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Board 405: The REU Site in Nanotechnology for Health, Energy and the Environment: Best Practices for Enhancing Research Skills, Professional Development, and Diversity

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The REU Site in Nanotechnology for Health, Energy and the Environment: Best Practices for Enhancing Research Skills, Professional Development, and Diversity

Abstract:

The Research Experience for Undergraduates (REU) Site in Nanotechnology for Health, Energy, and the Environment has been supported for the past thirteen years at Stony Brook University in New York State. Over the years, we have been fortunate to have had the opportunity to develop and pilot workshops, panels, and presentations that supported the professional development of our scholars and the advancement of research skills while providing opportunities for students from a wide range of institutions (including community colleges), educational levels (including many first and second-year students), academic majors, and demographic backgrounds. Having a history of over 120 participant feedback via surveys and interviews by an external reviewer allows us to analyze the effectiveness of the summer activities as the program has continued to evolve. Tracking personally identifiable data has allowed us to follow former participants and document their academic and professional outcomes for years after. In addition, we report on the results of recruitment activities which have resulted in an increasingly diverse cohort of participants (over 60% of our REU scholars have been female and more than 40% have members of historically underrepresented minority groups). The role of targeted outreach, the development of valuable professional development and social activities, and other factors which can positively impact diversity and inclusiveness are also discussed. Combining all of the evidence and information provided by our tracking systems has delivered significant insight which can inform the development of effective undergraduate research opportunities, and assist in identifying best practices for continuous improvement of our ongoing REU program site.

Description of program:

For the past thirteen years, Stony Brook University REU Site on Nanotechnology for Health, Energy and the Environment has responded to the need to provide experiential learning opportunities for undergraduates in the interdisciplinary field of nanotechnology. The project was inspired by the need to put in place a successful model for research-oriented undergraduate education that satisfied the requirements of both students (from various academic majors, types of institutions, including community colleges, and who have completed from one to three years of undergraduate education) and their eventual employers (or graduate programs) in the developing and shifting nanotechnology sector.

In a broader sense, it responded to the need to recruit students from diverse populations, including under-represented groups, for enhancing diversity in STEM fields. It also addressed the need to enhance engineering education with a focus on emerging technology systems in the context of applications and societal impact. We do this through a program of faculty-mentored multidisciplinary research, professional development, and exposure to real-world issues that

reflect the impact of nanotechnology on society, the business community, human health, and the environment. This approach also supports self-efficacy, multidisciplinary team-building, understanding the broader impacts of technology, and building the skills necessary for research and lifelong learning.

Overall, the key goals are:

1. To provide an exciting and productive research experience for each fellow.

2. To create a small cohort of students, who share common goals, that supports the development of research and professional skills, also known as a learning community

3. To encourage and prepare students for graduate and professional education programs

4. To enhance student learning and appreciation for (a) the ethical, legal, and societal aspects of nanotechnology and (b) life-long learning which is absolutely critical in areas of emerging technology

5. To create opportunities for students from various backgrounds, such as those from underrepresented groups, those attending community colleges as well as four-year institutions, students in their first or last year of undergraduate study, and those who attend colleges with weak research programs.

6. To expand our outreach and build our learning community through the inclusion of high school teachers who work side by side with the REU fellows and creating a larger cohort through working with partner institutions and by collaborating with other REU-style experiences on campus.

Nature of recruitment activities:

The Center for Inclusive Education at Stony Brook University serves as the administrative home of the REU site in Nanotechnology for Health, Energy, and the Environment. The Center for Inclusive Education (CIE) is Stony Brook University's critical campus resource for diversity initiatives, recruitment, and broadening participation in doctoral and postdoctoral research at the institution. The CIE works to advance diversity in graduate education, postdoctoral research, the professoriate, and the scientific workforce. To ensure its scholars' success, the CIE provides financial assistance, social support, and scholar advocacy through several externally funded initiatives from National and State funding agencies. The CIE develops and coordinates academic and professional development events designed to foster a strong sense of academic identity and professional capacity that bring together the diverse members of its interdisciplinary community.

The Center's strategy for the successful recruitment of underrepresented STEM scholars combines the engagement of prospective students with research faculty, graduate peers, and

university administrators to provide a comprehensive overview of the opportunities at SBU. This successful approach to student recruitment allows the Center to build a strong prospective REU participant pool.

Currently, the CIE leads multiple efforts in the areas of recruitment of REU scholars. Efforts include:

- **National Conference Recruitment:** The CIE coordinates Stony Brook's annual exhibiting to recruit underrepresented undergraduate students at approximately five National Conferences in STEM, such as the Annual Biomedical Research Conference for Minority Students (ABRCMS), the Society for the Advancement of Chicanos and Native Americans in the Sciences (SACNAS), and the Emerging Researchers National Conference (ERN) in STEM
- **Campus Visits:** The CIE visits local campuses with substantial populations of UR students and/or STEM diversity programs to recruit students for REU programs, including Institutions with LSAMP and McNair programs. In addition to local campus visits, the CIE plans recruitment "circuits" in other parts of the country, including Maryland (University of Maryland, Baltimore County, College Park, and Eastern Shore campuses; Morgan State University) and Puerto Rico (University of Puerto Rico university system). These visits include a CIE staff member, a University faculty member, and a graduate scholar. The teams are assembled based on the majors/research interests of the students to whom we will present, which not only increases attendance but also enthusiasm for applying to the REU program.
- **Dissemination of Electronic Recruitment Materials:** The CIE REU Program Manager disseminates electronic recruitment flyers to faculty, students, and administrators at SBU and other institutions that interact with substantial populations of UR and underserved prospective students. As members of the Institute for Broadening Participation (IBP), we will post SBU program information on their website (pathwaystoscience.org). The Program Manager will also utilize social media to engage with groups that are comprised of UR STEM scholars, including the National Society of Black Engineers (NSBE), the Society for Advancing Hispanics/Chicanos & Native Americans in Science (SACNAS), the Association on Higher Education and Disability (AHEAD), and the American Indian Science and Engineering Society (AISES). Finally, a contact database from previous Letters of Reference for REU applicants was created. These faculty members are contacted directly and asked to consider their current students for the REU program and to encourage them to apply.

Diversity of participants:

As a result of our recruitment efforts and value based on attracting applicants from historically underrepresented groups for the purpose of increasing diversity in STEM, our participants represent a diverse and inclusive community. Having a diverse group of participants each year enhances the learning experience for all student participants, helps to build an inclusive research environment for our laboratories, and provides an opportunity for mentors to work with an

increasingly diverse team. For example, diversity has been shown to be an essential element for the development and support of high-performing collaborative research teams.(1) As can be seen from Figure 1, the overall trend in percentage of URM in the REU site has increased (to 42% overall), and we have maintained a very high percentage of female participants (now 62.5% overall).

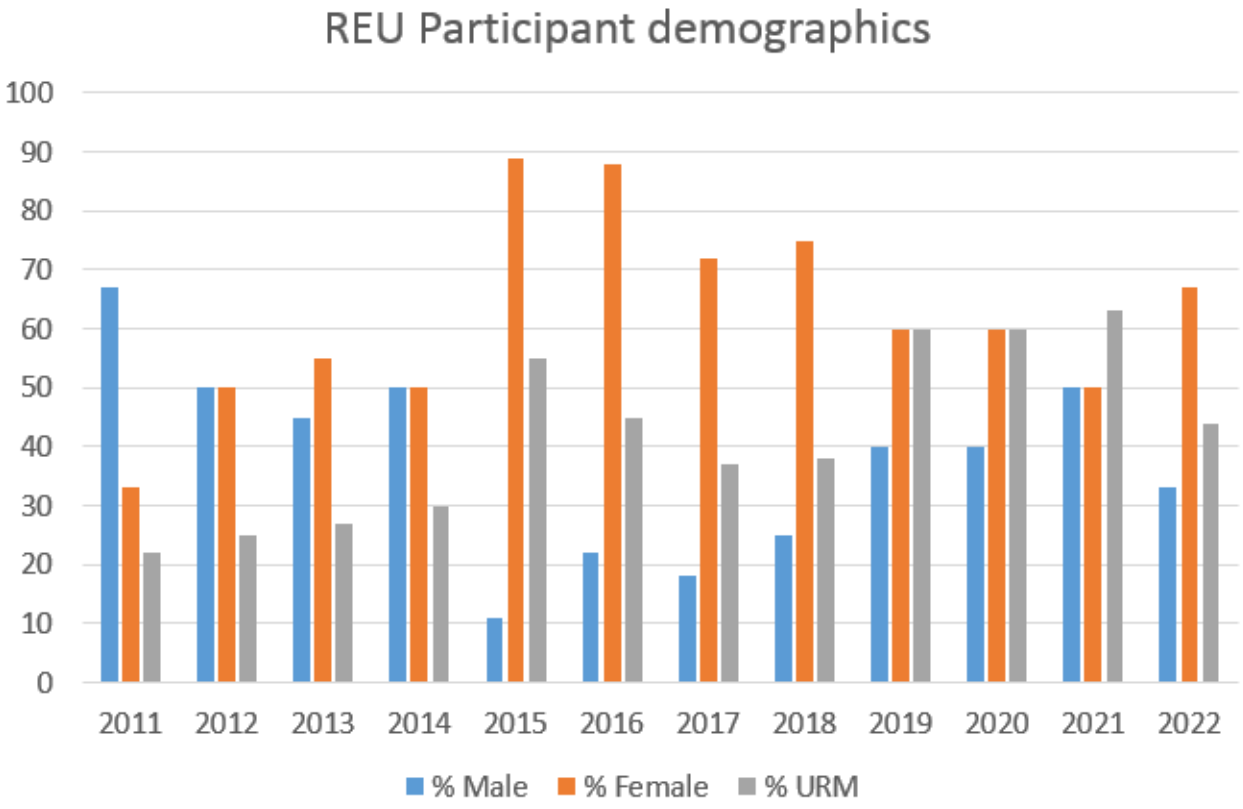

Figure 1: Chart showing diversity of REU site participants, 2011-2022, in terms of gender and percentage of underrepresented minority (URM) participants.

In some years (2015-2017 in particular) additional student support was provided by a community college partner which increased the number of participants supported. Also, from 2020-2021 the program was restricted to virtual participation due to campus COVID-19 protocols which decreased the number of participants. This was especially true in 2020, as in person recruitment was also suspended and some potential participants dropped out of the recruitment pool due to various reasons related to the pandemic. Despite the challenges presented in the rapid conversion of the program to an online format, our recruitment efforts continued (in virtual formats) and student participant satisfaction levels and learning outcomes remained strong. Research and professional development skills activities (as detailed below) also were converted to an online format for the 2020 and 2021 cohorts, though the learning outcomes and objectives of these activities remained consistent.

It should also be noted that a fairly large percentage of our participants are first or second year college students or come from a community college environment (about 20% overall). For these

students in particular the REU program is especially valuable in motivating participants to pursue high education and STEM-related careers.(2)

Research Skills and Professional Development:

The multi-programming model of the REU site in Nanotechnology for Health, Energy, and the Environment provides students with considerable opportunity for skill refinement in research training, professional development, and graduate school preparedness. As many of our REU participants (about 20%) have come from a community college environment in which development of such skills is a greater challenge, the inclusion of these skill refinement programs is especially important. Other programs have also reported on the effectiveness of professional development activities on the enhancement of the REU experience for students from diverse backgrounds.(3,4) The Center for Inclusive Education oversees the REU summer programming activities by using a multidisciplinary approach while collaborating with other areas of campus. REU students participate in both a 9-week Research Methods Seminar and a Graduate Prep Class that focuses on writing a personal statement for graduate school applications. These workshops were taught by Stony Brook Graduate students. This led to the development of near-peer relationships over the course of the summer.

Each week students participated in Lunch and Learn workshops in collaboration with the Center for Excellence in Learning and Teaching, the world-renowned Alan Alda Center for Communicating Science, the Office of External Fellowships, and the Career Center.

Program Title	Facilitator
Creating Connections	Alan Alda Center for Communicating Science
Teaching and Learning	The Center for Excellence in Learning and Teaching
Creating a Fellowship Application	Office for External Fellowships
Lessons Learned on the Path to the PhD	NIH IRACDA Postdoctoral Scholar
Graduate School Panel	Graduate School Program Directors
Preparing for a Career in Research	Career Center

The research skills and professional development programming led to an increase in participants confidence in their ability to conduct independent and collaborative research. Participants reported the following:

- *"It has made me a stronger researcher. It opened my mind to what graduate school can look like and how much of it depends on your own motivation."*
- *"I learned that a good scientific researcher should have important lab skills, leadership skills, collaboration skills, and be able to work independently."*

- *"I didn't have previous research experience. I did have classes with labs, but this was completely different. I feel now that when I go back to labs I'll be a better student because I had to work through things on my own."*
- *"I believe the skills that I learned this summer will greatly complement my career path. I am strongly considering going for a PhD before diving straight into industry, as one of my goals is also to teach college engineering courses part-time."*

Other Benefits

Although the primary goal of REU is to prepare students for graduate study and research careers, an inclusive community with trusted friendships has been documented as a necessary component of the summer experience, strengthening the learning culture. In addition to fostering a better sense of community, social and educational group programming can aid in bridging the isolation of scientific study. Cheruvelil, et.al. (1) have discussed the added value of such activities for fostering communication for diverse research groups in particular. Some activities included kayaking, paint nights, bowling, lunch socials with the graduate student community as well as trips to the federally funded nearby Brookhaven National Laboratory. Students praised the program's inclusive and inviting atmosphere, which the CIE and program staff helped to establish. As one participant stated: *"I really liked how the CIE (Center for Inclusive Education) did a great job of showing support to us. It was a great community to be part of. We had a lot more seminars and programs compared with some of the other REUs and I really liked how the CIE made us feel that our voices could be heard."* Other student comments included:

- *"The CIU was very welcoming - it's a place I just want to go to hang out with the staff, or even attend their socials going forward. One of the best socials was kayaking."*
- *"Our trip to Brookhaven National Lab was a really engaging experience for all of us - I think we all really enjoyed going and we all learned so much."*
- *"I really liked the graduate school panel we had - physics, BME, and engineering. We got asked all sorts of questions, some silly, some not, and they were really good about offering honest feedback, and gave us insight into how they approach the admissions process, so we had an idea for what they look for first, what would be a red flag."*

Program outcomes:

Assessment of program outcomes has included both immediate assessment of participant accomplishments as well as long-term tracking of participants via both direct communications as well as collection of data from internet searches and evolving Linkedin.com profiles. While such online searches are limited in the availability of data, it allows for the identification of publicly recorded achievements which are valuable for program evaluation.

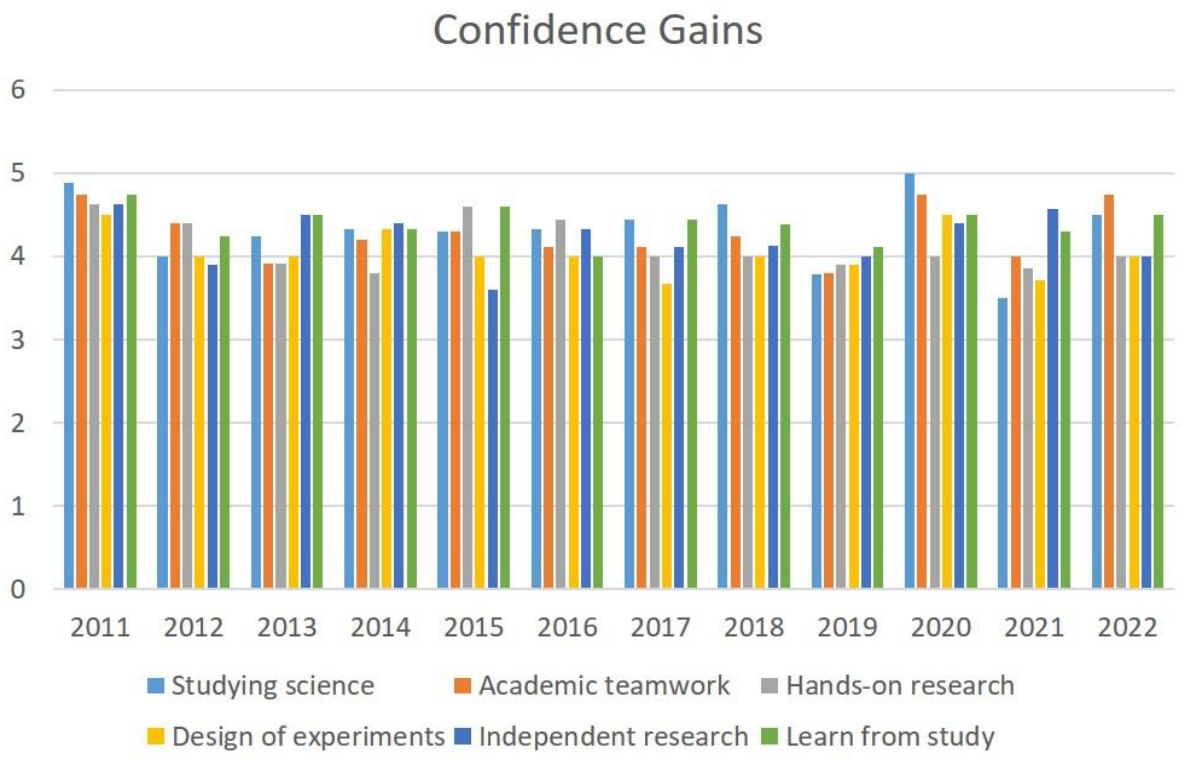

Figure 2: Tabulated results of Likert test of confidence levels in various abilities, measured at the end of the summer internship (and asked in terms of how much students feel this experience enhanced these interests and skills, with a rating of 5 indicating the strongest agreement). The legend represents shortened forms of the actual questions: Your level of satisfaction in studying science; your level of satisfaction with teamwork; your skill level with hands-on science; your level of confidence in designing an experiment; and your ability to learn needed information from reading and studying.

A. End of summer evaluation: Each year, the participants have been surveyed and interviewed by an external review team. Evaluations have specifically aimed to ascertain the overall effect of the program on student perceptions and skill-building achieved by the conclusion of the summer program. Figure 2 shows changes in students' confidence gains – in continuing to study science and STEM, in academic teamwork, in conducting hands-on learning activities; in design of experiments; in conducting independent research; and in learning from independent study and reading.

The student participants clearly gained in all areas of confidence related to the summer research experience, a strong indication that the REU program had its desired effect on enhancing the likelihood of student success in further STEM-related academic and research endeavors. This occurred throughout all years of the program, including the two years where research was conducted primarily remotely (2020 and 2021) due to COVID-restrictions in place on campus. In fact, 2020 (where research was conducted entirely remotely) was an especially strong year for confidence-building. What is equally impressive is a comparison of survey data collected on

levels of frustration reported by student participants, primarily due to poor research results or equipment limitations and breakdowns, with increasing confidence in studying in STEM disciplines.

It is of interest to note that confidence gains in studying STEM coursework and research remained high, despite the inevitable frustrations that can and will occur in the conduct of research (see Figure 3). The overall trend in frustration seems to have decreased slightly over the past decade, likely due to increasing faculty experience with providing an achievable and valuable summer research experience. In all cases, even where major equipment failures resulted in significant changes in direction of research or where experimental outcomes did not go as planned, student confidence in themselves remained high.

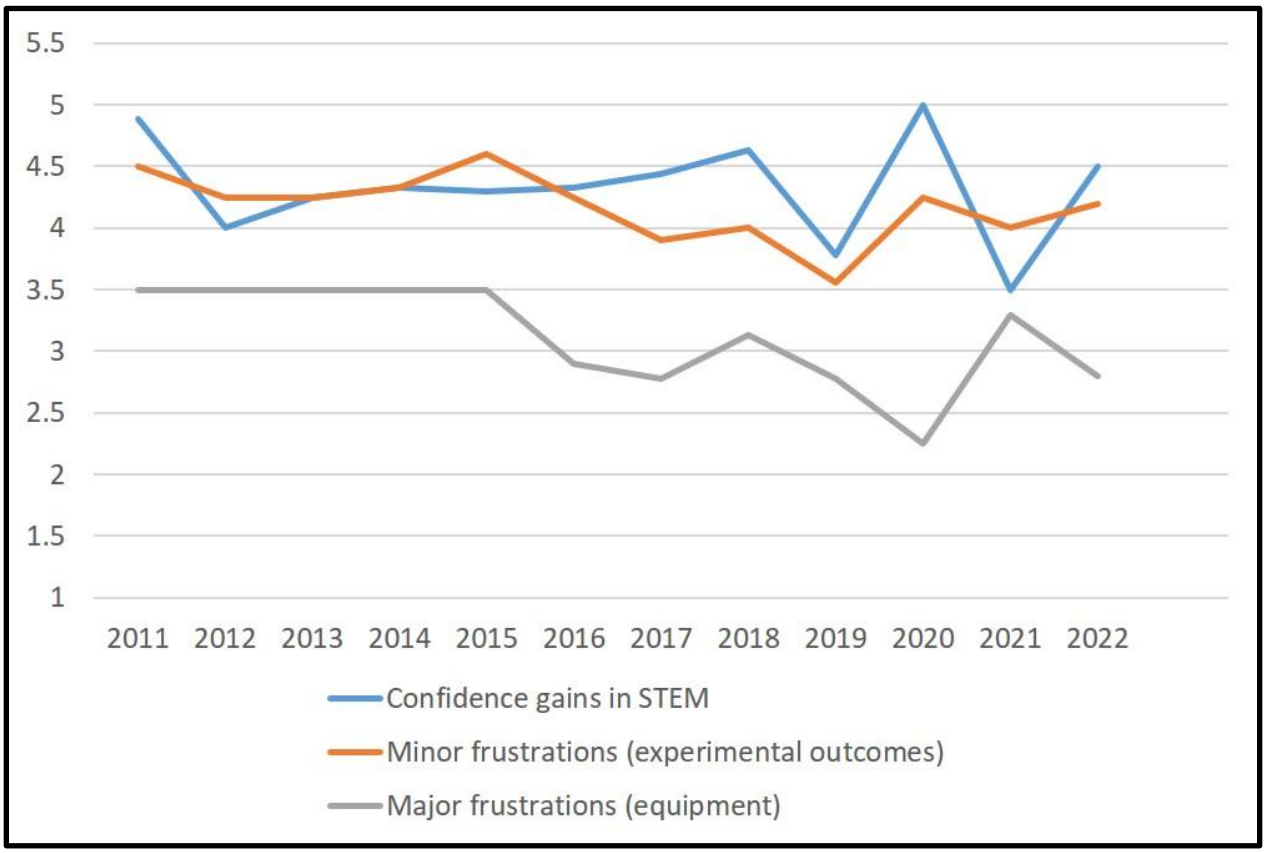

Figure 3: Charting of student confidence and satisfaction in studying STEM; compared with a Likert scale of agreement (5 being the highest) with the statement that (a) there have been minor frustrations in completing experiments and achieving results and (b) there have been major frustrations completing experiments, usually due to equipment issues.

This is especially significant as undergraduate research experiences have been shown to strongly contribute to self-efficacy for underrepresented minority students in STEM. (5) Yet little is written about the impact of frustration – whether from negative or unexpected experimental outcomes of due to equipment malfunctions – on experiential learning gains, and on self-efficacy specifically. Some studies have reported on finding learning opportunities in failure, whether that

refers to failure of equipment (6-7) or learning from failure itself in engineering courses (8). In our case, our evaluative feedback data indicates that enhanced confidence occurs for all our REU participants, which include a high percentage of students from underrepresented populations in STEM. It may be that learning to deal with frustrations in the research enterprise can enhance resilience for underrepresented students, or that these students already possess a degree of resilience due to their previous academic experiences (especially where such experiences have involved significant challenges to academic and personal success). In any case, it is crucial to better understand, design and implement approaches which enhance resilience and self-efficacy, especially for students from underrepresented demographics.

Based on feedback provided by program participants, we begin to see evidence that the types of activities and approaches developed for our REU program are providing a basis for confidence building and hence academic resilience. It has been reported that successful research mentoring enhances self-confidence. It is likely that such skilled mentoring is even more important when students are faced with frustrating situations or disappointments in the research enterprise. Students have specifically and repeatedly commented on the value of the mentoring experience. Mentors are repeatedly referred to as "attentive", as having provided a "meaningful (and well-planned) research experience", as "focused on student learning goals", as having developed strong connections with their research students, and having developed a supportive research structure through their labs and research groups. Further, in their comments, the REU participants highlight "a very strong coordinator and program staff", valuable preparation workshops for graduate studies and applying to graduate school, fun social activities which helped build connections among participants and with project staff, and a helpful orientation program and final symposium. All these features allow the program to build strong positive experiences (despite the unavoidable frustrations which can occur during true research into new knowledge). In turn, the outcomes of these experiences have resulted in long-term impact and success in STEM fields for almost all of our participants.

B: Long-term tracking: Online data has been located (and combined with information from communication of past participants with mentors and program coordinators) from 107 of the past participants. Key outcomes indicating the positive impact of the program include:

- Papers published in leading journals, including Electrochemical Society Transactions, ACS Catalysis, Journal of Catalysis, Angewandte Chemie International, Electrochemistry Communications, Nature Materials, Applied Catalysis B, Biomass and Bioenergy, Physical Review, Journal of Applied Sciences, Journal of Physical Chemistry, Columbia University, University of Pittsburgh, Rensselaer University, Journal of the American Chemical Society, Biomedical Nanotechnology, Inorganic Chemistry Frontiers, Materials Today, MRS Advances, Nanotechnology Reviews, Journal of Colloids and Interfacial Science, Coatings, Fashion and Textiles, Applied Surface Science.
- Graduate studies at leading institutions, including MIT, Northwestern, Stony Brook University, Cornell University, Vanderbilt University, Northeastern, University of California (Irvine), University of Nevada (Reno), Binghamton University, Rutgers, North Carolina State, Carnegie Mellon University.

- Further professional development and employment, including publication of a textbook on nanotechnology, an assistant professorship in chemical and biological engineering, manufacturing engineer in aerospace, post-doctoral researcher at Lawrence Livermore, several medical professionals, a vice president of engineering at a medical manufacturer, several environmental engineers at leading companies in the field, a scientist at US Air Force, and a number of staff scientists at national laboratories and consultants.

Future plans and recommendations:

The results of our assessment have indicated a strong level of success in building exciting and productive summer research and professional development experiences for our REU participants. This also provides an excellent opportunity to continue to build on these accomplishments as we plan for the future of our REU site. Specific areas in which we plan to build our activities include enhancing the role of industrial partners in supporting the summer research effort, including providing lectures on cutting-edge applications of nanotechnology in biomedical and energy-related sectors; working with an expanded range of partner feeder institutions, in particular those with large minority demographics; and recruiting new mentors among the incoming faculty (who themselves are from diverse backgrounds in STEM fields). In addition, we will continue to leverage the growing support, programs and activities for undergraduate research at Stony Brook, including integration of REU scholars with Stony Brook's interdisciplinary Vertically Integrated Project teams (a multi-level experiential education program focused on ling-term problem solving for key societal challenges).

Conclusions:

As we look back on the past years of the REU Site in Nanotechnology for Health, Energy and the Environment, we can demonstrate how active collaboration with the University's Center for Inclusive Education, including recruitment at national scientific conferences that focuses on participation from underrepresented demographics, campus visits to MSI, and use of social media and contact lists to reach out to minority-serving scholar programs and professional societies, has resulted in increased participation from underrepresented demographics. In addition, design and integration into the summer experience of enriching professional development activities, research knowledge and skill training programs, communication and graduate school preparation activities, combined with a cohort of excellent (and diverse) mentors, has led to a high degree of student reported program satisfaction and contributions to exceptional academic and professional careers of our former program participants. Further, it is important to note that the strength of the program and the dedication of support staff, mentors and their research teams enable students to report increased confidence and ability to study and conduct research in STEM fields, despite the expected minor (and major) frustrations inherent in the scientific research enterprise. This is especially valuable in supporting the academic and professional success of scholars from diverse backgrounds and will facilitate the continued success of our REU site program and other undergraduate research programs at our University.

Lessons learned can also support other undergraduate research programs by presenting and disseminating our site structure and operations.

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