Implementing Structured Mentorship to Broaden Participation of Underrepresented Minorities in Aerospace Engineering

Dr. Carl Anthony Moore Jr., Florida A&M University - Florida State University

Carl A. Moore Jr. is an associate professor at the FAMU-FSU College of Engineering. He earned his B.S. in mechanical engineering from Howard University and his M.S. and Ph.D. from Northwestern University. Before entering graduate school, Dr. Moore worked as a research engineer and manufacturing engineer for Eastman Kodak Company in the Copy Products and Single-Use Camera divisions. He also has professional research experience with Ford Motor Company's Interactive Conceptual Design and Applications lab. Dr. Moore was instrumental in developing cobots - a novel human-robot collaborative technology for applications requiring humans to work in physical contact with robots. His research interests include robot-based 3D printing, haptic interface design and control, and teleoperation. Through grants from NASA and NSF, Dr. Moore is preparing students for STEM-related fields and developing success strategies for undergraduate and graduate STEM majors. He is also a member of the NASA SMD Bridge Workshop Organizing Committee. Dr. Moore has published 22 papers in robotics, graduated 12 graduate students, and been awarded nearly $11.0 million as principal or co-principal investigator. In the classroom, Dr. Moore enjoys implementing nontraditional instructional methods, including flipped classroom learning. He and his wife have five children and live in Tallahassee, Florida.

Dr. Chiang Shih, Florida A&M University - Florida State University

Dr. Chiang Shih is a Professor of Mechanical Engineering Department, FAMU-FSU College of Engineering, Florida State University. He received his Ph.D. degree from the Aerospace Engineering Department at the University of Southern California in 1988.

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Abstract

Traditionally, aerospace engineering disciplines are substantially underrepresented by African American, Hispanic, and female students. For example, Black and Hispanic American students collectively earn only 10.6%, 8.4%, and 6.4% of the BS, MS, and Ph.D.'s in aerospace engineering, respectively. They are among the lowest percentages of all major engineering disciplines, leading to underutilization of the talent pool in the aerospace industry.[1] To tackle this concern, a multi-institution coalition sponsored by NASA is established to engage underrepresented minorities in coordinated educational and professional development activities, including senior design projects, undergraduate research experiences, and career traineeship in aerospace-centric fields. The streamlined process of recruitment and project-based learning in collaboration with NASA and other aerospace professionals has shown to be effective in training the first cohort of undergraduate and graduate students during the first year of program implementation.

During the summer of 2022, 6 NASA interns and 6 summer Research Experiences for Undergraduate (REU) students participated in the 10-week summer program with professional development (PD) program featuring project management, career planning, RCR training, self-reflection, and technical communication. Because research shows that STEM students cite positive mentoring experiences as the most crucial factor in their retention, we developed a structured and evidence-based mentoring program as a critical element to make the professional preparation process more robust and sustainable. The program contains 4 parts: an Individual Development Plan (IDP) uses self-assessment to explore career opportunities and identify developmental needs and priorities for the mentoring relationship. 2) A mentorship compact illuminates the dimensions of the working relationship to eliminate misunderstandings between the mentor and the mentee. 3) A mentoring map survey identifies sources to help the mentee achieve goals, and if necessary, shows where unmet needs will benefit from additional support. 4) Finally, a mentoring plan includes the tools and philosophy that guide the program for a group of mentors and mentees. In this paper, we discuss the design and implementation of the BP-AE mentoring program and show how we plan to expand and evaluate the program.

Introduction

Aerospace engineering is a relatively new branch of engineering that has plenty of momentum behind it thanks to a booming commercial air transport industry, the popularity of technologies

that rely on satellite technology, and the consistent needs of the U.S. defense and travel industries.[2] Although the U.S. is a global leader in the production of aerospace and aviation technology and talent, it is facing increasingly stiff competition. As pointed out by recent reports, the increasing global competition is due to the aging of the current aerospace workforce and the fact that aerospace and related engineering and science fields do not attract sufficient numbers of students.[3,4] There is no doubt that broadening the participation of underrepresented minority (URM) students in AE is desperately needed to help the U.S. maintain its competitive edge in advanced aerospace development and to ensure hiring equity in this competitive STEM field.

Regrettably, URM students often do not get the training needed to help them pursue opportunities and graduate degrees in Aerospace-related disciplines. While 19% of all students participate in an undergraduate research experience (URE)[5], most program directors have difficulty getting URM students to take advantage of the opportunity.[6] This is regrettable, especially since UREs can be a major indicator of who is retained in STEM majors, pursues graduate education, and matriculates into fields in which they are underrepresented.[7,8,9,10] Perhaps not surprisingly, African-American students earn only 2.2% and 3.2% of the Ph.D.'s in ME and AE, respectively, the lowest and second to lowest percentages of the major engineering disciplines.[11] Structured programs are needed to address the gap in URM participation in aerospace-related undergraduate education and research experiences.

In response to this environment of needs, we started the NASA MUREP INCLUDES program by forming a multi-institution coalition focuses on recruiting underrepresented minorities (URMs) for a coordinated educational and professional enhancement program while engaging them in senior design projects, undergraduate research experiences, professional traineeship, advanced research, and career development activities in NASA-relevant fields. The coalition is led by University A (U-A, an HBCU), and University B (U-B, a PWI), and University C (U-C, an HSI). in collaboration with Air Force Research Laboratory–Munitions Directorate (AFRL), Florida Space Grant Consortium (FSGC) and four NASA centers: MSFC, KSC, JSC, and JPL. The research and development theme focuses on aerospace systems and technologies, including high-speed aerodynamics, combustion, propulsion, active flow control, smart materials, and additive manufacturing. These topics fit well with the primary mission of the Center of Excellence (CoE) to train and sustain a highly skilled workforce as well as design and develop new technologies and products for the aerospace enterprise. BP-AE has leveraged the CoE's goals to expand recruitment, curriculum development, mentorship, and research collaborations to maximize the overall impact of the program.

The leading Institution (LI) has established track records in scholarly activities, recruitment, and education of African American and female engineering students. The addition of U-C will further enhance diversity with Hispanic workforce inclusion. The coalition members have already developed long-term partnerships with stakeholders from AFRL, NASA centers, and other relevant institutions in terms of integration of research and education endeavors with demonstrated success. The BP-AE activities will leverage those accomplishments while working to significantly increase the number of URM and women engineers pursuing advanced degrees and furthering their careers in aerospace-related disciplines by structured professional development program as described below.

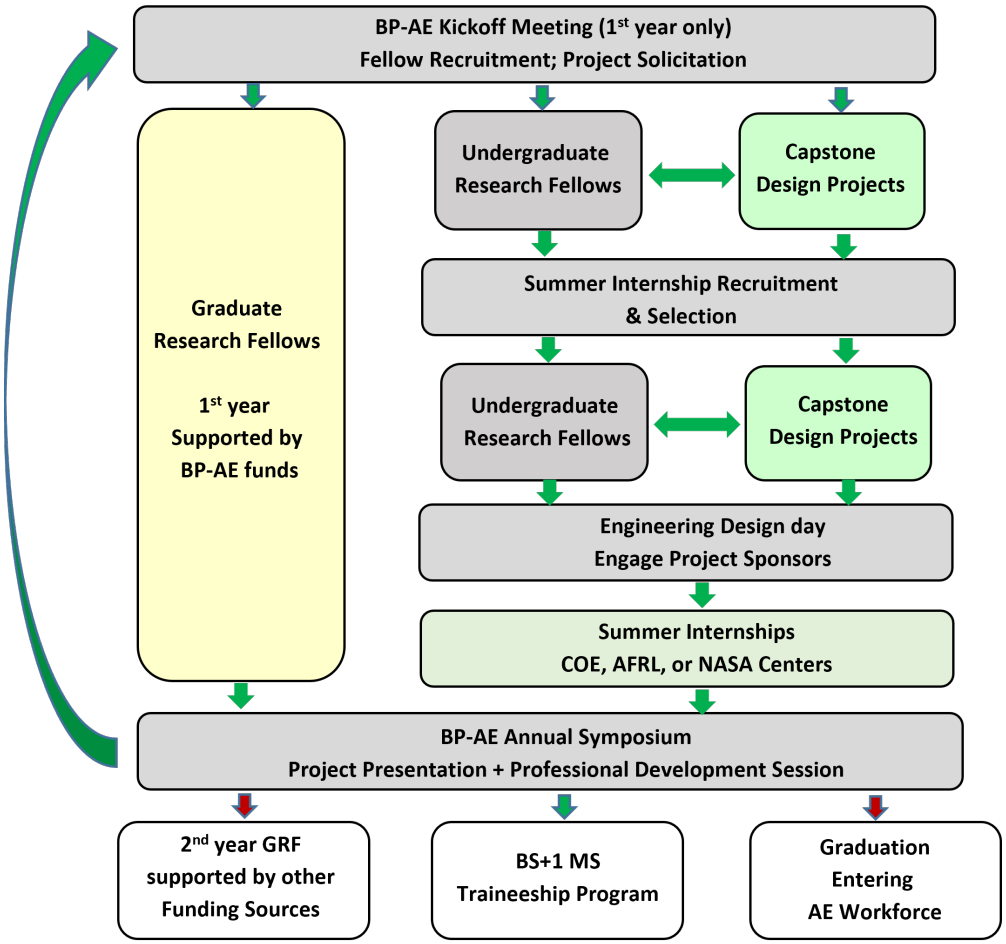

Figure 1: Integrated Research and Education Training Process for the current MUREP-INCLUDES BP-AE project.

The proposed professional development program is comprised of four interconnected activities to engage students early while implementing during their academic careers as illustrated in the educational and training process diagram shown in Fig. 1. These activities include (1) Senior capstone design project sponsorship; (2) summer research and professional development for undergraduate and graduate students; (3) MS-level Traineeship degree integrating internship and project mentorship from aerospace professionals; and (4) co-advising graduate students' research projects with AFRL and NASA collaborators. Collectively, these activities can engage stakeholders from these consortium universities with NASA centers and AFRL to develop pioneering collaborations while enhancing existing connections to build a long-lasting partnership.

Accomplishments 2021-2023

The BP-AE program officially started in September 2021 and we have successfully implemented many proposed activities meeting and exceeding initially proposed goals and programmatic metrics. In the following, we will provide a brief overview of these activities and their respective

contributions to the primary objectives of broadening the participation of URM engineering students.

- Recruitment: Since its initiation, BP-AE has engaged motivated URM students as both graduate research fellows (GFs) and undergraduate BP-AE fellows (UFs). During the first seventeen-month period, we have recruited 6 GFs – three from U-A (all African Americans, one male and two female, who has also been selected as a DoD SMART scholar), two from U-B (a male, African American, and a female), and one from U-C (male, African American). All are pursuing doctoral degrees and have already engaged in advanced research in aerospace-centric fields. In addition, the program has engaged a total of 30 UFs (12 from Univ A, 12 from Univ B and 6 from Univ C; 15 African Americans, 15 Hispanic Americans; 21 males and 9 females). They have participated in various variety activities, including senior design projects, Engineering Design Day, undergraduate and graduate research assistantships, NASA and BP-AE summer internships, and other program events.
- Capstone design projects: The program has coordinated and completed 9 NASA-centric senior design projects with 10 more ongoing projects (7 sponsored by NASA MSFC, 7 by FSGC, 2 by JPL Psyche, and others). 87 graduating seniors participate in these projects as they work on real-world, practice-oriented engineering design topics with supervision by NASA engineers and professional practitioners over two semesters.
- Engineering Design Day: These senior design students then showcase their work in the annual Engineering Design Day in a formal professional setting through both oral presentations and poster sessions to the panel judges comprised of external advisory council members and engineering professionals.
- NASA summer internship: In the 2022 summer, six BP-AE students had completed their internship training in two NASA centers (three each to MSFC and KSC) and sponsored six NASA internship positions to include four African Americans (1 female and 3 males) and two Hispanic Americans (1 female and 1 male). All had completed their 10-week summer program working on NASA projects and engaged in professional development and training activities. In 2023, we are in the final stage of recruiting and selecting NASA BP-AE interns with the expectation of another 7-8 students to at least three NASA centers (MSFC, KSC, and JSC). Coordination is ongoing to involve two other centers (JPL and AMES).
- BP-AE REU Program: Concurrently in 2022, we recruited five students to participate in the local Research Experiences for Undergraduates (REU) program. Four are URMs (2 African Americans and 2 Hispanic Americans, 1 female and 3 males). We also engaged another three non-URM students through AFRL Scholar and Hypersonic Workforce Development programs. They were engaged in structured research experiences and professional training activities, including RCR training with certification, graduate schools and career options, technical communication, and mentorship training. We expect to organize the BP-AE REU activities again in 2023 with an enhanced session of mentorship training as it is one of the essential components of our program (to be elaborated later).
- Annual BP-AE Symposium: One of the major milestones for the program is the annual BP-AE symposium held at the end of the BP-AE summer program. All stakeholders, including PIs, and BP-AE REU fellows. NASA interns, Advisory Council members, and

interested aerospace professionals will attend the one-day event. The symposium focuses on the following activities: (1) Oral presentations for all BP-AE interns (in-person for COE interns and in virtual format for NASA interns who cannot attend) during the morning session. (2) A virtual poster session will be held early in the afternoon with all interns presenting their work in an asynchronous mode. (3) Coordinated reflection and feedback sessions for all interns detailing their experiences with their peers and other stakeholders. (4) The symposium will culminate in the assessment and evaluation session of program outcomes and objectives with the Advisory Council and other key stakeholders based on participants' feedback and testimonials for needed corrective actions and continuous improvements.

- Mentorship: We have been developing a structured mentorship program for our BP-AE participants based on the National Academies of Science's research on effective mentorship.[12] The plan has multiple parts that will be addressed in the next section. During the first summer of BP-AE program, we presented the characteristics of structured mentorship to all program participants. Student feedback indicated that most had never been part of a structured mentoring program. We elected to implement the program during the coming school year.

Mentorship Program Structure

Whether the focus is on academic, athletic, or professional pursuits, a mentor helps a mentee evaluate goals, establish plans, and monitor progress. Since the impact of mentoring is substantial, why do fewer than one-quarter of students have a mentor?[13] The answers are numerous, but one that stands out is that many who are well-intentioned don't know how to establish and maintain a structured mentoring relationship. And because many are unsure of what makes mentoring effective, mentoring relationships can devolve into ordinary advisor-advisee relationships or even friendships. To help guarantee the effectiveness of the BP-AE mentorship program, we used recommendations from the National Academy of Sciences to create a four-part program which we describe below.

Part 1: Discovering Needs. A mentee's lack of clarity on their goals or needed improvements makes it harder to select a mentor and more difficult for a chosen mentor to know where to focus the mentoring. Therefore, the first step in establishing a mentoring relationship is self-evaluation. The suggested tool is called the individual development plan (IDP). Like a traditional personality test, the IPD asks the mentee to look within themself, consider their short, mid, and long-term goals, and which skills will be needed to accomplish them. The IDP better positions the mentee to choose an appropriate mentor. If the mentee already has a mentor but has not completed an IDP, the mentor should suggest completing one. In either case, the mentor should review the IDP results to understand the mentee's needs better.

Below are some popular IDPs.

- Dr. C Gita Bosch IDP for Undergraduate Students shows how to create an IDP for undergraduates, complete with examples. Dr. Bosch's IDP includes a goals worksheet, a self-assessment, and a list of traditional core competencies for undergraduate students.[14]

- myIDP from ScienceCareers.org is a long-form online survey of goals and areas for improvement according to STEM discipline. It is general enough for use by undergraduates though it was developed for Ph.D. students and postdocs.[15]
- The University of Wisconsin-Madison Self-Assessment questionnaire was established for graduate students. It is a flexible tool that is appropriate for students of any discipline.[16]
- UC San Diego Standard IDP Form for Graduate Students is meant to be completed by both the mentor and the mentee. It uses a table format to organize a list of skills to be assessed, action steps, and target completion dates.[17]

Throughout the mentoring relationship, mentors should also evaluate themselves using a reverse IDP. For this, consider The Mentor Mirror by Dr. Renetta Tull.[18] It flips the standard mentee IDP questions around to help the mentor see if they are providing the mentoring experience their mentee needs. Finally, note that the IDP is not a once-and-done process. Both mentor and mentee should return to it yearly to evaluate progress and update goals.

Part 2. Establishing Commitments and Expectations. Incorrect assumptions can doom the mentoring relationship. For example, should the mentor assist with professional development or introduce the mentee to influential persons in the field? The Mentorship Compact establishes responsibilities that will answer questions like these and eliminate misunderstandings. Not a contract, the compact highlights promises that each party in the mentoring relationship makes to the other. Part of the compact value comes from clearly setting forth expectations.

The mentorship compact will be specific to the mentor and mentee, their respective positions, and their college or workplace requirements. We modified a compact developed by the Association of American Medical Colleges for use by our summer REU (research experience for undergraduates) participants and their advisors.[14,19,20]

Part 3. Managing the Mentoring Relationship. After personal introspection and establishing expectations, it is critical to managing the mentoring relationship. Participants should address how often they will meet, the purpose of the meetings, and how to evaluate progress. The Mentor Map is a tool designed to address these requirements and keep the mentoring relationship on track. It is helpful to think of the mentor map as a set of post-it notes on a calendar reminding you when to meet and how to evaluate progress and goal completion. Table 1 contains two example mentor maps. The map on the left is for a graduate student who is intent on publishing and presenting her work this year and wants help monitoring her health. The map on the right is for an undergraduate who wants to earn no less than a B in one of his required courses. Each map specifies meeting types and backup dates if a session is missed. For the graduate student, the mentor and mentee will discuss wellness issues at every meeting and the progress toward the goals at every other meeting. The undergraduate course will last only a semester, so the mentor reviews the mentee's course folder and goals progress weekly.

In the beginning, both parties should discuss the goals of the relationship and what should happen when these goals are satisfied; perhaps they should identify new goals, end the mentoring relationship, or start a new one. Whatever the case, the mentor map is a reminder to consider these possibilities. Because some goals may be missed, the map should also include contingencies for missed goals.

Grad Student Mentor Map

1. Regular Meetings (Build the relationship, discuss wellness)
   (a) 2nd Monday in Feb, April, June, Aug, Oct, and Dec.
   (b) Make up a missed meeting on Wednesday
2. Goal Check Meetings (Evaluate progress toward goals)
   (a) Goal 1: Paper. Evaluate in Feb, June, and Oct.
   (b) Goal 2: Presentations. Evaluate in April, Aug, and Dec.
   (c) Consider remediation with the research advisor if goals are not satisfied
3. Mentoring Evaluation in Dec.
   (a) All goals met?
   (b) Set new goals and seek new mentoring

Undergraduate Mentor Map

1. Regular Meetings (Build the relationship, discuss wellness)
   (a) Every 2nd Tuesday
   (b) Make up a missed meeting on Thursday
2. Goal Checks (Evaluate goals at each meeting)
   (a) Goal 1: Visit the professor during office hours.
   (b) Goal 2: Start HW on the day assigned.
   (c) Goal 3: Give topic mini-lectures.
3. Consider student services support if low assignment grades
4. Mentoring Evaluation
   (a) End relationship at semester's conclusion?
   (b) Select a new mentor for the next course.

Table 1: Example Mentor Maps

Part 4. Keeping Everything Organized. The Mentoring Plan is the final step for administrators to establish a broader mentoring program. The mentoring plan includes the tools and philosophy that guide the mentoring program for a larger group of mentors and mentees. It should set the tone without overly constraining and be unique because every institution is different. For starters, a mentoring plan should include the standard tools like the IDP and any others that benefit the participants. It is helpful to gather example documents for the mentorship compacts and mentor maps, presentations on the benefits of mentoring, and anything else that supports the vision of the mentoring program. We also have as a goal to share best mentoring practices with people in similar institutions. The most important thing for us to remember is that mentoring is about relationships, so whatever we do, we encourage relationship-building between all of the participants in our mentoring program.

In the next section, we detail the steps we have taken to implement the BP-AE mentoring plan.

Mentorship Program Implementation

There are multiple forms of mentorship including dyadic pairing, collective or group mentorship, triads, and mentorship networks. In dyadic pairing, one mentor interacts with one mentee. This is the most common form of mentorship but can suffer when a mentee needs mentorship along multiple dimensions that cannot be supplied by an individual mentor.[21,22,23] Collective mentorship will involve two or more mentors forming a group to mentor multiple mentees. Triads can be one mentor and two mentees or two mentors and one mentee. Generally in a triad, there is a cascade of mentoring where each member of the triad mentors the member just below them in experience.[24] Finally, the mentorship network is where multiple mentees have access to multiple mentors a mentorship node, i.e. peer-mentors, and resource nodes such as faculty support, social media forums on mentoring, etc.[25,26,27]

We chose two implement a formal mentorship network where the mentoring relationship is peer-to-near-peer. Specifically, we asked the BP-AE graduate students to mentor the undergraduate participants. We believe that this structure has multiple benefits. (1) Research has shown that mentees can quickly develop the professional intimacy with peers and near-peers needed to propel a mentoring relationship.[28,29] (2) Mentees can gain the confidence needed to persevere when they are exposed to near-peers that have succeeded.[30,31] (3) In a structured program, near-peer mentors learn what makes good mentorship and what does not, which will be beneficial when they assess the mentoring they receive.[32] (4) Finally when our graduate student mentors enter the job market, they will do so having facilitated a mentoring relationship which is an important skill set in today's workforce.[33,34]

We recruited 5 BP-AE mechanical engineering Ph.D. students to be the mentors. All 5 were URM students including 3 women, and each participated in our structured mentorship presentation during the previous school year. We asked all current BP-AE undergraduate students to participate as mentees along with others who asked to be included. We explained to the graduate students they would lead the program and that the PI and Co-PI would assist whenever needed. The graduate students organized a kickoff meeting complete with pizza in the early weeks of the 2023 spring semester.

Ten mentees participated in the kickoff which included graduate students' introductions and a presentation of the structured mentoring program. At the conclusion of the meeting, the undergraduates were asked to complete an IDP from Sciencecareers.com and to select one or more of the graduate students as their mentor(s). Of the 10 undergraduates, 5 have chosen a mentor. The remaining 5 reported not feeling comfortable or lacking enough information to choose a mentor effectively. To complete the selection process, the PIs are going to meet with the 5 undergraduates and help them finalize a choice of mentor. To encourage program ownership, we desire that each mentee be engaged in mentor selection.[35,36] After all mentor-mentee groups are chosen, the mentors and mentees will use templates created by the authors to develop mentoring compacts and mentoring maps for the most effective management of the mentoring relationships. Since the kickoff meeting, 4 additional undergraduates have requested inclusion in the mentoring program as mentees. We asked them to complete the IDP and select a mentor based on a collection of our mentors' biographies.

To better manage the mentoring program, the authors enrolled in the U B Research Mentor

Academy. The Academy's goal is to promote a culture of support for mentoring and to provide faculty training in optimizing mentoring relationships for mentors with their mentees at all levels of their research careers. The Academy is based on the research mentoring curriculum, "Entering Mentoring", an evidence-based curriculum from the Center for the Improvement of Mentored Experiences in Research (CIMER) at the University of Wisconsin-Madison. Course topics include aligning expectations, assessing understanding, promoting professional development, cultivating ethical behaviors, promoting mentee research self-efficacy, enhancing work-life integration, and articulating a mentoring philosophy and action plan.[37]

Plans for Evaluation and Expansion

We are currently designing a peer-to-peer mentoring certification course for BP-AE students. The purpose of the course will be to teach the students about structured mentoring and to provide both mentors and mentees with the tools needed for successful mentoring relationships. The course will be divided into 3 modules, Maintaining effective Communication, Addressing Equity and Inclusion, and Fostering Independence. As with the U B Research Mentor Academy, the certification curriculum is based on ideas from CIMER. During the first week of the summer BP-AE program, all students who complete the certification course will receive a certificate. We will offer the course in person and online.

As discussed, we plan to leverage the ongoing BP-AE program success to inspire network-wide adaptation of best practices, with structured mentorship as the cornerstone training, to prepare URMs for aerospace-centric and other STEM careers. We plan to evaluate the effectiveness of mentorship and other training activities on academic performance and professional engagement for BP-AE participants. The process will involve key stakeholders, including all BP-AE students, the leadership team, NASA mentors, and the External Advisory Council (EAC). An external evaluator, to be described later, will coordinate the assessment process.

For the programmatic assessment, standardized evaluation forms based on our established BP-AE model will be used for all coalition schools, including measurable metrics and evaluation criteria to determine the level of achievement for all planned activities and expected outcomes. Quantitative and qualitative data sets to be collected include student performances, cross-institutional projects, internship and career placement data, mentorship participation for mentors and mentees, faculty engagement, federal agencies, and industry-sponsored projects and internships, team conference attendances, and technical publications. This set of evaluation results focuses on student-centric outcomes, including their academic and professional experiences and their advancements after the program's interventions.

The evaluation will engage multiple perspectives and will use a wide range of methods to assess and interpret a multiplicity of information. Data will be gathered during all phases of the program to provide formative feedback to/from project stakeholders on implementation, participants' perspectives about the activities and what they have learned, and how goals and objectives are being met. There are two milestone events perfect for focus group interviews and discussion forums for reviews and stakeholder feedback. (1) The annual Engineering Design Day when all graduating senior students showcase their year-long projects. Many engineering professionals and project sponsors attend the event as panel judges who can provide timely feedback to not only the

design projects but also the effectiveness of mentorship and cross-institutional projects to expand stronger network connections, both critical components of the program. (2) Annual BP-AE program symposium when all summer interns (NASA, AFRL, industry, and all affiliated REU) present their traineeship projects together in a professional setting. Highlighted events include oral and poster presentations, student feedback sessions, and culminating the Advisory Council meeting consisting of a roundtable discussion for just-in-time evaluation. This venue is ideal for conducting in-person interviews, focus group forums, and formative assessments to identify the program's strengths and weaknesses while improving its implementation.

External evaluator: An external evaluation expert, Dr. JT from the College of Education, U-B, has been involved in conducting formative and summative evaluations. Having an external evaluator provides a triangulation of perspectives as well as protects against conflicts of interest with respect to data collection, analysis, and reporting of evaluation findings. BP-AE PIs will be primarily responsible for the coordination of the "in-house" coalition evaluation processes, while Dr. JT will coordinate external evaluation processes and assessment data collection and analysis. She will conduct the following formative and summative evaluation activities: (1) interviews with all campus PIs and key stakeholders, (2) student surveys, (3) observations of program activities, (4) interviews with mentors/mentees, (5) goals/objectives/metrics document reviews, and (6) follow-up surveys and evaluation reports. Dr. JT's "distance" from the project and coalition, provides objective data collection, analysis, and interpretation. Assertions derived from these data will be used for triangulation with the "in-house" assessment activities. The findings from the data will be discussed with all PIs and other stakeholders involved in the program in an ongoing process so that these findings can shape program improvements and future implementation.

Conclusion

Since 2001, the BP-AE MUREP-INCLUDES program supported 3 Ph.D. and 19 undergraduate students, facilitated 9 NASA-centric senior design projects impacting 37 students, placed 6 REU students and 6 NASA Interns (3 each to MSFC and KSC), and hosted a summer professional development (PD) program featuring project management, mentorship education, self-reflection, and technical communication. As we continue to support students we are significantly improving the program through the addition of a structured mentorship program where undergraduates engineers are mentored by graduate students in a peer-to-peer formal system. While this mentorship program was developed for BP-AE, we believe that purposeful attention to creating a culture of mentorship within our college will result in all of our students being successfully developed to assume their rightful place in occupations that will help solve the problems of the future.

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