

MACES Undergraduate Research Fellowship Program: Integrating Research and Education

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Abstract

With support from the National Aeronautics and Space Administration (NASA), the Merced Anomaterials Center for Energy and Sensing (MACES) was launched in the summer of 2015 at the University of California Merced (UC Merced). MACES is a research and education center, focused on creating innovative materials-enabled solutions for energy and sensing-related space applications. The center established its MACES Undergraduate Research Fellowship Program to provide training and professional development opportunities for students, specifically aimed at groups traditionally underrepresented in science, technology, engineering and math. This program consisted of Academic Year and Summer components that integrate research experience, mentoring and workshops on topics ranging from presentation skills to career preparation. The program engaged students from varied backgrounds, more than half of whom were from underrepresented groups, and provided them with tools that enabled greater confidence, expanded career perspectives, and enhanced conceptual and interdisciplinary knowledge. This article details the Academic Year and Summer program components and outlines the impact of respective activities on student participants.

Keywords

MACES undergraduate research fellowship, underrepresented groups, mentoring, student impact, student professional development, summer research

Introduction

Low participation and poor retention of students from underrepresented groups (URGs) in science, technology, engineering and math (STEM) fields are attributable to a lack of understanding of how society benefits from science, coupled with low self-confidence (Bianchini, 2013; Eagan et al., 2011; Lopatto, 2003; Teitelbaum, 2014). Directly placing inexperienced undergraduate students into established research programs exposes these students to a risk of underachieving, even under the best of circumstances. That risk is higher for students from backgrounds

that do not emphasize the skills and mindsets necessary for independent research (Lopatto, 2003). Literature supports the importance of a research mentor (Cooper et al., 2019) and the assertion that the “undergraduate experience is greatly enriched by attaining research experience early and often” (Teitelbaum, 2014). Studies demonstrate the positive impact of participation in a research experience for undergraduates (REU) program, not only on students from URGs but, more generally, on any student with limited access to research opportunities (Estrada et al., 2016; Estrada et al., 2018; Yang et al., 2019). Studies also indicated that students’ learning improves when research components are integrated into course work (Mumford et al., 2017) and revealed that participation in research improves students’ abilities to comprehend fundamental concepts across academic disciplines (Munroe, 2016). Accumulated studies have proven that undergraduate research training serves as an essential ingredient for success in subsequent graduate studies and also in their other future STEM endeavors (Hernandez et al., 2018; Iovacek et al., 2012; Newman, 2020). In an effort to harness such insight and best practices, MACES at UC Merced developed its Undergraduate Research Fellowship Program which integrated research into a variety of educational experiences and advances participants’ professional skill growth via workshops and one-on-one mentoring.

MACES Undergraduate Research Fellowship Program

Overview

With support from NASA, the Merced nAnomaterials Center for Energy and Sensing (MACES) was launched in the summer of 2015 at UC Merced, the only public American research university founded in the 21st century. MACES serves as a nexus for nanomaterials-based research and education; research initiatives focus on creating innovative functional material platforms to enable lightweight, compact, and high-performance energy conversion and storage for future space missions, and on developing new types of biosensors critical for planetary exploration to allow in-flight health monitoring and disease diagnosis.

These initiatives underlie both the research and education activities of the center. The center’s educational goal is to establish a vertically integrated STEM program that will produce a highly skilled and diverse workforce for NASA missions and beyond. Therefore, undergraduate STEM education is an integral part of MACES.

To fulfill this commitment, MACES created an undergraduate research and training program to integrate education and research and to increase student participation, particularly for students from groups traditionally underrepresented in the STEM fields. To nurture the professional development of the participants, the program focuses on structured mentoring and hands-on research where students experience the connection between basic science, technological advances and their social benefits. The MACES Program consists of two components: the **Summer Research Program (SRP)**, which takes place over 9 weeks from June to August; and the **Academic Year Program (AYP)**, in which students conduct research through both fall and spring semesters. The AYP was initiated in fall 2015 and the first SRP cohort started in the summer of 2016. The central goal of this article is to discuss these two components of the MACES program and to evaluate the impact of the program activities on each successive cohort of participants.

Specifics and Participant Activities

Both Academic Year and Summer Research Programs require participants to be a full-time undergraduate student with a GPA of 3.0 or above, and be US citizens or permanent residents. The Summer Research Program is open to all undergraduate students who meet the above eligibility criteria while the Academic Year Program is open to current UC Merced undergraduate students only. Specific program activities for both, AYP and SRP, and their intended impact on participants are listed in **Table 1**.

Both AYP and SRP provide financial support to students, which alleviates their financial burden and allows them to concentrate on their academic training and research. Mentoring is a key component of a successful undergraduate research experience (Haro, 2004; Pfund et al., 2006; & Eby et al., 2008), because it enables students to

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	Activity	Outcome: Benefits/Impact on Students
1	Environmental, health and safety training	Learn how to follow policies and maintain a safe work area within the lab; gain transferable skills to work safely on any future project.
2	Research on a well-defined project related to MACES goals	Gain comprehensive knowledge of the research topic; learn how to gather information, to formulate important relevant questions and to develop solutions; acquire an understanding of research in an academic environment; develop and hone team-work and time-management skills.
3	Faculty and grad student mentors' weekly meetings	Develop professional communication skills; understand responsible conduct in research.
4	Professional development workshops	Prepare for graduate record exam (GRE) and take practice test (SRP only); understand how to critically assess scientific publications and develop scientific writing skills; learn specifics of preparing and presenting posters and research talks; demonstrate effective written and verbal communication skills through development of resumes, personal statements, and personal brands.
5	MACES social events	Enhance social interaction skills and effective social behavior; deepen the understanding of community building and the role of a diverse research community in both local and global context.
6	Research symposium	Gain presentation experience; network with UC Merced faculty, grad students and research staff
7	NASA summer fellowship	Experience first-hand NASA research/work setting outside an academic environment; network with NASA professionals and open doors for future collaborations and career opportunities

Table 1. MACES program activities and their intended impact on participants

become independent, self-confident and self-motivated researchers. Therefore, as part of MACES, each undergraduate student is assigned faculty and graduate student mentors who provide support and direction. While in the program, the students are required to participate in academic enhancement and professional development activities which guide them in setting long-term goals and

making well-informed choices. Each SRP summer cohort is a part of UC Merced's *Summer Undergraduate Research Institute (SURI)* and students conclude the program with a presentation of their research at the SURI Symposium. The AYP students participate in research activities during the academic year and are required to present their research at the end of the spring semester. Additionally, each year a

selected group of AYP students is nominated to receive summer funding to do an internship at a NASA Research Center.

Method

Literature demonstrates that using a mixed-method approach leads to comprehensive understanding of study goals (Creswell & Plano Clark, 2018; Poth, 2018). To create an efficient research design and generate meaningful program insights, the MACES Undergraduate Research Program used qualitative and quantitative approaches to collect data and then conducted formative and summative evaluations. Sets of pre- and post- surveys were developed to collect students' feedback on specific components of the AYP and SRP and to measure participants' progress with program activities. The surveys were developed in collaboration with MACES' faculty, staff and external evaluator, and UC Merced's Students Assessing Teaching and Learning (SATAL) program, which is a part of the Center for Engaged Teaching and Learning. For the SRP, in collaboration with SATAL, focus groups were implemented to assess students' learning outcome regarding the impact of summer activities.

Investigative Studies: Enrollment and Demographics Summary

The MACES undergraduate research and training program was initiated in fall 2015 and participant data collected over the span of four years. For clarity, data has been analyzed and results are reported separately for AYP and SRP.

MACES Academic Year Program (AYP)

The four AYP cohorts included a total of 43 undergraduate participants. Of them, 96% successfully completed the program. The total number of participants in the MACES AYP has steadily increased over four years. By year 4, the number of participants more than doubled compared with year 1 (Figure 1, left).

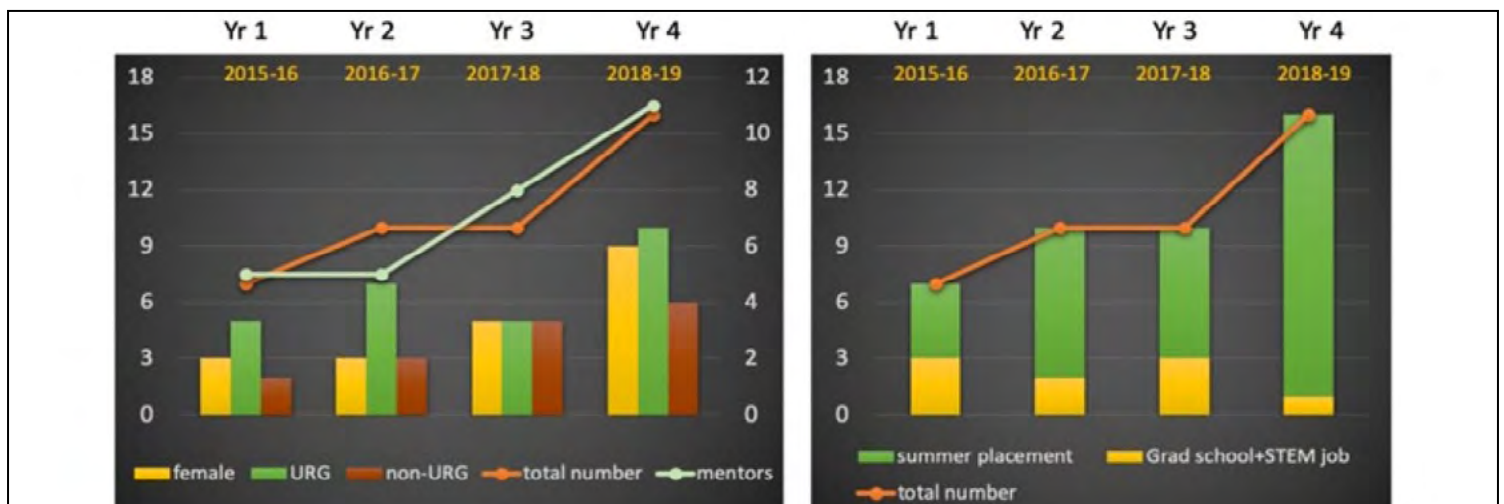


Figure 1. (left) Enrollment and participation data for the AYP for all four years since program inception. The histograms correspond to the left axis. The right axis lists the total numbers represented by the lines. (right) Placement of participants during the summer following the conclusion of their AYP.

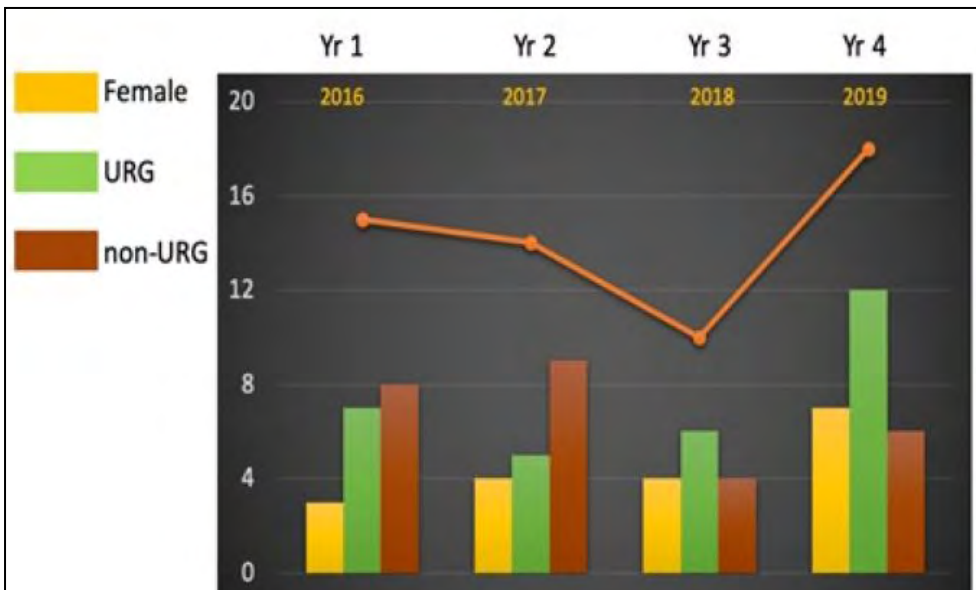


Figure 2. Enrollment data for four years of SRP. Data is inclusive of UC Merced and students from other institutions, many from community colleges and California State University (CSU) campuses. Solid line represents the total number.

This increase was enabled by more faculty participation in MACES, allowing for more research opportunities for students while maintaining our high standards. The basic tenets of the program, which include close faculty mentoring of every participant have remained consistent. The total number of faculty who accepted students into their research groups increased from five in year 1 to eleven in year 4. We have also continuously strived to increase the number of students from URGs.

As described in Table 1, this program endeavors to (a) inspire participants by highlighting STEM career options, (b) direct participants to internships and other opportunities that will enrich their experience and strengthen their career paths, and (c) help them develop skills to successfully apply for graduate programs, jobs or other post-undergraduate ventures. All of those who completed the AYP, if they were seniors, either enrolled in graduate programs or accepted jobs in STEM fields. Those who were

sophomores or juniors participated in research either as NASA interns, or in another REU program at UC Merced or other universities during the summer (Figure 1, right).

MACES Summer Research Program (SRP)

Four cohorts with a total of 57 students have completed the SRP (2016 – 2019). To date, the completion rate for SRP participants is 98%. MACES focuses on offering STEM training opportunities not only to UC Merced students, but also to those in local community colleges and in the nearby campuses of the California State University (CSU) system. The selection criteria are like those for the AYP, and Figure 2 summarizes the participation numbers and demographics. While the total number of participants has been roughly consistent over the past four years, the program has increasingly been more successful at attracting students from URGs.

Geographic Impact and Connections

The geographical reach of MACES has increased tremendously over the past four years, as well. Figure 3 shows growth of MACES educational network from its beginning in 2015 to the present.

Data used to generate these maps include institutions where MACES AYP students have gone for internships and graduate school, as well as those from which summer students have traveled to UCM to join the SRP. At the beginning, we focused only on institutions close to UC Merced for SRP recruitment. This allowed us to establish strong bonds with CSU Stanislaus, CSU San Jose and with Merced College, a nearby community college. By 2019, SRP attracted students not only from farther CSU campuses, including Sonoma, Sacramento and the Pomona colleges, but also from out-of-state institutions, such as Oregon State University and MIT. Also, in the first year, UC Merced students participated in internships at only two NASA Centers, Ames and Langley, and by 2019 two more NASA Centers, Glenn and Jet Propulsion Lab, had begun accepting these students.

Results: Impact on Student Participants and AYP Assessment

The main goal of the MACES program is to integrate research and education and to increase student participation in research, particularly for student groups traditionally underrepresented in the STEM fields. In this respect, the programs' investigative studies address the impact of research and professional development activities in the following key aspects:

1. Enhanced Learning – Intellectual Development and STEM Knowledge;
2. Workforce Preparation – MACES Professional Development Workshops;
3. Interdisciplinary Learning Environment;
4. Student Overall Satisfaction, Gains and Challenges.

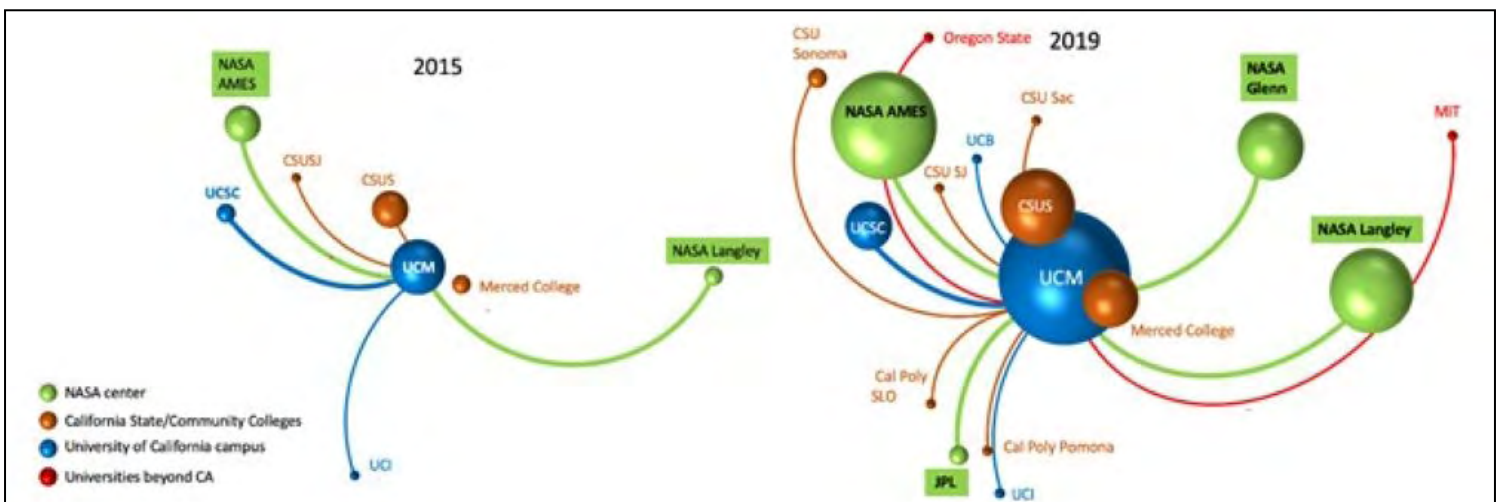


Figure 3. Growth of the MACES educational network from its beginning in 2015 to the present. Data used to generate these maps include institutions where MACES AYP students have gone for internships and graduate school, as well as those from which summer students have joined the SRP. The diameters of the spheres represent the cumulative number of individuals at each node.

1. Enhanced Learning – Intellectual Development and STEM Knowledge

AYP participants continuously demonstrate excellent academic performance and subject knowledge. At the end of the fall and spring semesters, participants' GPA is obtained from Banner, UC Merced's Student Information System. Consistently, 100% of the students demonstrate a GPA above 3.0 and are in good academic standing throughout the duration of the program. In a few cases, during the program, early interventions were necessary to help students improve their academic performance for obtaining a satisfactory course grade. This approach helps students set academic priorities and motivates them to be successful in their academic and extra-curricular activities. Summer program participants are required to submit weekly assignments to CatCourses (Canvas), UC Merced's Learning Management System. These assignments are evaluated based on timely submission and content. Results demonstrate that 98% of participants completely satisfy the assignment evaluation criteria. Students are engaging in research-related activities with their faculty and graduate student mentors for a minimum of 10 hours per week during a regular semester and 25 hours per week during the summer program.

2. Workforce Preparation – MACES Professional Development Workshops

To prepare participants for graduate school and

broaden their STEM career prospects, the MACES AYP developed and implemented a Professional Development Workshop Series. In each workshop, students participate in hands-on activities related to a specific theme. For example, one workshop theme is *Oral, Poster and Written Presentations*. During the workshop, faculty discuss what constitutes a good presentation, the importance of motivating the topic of the presentation, the duration of presentations, knowing the audience, and how to access other available resources on the subject of presentations. In addition, MACES undergraduate students who have done research in prior years discuss their experience through 15-minute presentations. All students are asked to write an abstract on their current research which is then evaluated by MACES faculty, who also provide feedback to the students. Additional one-on-one consultations are offered to students who need further help on the topic. To enhance their presentation skills, all MACES participants are required to present their research at the end-of-the academic year Symposium or at the SURI Symposium. The data analysis performed by MACES external evaluator (Chang, 2020) demonstrates that 90% of students strongly agree that participation in the program increased their interest in STEM careers. 95% of participants report strong interest in attending graduate school in STEM fields (2018 and 2019 data, N=20).

During another workshop on *Graduate School Applications*, attendees are provided with comprehensive

feedback as to what constitutes a great application package to graduate school. Participants then break-up into mock admissions committees to evaluate and rank real-life graduate school applications. The session ends with a group discussion in which students are guided to reflect on their findings and list the qualities of a strong graduate school application. The active component of this workshop is always highly rated by the students as it addresses the metrics of how the applications are viewed by students as opposed to faculty. During MACES SRPs, participants have the additional opportunity to take practice GRE tests.

The *Personal Brand* workshop theme was implemented to help students develop a personal brand for their professional career. Students write a 1-2 sentence brand statement/elevator speech and a 150-word brand description (similar to a LinkedIn profile). These are then electronically submitted for grading by faculty and returned to students with comments and corrections. To assist students further in their professional preparation, a Personal Statement workshop addresses the importance of a personal statement. Students are coached to develop a personal statement that may be applicable to applying for graduate school and internships positions. The workshops start with a presentation on how to construct a successful resume, which could provide adequate information to the reader in a short time. This is followed by a writing session where students work on their resumes. Graduate students function as guides, offering advice and evaluating

resumes. The workshop series ends with the Resume theme, where students learn how to enhance their resumes and create an effective LinkedIn profile. Overall, the workshop series has been very effective. In the span of four years, nine students (21%) participated in NASA internships and twenty-five students (59%) were selected for industry internships and summer research positions in academia or national labs (see Figure 1).

3. Interdisciplinary Learning Environment

MACES encompasses two major research areas, energy and sensing, with 17 faculty members from five separate departments collaborating on projects related to these topics. The departments include Physics, Chemistry, Applied Math, Mechanical Engineering and Materials Science and Engineering. This provides opportunities for students to conduct research in different disciplines and increases their understanding of the interdisciplinary nature of the science and engineering fields. According to external evaluation reports (Chang, 2016-2018), students learn important skills, such

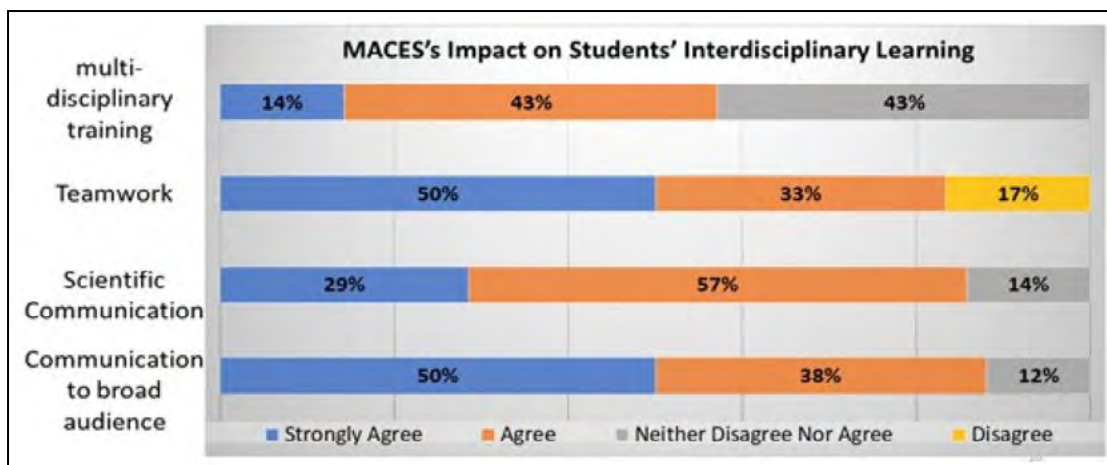


Figure 4. Data collected via surveys designed and analyzed by external evaluator for MACES. Data tabulates results of AYP 2018 survey. N=8

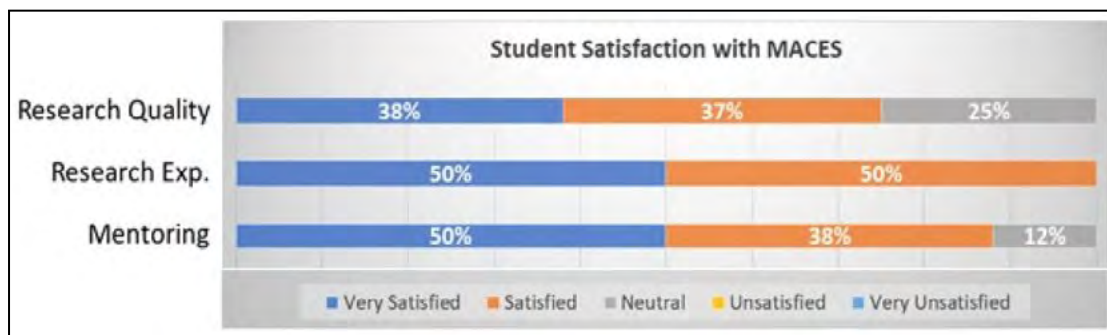


Figure 5. Data collected via surveys designed and analyzed by external evaluator for MACES AYP 2018. N=8

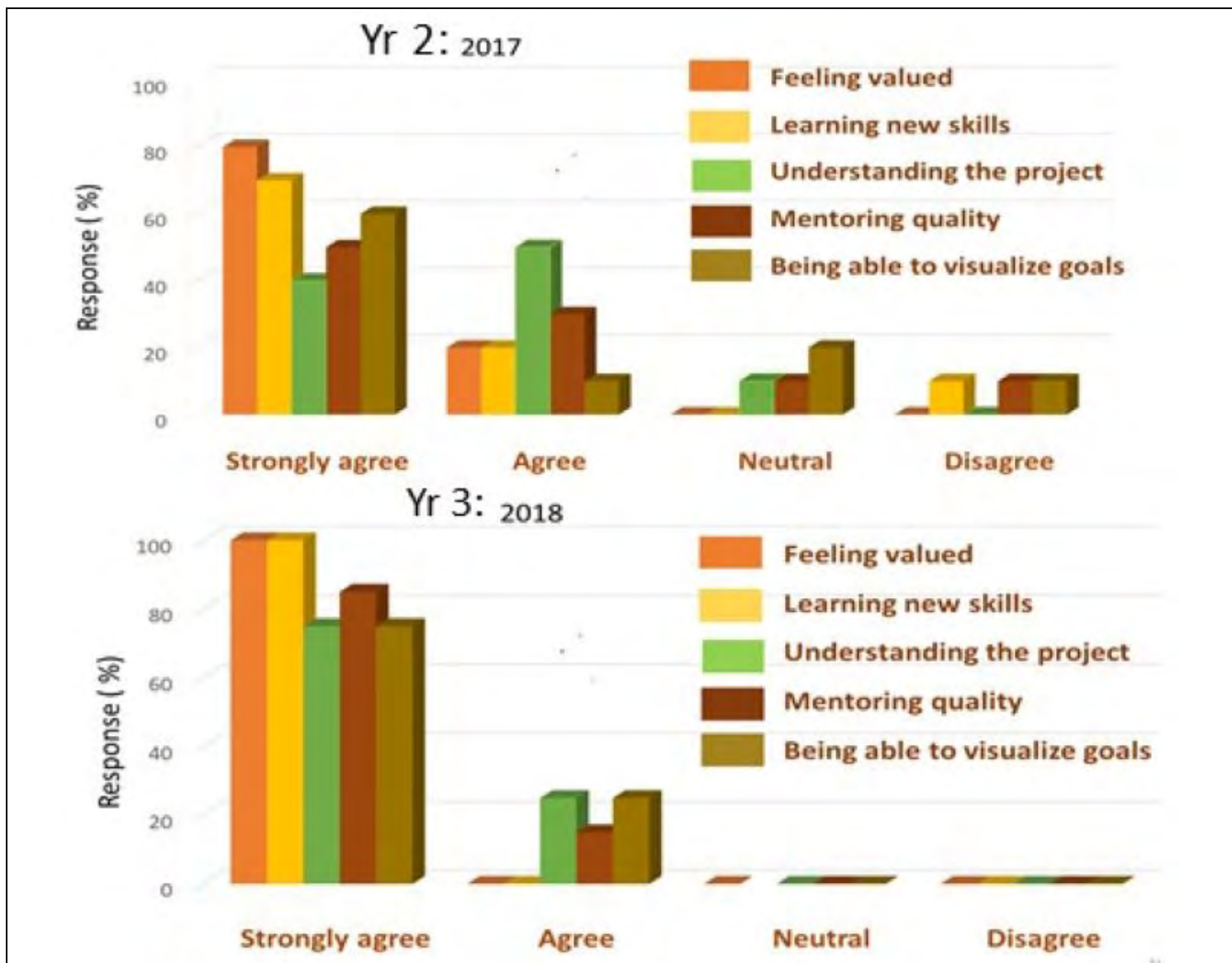


Figure 6. SRP student survey data for two successive years of the program.

as how to work in a multi-disciplinary team and how to best communicate their research to those from other disciplines and to a general audience. Representative survey results in **Figure 4** indicate these findings for the 2018 AYP cohort.

4. Student Overall Satisfaction, Gains and Challenge

When asked to reflect on the ways they benefited from participating in the MACES program, students described a range of benefits, including better research skills, access to mentors, internships, and opportunities that they would not have had otherwise. Students reported that MACES had a very positive impact on their intellectual development by increasing their STEM knowledge, helping them develop critical thinking skills, and increasing their level of confidence in their abilities. For almost all students, participating in MACES increased their interest in STEM careers and in attending graduate school. MACES evaluations (Chang, 2016–2018) validate the effectiveness of the workshops and indicate that the implemented activities increase stu-

dents' awareness and interest in a STEM career and graduate school. A representative graph in **Figure 5** from a 2018 survey illustrates program's findings.

Results: Impact on Student Participants and SRP Assessment

The assessment for the SRP varies slightly from the metrics used for AYP, since the former is of shorter duration and focuses more strongly in developing connections whereas the latter focused on creating a STEM pipeline. The background and experiences of the participants are also widely different, given that some are from community colleges with little or no prior research experience, while others are from institutions with excellent research capabilities. Through pre- and post- surveys and focus groups, the SRP was assessed at a personal level to ensure student satisfaction, as well as at a professional level to ensure program quality and perception (Chang, Summer 2018; Signorini, 2017). **Figure 6** outlines the survey data

of participants' opinions from two successive SRPs. In Summer 2017, 11 students (80% response rate) responded to the survey and in Summer 2018 this number was 8 (80% response rate). Across all the different parameters, the assessments demonstrate improvement.

Conclusion

In conclusion, internal and external assessment of the MACES Undergraduate Research Fellowship Program demonstrated its overall positive impact on participants' academics and career preparation. Findings of formative and summative evaluation revealed that students developed significant STEM aspirations. It was demonstrated that integrating interactive workshops with research coupled with close mentoring delivered effective, structured and concrete learning experiences for undergraduate students. Both the AYP and SRP aspects of the MACES Undergraduate Research Fellowship Program were successful in meeting the center's goal of providing training and

opportunities for students from groups traditionally underrepresented in STEM fields. Of all undergraduate participants, an average of 58% were from underrepresented groups and 40% were women. Participation in the MACES program not only helped undergraduate students build confidence but also increased their awareness of a broad range of STEM career opportunities and advanced their conceptual and interdisciplinary knowledge. Participants' overwhelmingly positive feedback to the program demonstrated the effectiveness of our approaches. Through the implementation of a series of research and extracurricular activities designed to meet specific program goals, the AYP and SRP provided an excellent opportunity for the participating students and faculty to integrate research and education.

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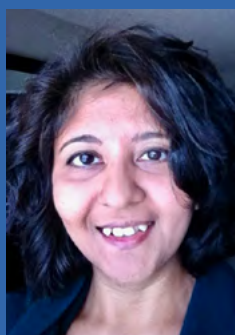
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Sayantani Ghosh is a Professor of Physics at UC Merced and works on understanding and manipulating fundamental interactions at the nanoscale with specific focus on nano-assembled actuatable materials, plasmonics and nano-structured photovoltaics. She serves as the Associate Director for undergraduate education and research for MACES.



Ashlie Martini is a Professor of Mechanical Engineering at UC Merced who studies friction, wear and lubrication. She is a member of the MACES team, currently leading the Center's efforts focused on graduate education.



Jennifer Lu received her PhD from University of Michigan. Prior to joining UC Merced, she acquired ten years industry experience at IBM and Agilent Technologies. She is now an associate professor in Materials Science and Engineering. She serves as the Director of the Merced NANomaterials Center for Energy and Sensing (MACES).

