew Research Center STEM employment has grown 79% (9.7 million to 17. 3 million) and will continue to rise in the next few decades [4]. The U.S. Bureau of Labor Statistics estimated that STEM related occupations are expected to grow more than 9 million between 2012 and 2022. The increase in jobs in STEM fields means that more workers will be needed to fill these occupations and therefore the cultivation of a robust, diverse, and equitable STEM workforce pipeline is essential.

For the past couple of decades, efforts to establish systematic initiatives to nurture a strong STEM workforce pipeline has been a major topic of national educational reform debates. Although there are various perspectives regarding the processes to advance STEM excellence, there is a consensus that STEM education is fundamentally linked to national prosperity and enhanced quality of life for individuals working in STEM fields. The investment in STEM education has significant economic and societal impacts. According to the U.S. Bureau Labor Statistics (2017), that national average of STEM related occupations was $87,500 which is nearly double the average national wage of non-STEM occupations. The national commitment to promoting STEM excellence is evidenced by the State-Federal STEM Education Summit that was hosted last summer. The STEM Education Summit convened a wide range of STEM leaders from all 50 states, five territories, and several tribes. The goal of the summit was to outline and develop a national STEM education plan that "will to help inform the development of the upcoming Federal 5-Year STEM Education Strategic Plan" (p.3). To help support the initiative to enhance STEM education, the prioritization of improving STEM education U.S. Department of Education has allocated a $279 million dollars in discretionary funds for Fiscal Year 2018.

While federal, state, and district initiatives have created and implemented policies designed to bolster STEM achievement, there are numerous issues that prove to be challenging in formulating effective solutions that adequately remedy those issues. One concern regarding the exponential growth of STEM-related occupations is the challenge for educational institutions to help meet the demand of these growing fields. As critical contributors to the development and creation of a strong STEM workforce, post-secondary institutions have tremendous responsibility to attract, retain, and develop STEM talent that will advance national economic interests and prosperity. Though significant efforts have been made to achieve this demand, certain issues such as student attrition, access, and equity continue to play a major role in advancing STEM excellence and developing STEM talent. A formidable task is overcoming the high attrition rates of students majoring in STEM. Data from the National Higher Education Research Institute (2010) revealed that more than half of students who declared majors in STEM during their freshman year do not achieve a STEM degree.

These statistics become even more concerning when examining the racial and gender factors related to STEM degree attainment. Though progress has been made over the past two decades, a considerable gap remains between underrepresented groups such as Black and Hispanic students and their white counterparts in attaining STEM degrees. According to the National Science Board, from 2000 and 2015, the number of science and engineering degrees awarded to Hispanic students has increased from 7% to 13% compared to 61% awarded white students [3]. These trends significantly impact the professional and career trajectories of students and limit the diversification of the STEM workforce. For example, according to Pew Research Center Black and Hispanic groups continue to be underrepresented in STEM fields [4]. Today the Black community compromises 9% of all STEM workers, while 7% of the total STEM population is represented by the Hispanic community. Moreover, The Pew Research Center studied perceived reasons why women Blacks, and Hispanics are not pursuing STEM fields [4]. They concluded that 42% of such demographic groups do not pursue STEM fields given their lack of access to quality education that prepare them for such careers, while 41% because they were not encouraged to pursue STEM from an early age.

II. PROPOSED WORK

Given the concerning and alarming statistics, it is imperative for supporting the cognitive and social development of underrepresented students. At the microlevel, which is the classroom, faculty members can and do play an important role the educational progression of students. This means that faculty members can and should take a proactive role in supporting, promoting, and advocating for educational equity that help advance the educational success of underrepresented students in STEM. Although there are many forms and modes of support that can be employed by in the classroom, in the context of this study, a scaffolding technique is implemented in undergraduate research to cultivate, enhance engineering related aptitudes and stimulate additional experience that will allow underrepresented minority students to fully engage in communication and leadership roles post-graduation.

The authors conceptualize undergraduate research venues as an innovative and creative approaches that help promote and advance the academic success of underrepresented students. As conceptualized in this study, the research venues provide robust opportunities to aid in the development of existing technical, communication, and leadership skills that may be largely enhanced given that students are solving challenging problems, they need to communicate, collaborate, write weekly reports, practice decision-making, and character adaptability.

Research attest that 53% of all STEM majors are involved in some form of research activity throughout their undergraduate matriculation given its short-term and long-term academic and personal benefits [8], [9], [10] [11], [12]. In a study conducted by the National Science Foundation (NSF), 88% of its respondents, which held undergraduate research positions, reported significant growth in structuring a research project, 83% expressed greater confidence in research and professional abilities, and 73% attested awareness of a graduate school environment [10], [15], [17]. [19]. It has been further reported that research opportunities have further facilitated the pursuit of STEM degrees and graduate education for every ethnic group [9], [12], [13], [14], [15], [16].

The application of theoretical frameworks that inform classroom practice is an essential component of effective teaching. To provide students a structured, responsive, and meaningful method of instructional support, a scaffolding process was employed when engaging students in undergraduate research. The term ‘scaffolding’ was first mentioned in studies conducted by Wood *et al*. as they observed the interactions between parents and teachers with young children in supporting acquisition of cognitive skills through the construction of pyramids using three-dimensional blocks [6]. The dynamic support provided by the adults were designed to extend the children’s ability to assist them in completing the task [1]. As such, the intervention was a method that provided a certain level of assistance that helped the children develop the individual problem-solving abilities, knowledge, and skills [7].

Though Bruner and his colleagues first coined the term, theoretical foundations of scaffolding can be found in the seminal work conducted by Lev Vygotsky [5]. Vygotsky posited that learning is primarily a social endeavor which are influenced by cultural factors and is greatly aided by the assistance of a more knowledgeable other or capable peer [5]. Davis and Miyake reported in 2004 that the more knowledgeable other helps provide ‘scaffolds’ that supports learners’ acquisition of important skills and knowledge required to reach a certain goal [2]. In the context of this study, the instructor serves as the ‘more knowledgeable other’ who strategically implements five technical aspects or ‘scaffolds’ that are incorporated to reinforce engineering curriculum, develop academic aptitude, and enhance cognitive development: literature review, design, implementation, testing, and research (Figure 1). Further, communication competence is fomented through 1.) continual oral interaction within team members and faculty, and 2.) written reports that enrich technical language and the need of proper documentation. Whereas leadership skills are instilled through character adaptability between team members, decision-making, team management, and collaboration.

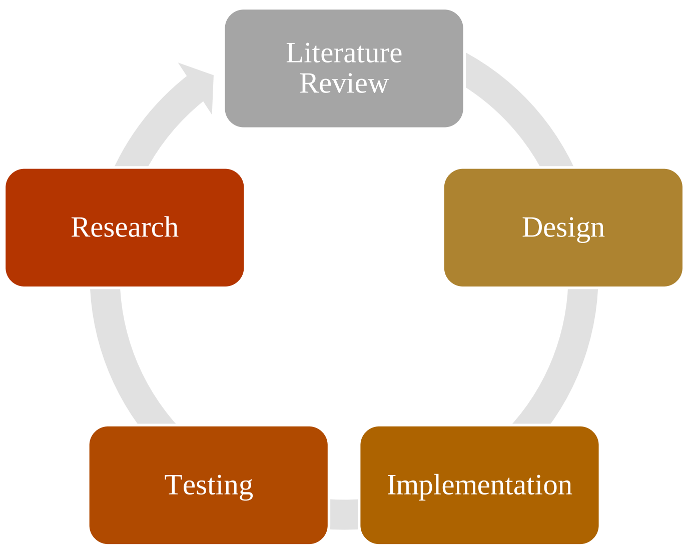

Figure 1. Proposed Scaffolding Technical Areas

Engineering curriculum is reinforced in the proposed model by allowing research students to perform literature readings on specific technical areas of need. Such component of the model exposes students to the existing real-world research problems and the various types of solution techniques. As such, the literature review will enhance the technical notion of beyond undergraduate education and allows a broader perspective on specific themes. In addition, the proposed model introduces design problems to enhance engineering aptitudes. Students are asked to implement mathematical tools to activate their design capabilities and consider all the potential resources that may optimize their criteria before the implementation and testing aspects of the project.

III. METHODS AND ANALYSIS

Based in a small private university in Texas, the authors utilized a case study approach to gather data to examine the impact of instructional scaffolding practices employed by the faculty advisor with underrepresented students participating in undergraduate research. The participant demographics for cohort 1 consisted of one female and ten male students (Table 1). The eleven participants were comprised of 50% of Latino, 25% White, both 8% African American and Asian respectively and 2% other. Moreover, 45% of the participants have been part of a research group for three or more semesters. The same percentage has one semester of research participation and only one student has been involved in research for two semesters.

Table 1: Student Demographics – Cohort 1 and Cohort 2[1]

Variable	Total	Percentage
Gender		
Females	1 (1)	9.09% (40%)
Males	10 (4)	90.01% (80%)
Race/Ethnicity		
American Indian or Alaska Native	0	0%
Asian	1 (2)	8.33% (40%)
African American	1	8.33%
Hispanic/Latina/o	6 (3)	50% (60%)
Native Hawaiian/Pacific Islander	0	0%
White	3	25%
Other	1	1.89%
Duration of Involvement in Research Group		
1 Semester	5	45.45%
2 Semesters	1 (1)	9.09% (20%)
3 or More semesters	5 (4)	45.45% (80%)

The participant demographics for cohort 2 consisted of one female and four male students (Table 1). The five participants were comprised of 60% of Latino and 40% Asian. Moreover, 80% of the participants have been part of a research group for three or more semesters, while 20% have been involved for two semesters only.

A self-developed survey distributed via Qualtrics was the primary method of data collection utilized in the study. The questions developed for the survey were designed to gather insights into their experiences of participating and engaging in undergraduate research. The survey questions were generated based on recurrent conversations the faculty advisor had with his undergraduate students during research meetings, office hours, or arbitrary settings. Moreover, the survey

[1] Cohort 2 information is in parentheses

included an open-ended question that provided students an opportunity to reflect and share about their experiences in engaging in a research group setting. Descriptive statistics were employed for analysis and presentation of data results. The authors note the following limitations of the study: (a) small sample size; (b) self-developed survey instrument; (c) convenient sampling procedure.

The administered survey consisted of nine questions for Cohort 1 and Cohort 2:

Question 1: Faculty advisor made me feel welcomed?

Question 2: Current members made me feel welcomed?

Question 3: Research helped me gain competence in my field

Question 4: Research helped me develop critical thinking skills

Question 5: Research helped me develop communication skills

Question 6: Research helped me develop leadership skills

Question 7: Research will strengthen my career opportunities

Question 8: Research helped me develop social skills

Question 9: Participating in research motivated me to consider graduate school

The survey also included two open-ended question for both cohorts:

What have you learned about working with others?

Tell us how your technical, communication, and leadership skills have been influenced while conducting research?

IV. RESULTS

Results Cohort 1

Survey results reveal several important insights shared by the participants (Table 2). Two questions on the survey were included to assess students' perceptions regarding the social atmosphere of joining a research group. As indicated by survey results, all students strongly agreed that the faculty advisor made them feel welcomed when joining the research group. The students also strongly felt that the other students in the group were warm and receptive to their inclusion in the group. Descriptive statistics indicate that students that 90% of the students strongly agree or agree that their experience in undergraduate research has helped them gain competence in their field of study. Roughly the same percentage of students also strongly agree or agree that it their involvement in a research group has helped them develop critical thinking skills, communication, leadership skills, and social skills respectively. Additionally, over 90% of the student surveyed strongly agree or agree that this research experience will provide enhanced career and professional opportunities. Moreover, nearly 75% of the participants indicated that undergraduate research has motivated them to consider applying for graduate school.

Table 2. Student Responses Percentages – Cohort 1

Question	N	Strongly Agree	Agree	Neither agree nor disagree	Disagree	Strongly Disagree
I Faculty advisor made me feel welcomed.	11	100%(11)	0.00 % (0)	0.00%(0)	0.00%(0)	0.00%
Current members made me feel welcomed	11	72.73%(8)	27.27%(3)	0.0%(0)	0.00%(0)	0.00%
Helped me gain competence in my field.	11	45.45%(5)	45.45%(5)	9.09%(1)	0.00%(0)	0.00%
Helped me develop critical thinking skills.	11	63.64%(7)	27.27%(3)	9.09%(1)	0.00%(0)	0.00%
Helped me develop communication skills.	11	72.73%(8)	18.18%(2)	9.09%(1)	0.00%(0)	0.00%
Helped me develop leadership skills.	11	54.55%(6)	36.36%(4)	0.00%(0)	9.00%(1)	0.00%
Will help strengthen my career opportunities.	11	72.73%(8)	27.27%(3)	0.00%(0)	0.00%(0)	0.00%
Helped me develop social skills.	11	36.36%(4)	54.55%(6)	9.09%(1)	0.00%(0)	0.00%
Participating in this research group motivated me to consider graduate school.	11	27.27%(3)	45.45%(5)	27.27%(3)	0.00%(0)	0.00%

Open-ended Responses

Additionally, an open-ended question was posed in the survey to provide insights into their own learning and experiences of participating in undergraduate research. When faced with the question: 'What have you learned about working with others?,' student responses included several emerging themes: different skill sets; voicing your opinions; organizational skills; and developing professional and real world skills sets.

In regard to the organizational skills, two students responded with the following comments:

> *"I learned to make sure everyone knows what each person is working on and their commitments. By knowing more about other members' schedules, I can better plan meetings and discussion with them."*

> *"You have to divide the tasks so ultimately you might not get to work on what you want to the most. It's important to share your findings with the group regularly. You can always ask for help if needed."*

The participation in undergraduate research within a group context also provided students opportunities to negotiation responsibilities and ideas and help promote interpersonal skills. Two participants acknowledged an increase in awareness of the complex, dynamic nature of research groups:

> *"Through this research group, I have learned the dynamics of working in a team with engineering peers. This has included learning to compromise and combine ideas that other members may have, as well as reaching out to them for more information or specific requests when necessary."*

> *"From working with others, I have learned that not everyone approaches the same problem in the same manner, and there are multiple effective ways to solve a problem."*

These responses shed light on the importance of integrating a scaffolding technique to promote the technical, communication, and leadership skills for underrepresented students conducting undergraduate research. As more institutions commit valuable resources and energies to achieve or maintain tier 1 research status, the quality of developing minority students may be adversely affected and ultimately impact the level of student engagement and achievement outcomes. As evidenced by the student comments above, these insights compel practicing faculty members to critically reassess existing recruitment strategies and recommit to ensuring that minority students have access to high quality mentorship.

Results Cohort 2

Similar to Cohort 1, the students in Cohort 2 strongly agreed that the faculty advisor made them feel welcomed when joining the research group. Eight percent of the participants in Cohort 2 noted that current students in the group were warm and receptive to their inclusion in the group. Forty percent of the participants strongly agreed that that their experience in undergraduate research has helped them gain competence in their field of study, while another 60% noted that they agreed on the same survey item. Statistics indicate that students that all of the students strongly agree or agree that their experience in undergraduate research has increased their critical thinking skills, while eighty percent of the participants reported an increase in communication skills. Another 80% of the students strongly agree or agree that their experience helped to increase leadership related skills sets. Additionally, students in Cohort 2 strongly agree or agree that this research experience will provide enhanced career and professional opportunities. Moreover, 40% of the participants indicated that undergraduate research has motivated them to consider applying for graduate school, while 60% neither agreed or disagreed on the same item.

Question	**N**	**Strongly Agree**	**Agree**	**Neither agree nor disagree**	**Disagree**	**Strongly Disagree**
I Faculty advisor made me feel welcomed.	5	100%(5)	0.00 % (0)	0.00%(0)	0.00%(0)	0.00%
Current members made me feel welcomed	5	80%(4)	20%(1)	0.00%(0)	0.00%(0)	0.00%
Helped me gain competence in my field.	5	40%(2)	60%(3)	0.00%(0)	0.00%(0)	0.00%

Helped me develop critical thinking skills.	5	60%(3)	40%(2)	0.00%(0)	0.00%(0)	0.00%
Helped me develop communication skills.	5	80%(4)	0.00%(0)	20%(1)	0.00%(0)	0.00%
Helped me develop leadership skills.	5	60%(3)	20%(1)	20%(1)	0.00%(0)	0.00%
Will help strengthen my career opportunities.	5	40%(2)	60%(3)	0.00%(0)	0.00%(0)	0.00%
Helped me develop social skills.	5	40%(2)	60%(3)	0.00%(0)	0.00%(0)	0.00%
Participating in this research group motivated me to consider graduate school.	5	20%(1)	20%(1)	60%(3)	0.00%(0)	0.00%

Open-ended Responses

Regarding the open-ended question,'What have you learned about working with others?,' student responses included several emerging themes: acknowledgement and appreciation of diversity of thought and experience; development of interpersonal and collaborative skills; and organizational skills.

The following student open-ended responses illustrate how the research experience increased students' awareness of group dynamics and interpersonal collaborative skills:

> "*Although you may not necessarily mesh with every individual you meet in a team setting, every person has specific strengths that make them valuable to the overall project effort. Team synergy develops from mutual understandings of strengths and weaknesses between people*."

> "*From conducting research, I have learned how to integrate work that other people on the same team have done into my own work. To elaborate, before joining Dr. X's group, I often had trouble accepting the work that others would do and I would almost instinctive try to "redo" their work out of a misplaced sense that they could be wrong, even if they had more expertise in that area of knowledge than I did. As a result, I often worked really slowly and oftentimes the work that I did produce was of somewhat questionable quality. By learning how to "let go" and build up what others have done, I would say that I have become a much better teammate*."

> "*Research is often very team and self-motivated. To make progress, you need to take initiative to call people together and find ways of allowing everyone to contribute*."

> "*It's great, especially when working with people you trust and enjoy being around*."

One student response noted the organizational/logistical importance of group work and how to improve its effectiveness:

> "*I learned that it is very important to document your work such that others can build upon your work*."

Beyond an increase in group dynamics and interpersonal proficiency, the students also noted an increase in technical engineering skills sets such as problem-solving, critical analysis, leadership ability and effective communication of ideas. The following responses highlight these aspects:

> *"From participating in research, I've learned how to better synthesize and present information to other individuals. Successfully communicating and exchanging ideas is vital to the health of every project as the first set of solutions is never perfect. There is always room to grow and learn from both your peers and your mentors. Thus, you should never be afraid to revisit the literature or consider solutions proposed by others."*

> *"One technical skill that conducting research has greatly improved are my MATLAB skills. Before COVID-19 sent everyone home, I was in the process of creating a code that would simulate the motion of a bridge when it experienced point and distributed loads as part of an effort to gradually build it up to the point where I could simulate all motion in four degrees of freedom."*

> *"Research has made me better at independent work and finding resources on my own for when I run into issues or problems."*

> *"My technical skills improved greatly due to the direct application of concepts we learned in the classroom."*

> *"I was able to more effectively lead teams and design prototypes."*

One participant provided an in-depth, detailed response that underscored the potential of positive, meaningful student research experiences to positively impact students' technical, academic, and social competencies:

> *"Research has also improved my communication and leadership skills by forcing me to communicate in a more succinct and direct manner and to act more decisively. For example, during team meetings where time is limited, I cannot (or should not) waste my professor's and teammates' time by rambling and speaking indirectly, which is a bad habit I have if I get nervous. Furthermore, since the ultimate goal of the research project I am doing is to eventually publish a paper, there is a timeline that should be adhered to. This last point was especially helpful during my internship last summer, during which there were many deadlines that came quickly since I worked at a very small company that was in its rapid-growth phase, to paraphrase my boss. Having had the experience of conducting fast-paced research, I was more easily able to adapt to this new working environment than if I had not done research."*

Based on the student responses listed above, students can greatly benefit from engaging in positive research experiences. In order for faculty advisors to facilitate positive, enriching research experiences for students they must embrace and employ pedagogical frameworks that emphasize the importance of the social and cognitive aspects of learning. This includes valuing and nurturing relationships with students and balancing academic rigor with adequate support systems in place such as instructional scaffolding and mentorship to ensure student success.

V. CONCLUSION

For over four decades, the concept of instructional scaffolding has been widely practiced by educators to support the cognitive development of students. When thoughtfully and meaningfully employed as an instructional method, scaffolding is a powerful pedagogical tool that enhances the teaching and learning process by responding to student learning needs and help them acquire relevant knowledge and skills. In the context of the engineering classroom, scaffolding may prove to be an effective means to help students acquire essential engineering concepts knowledge. In this study, a scaffolding technique was implemented in undergraduate research to cultivate and enhance engineering related aptitudes and stimulate additional experience that will allow underrepresented minority students to fully engage in communication and leadership roles post-graduation. The authors incorporated five technical aspects to reinforce engineering curriculum and develop academic aptitude: literature review, design, implementation, testing, and research. Communication competence was additionally encouraged through 1.) continual oral interaction within team members and faculty, and 2.) written reports that strengthens technical language. Whereas leadership skills were instilled through character adaptability between team members, decision-making, team management, and collaboration. The range of student responses indicate that effective undergraduate research experiences promote a variety of benefits that serve to enhance student learning, development, and communication. Through the interaction with mentors and peers, undergraduate research present venues to engage engineering students by exposing them to real-world settings that serve to reinforce and strengthen engineering related skills.

Future Work

The authors note the following limitations of the study: (a) small sample size; (b) self-developed survey instrument; (c) convenient sampling procedure. Phase 2 of this long-term project includes surveying current undergraduate students conducting research in every engineering discipline and identifying the scaffolding technical and leadership areas of need. The authors are in the process of developing an agenda to create survey data and organize focus group interviews with such students. In this regard, focus group interviews will be utilized to facilitate collective reflection and dialogue by providing students opportunities to openly discuss their learning experiences with fellow peers. The facilitation of the focus group interviews employs a semi-structured approach in which the researchers generate a series of open-ended questions designed to guide group conversation. This approach will assist in generating an organic, conversation-oriented environment that encourages participant autonomy such that individual and collective experiences are respected.

Once the survey and focus group interviews have concluded, the authors will initiate, in Phase 3 of the project, a series of meaningful conversations aimed at engaging engineering faculty members who have undergraduate research students in exploring collaborative efforts to implement the proposed model. This effort will draw on data collected from the study to inform the material required to develop and facilitate in-depth, dynamic training sessions in which the model is explained in detail.

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