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# An Effective Model for Enhancing Underrepresented Minority Participation and Success in Geoscience Undergraduate Research

Reginald A. Blake,<sup>1,a</sup> Janet Liou-Mark,<sup>2</sup> and Chinedu Chukuigwe<sup>3</sup>

## ABSTRACT

Geoscience research is a fundamental portal through which geoscience knowledge may be acquired and disseminated. A viable model to introduce, stimulate, and prolong geoscience education has been designed and implemented at the New York City College of Technology through a National Science Foundation (NSF) Research Experiences for Undergraduates (REU) program in satellite and ground-based remote sensing that targets underrepresented minority students. The program is composed of three primary components: *Structured Learning Environments: Preparation and Mentorship*, *Student Support and Safety Nets*, and *Vision and Impetus for Advancement*. The first component, *Structured Learning Environments: Preparation and Mentorship*, places REU scholars within a research team and provides them with the skill sets necessary for proficiency in satellite and ground-based remote sensing research. The second component, *Student Support and Safety Nets*, provides a structured and holistic learning environment that supports the undergraduates in becoming successful researchers and scholars. The last component, *Vision and Impetus for Advancement*, exposes the REU scholars to geoscience in a wider context and inspires them to envision themselves as the geoscientists and the science, technology, engineering, and mathematics (STEM) workforce professionals of the 21st century. Since the inception of this NSF REU program in 2008, 47 undergraduate students—39 (83.0%) of whom are underrepresented minorities in STEM (including women)—have completed geoscience research or are engaged in geoscience or STEM careers. © 2013 National Association of Geoscience Teachers. [DOI: 10.5408/12-417.1]

**Key words:** research experiences for undergraduates (REU); underrepresented minorities; science, technology, engineering, and mathematics (STEM); academic support; program design

## INTRODUCTION

The United States remains in grave danger of losing its global competitive edge in science, technology, engineering, and mathematics (STEM). Recent concerns were elevated into the national spotlight with the *American Competitiveness Initiative* of the Bush Administration (Domestic Policy Council, 2006) and the *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future* (Institute of Medicine, National Academy of Science, and National Academy of Engineering, 2007) report of the National Research Council. The Obama Administration has continued to address the STEM crisis by way of two national initiatives: the *Educate to Innovate* initiative (Obama, 2009) and the \$100 million government and private-industry initiative to train 10,000 STEM teachers and graduate 1 million additional STEM students over the next decade (Obama, 2012). In its February 2012 report to President Obama, the President's Council of Advisors on Science and Technology made the following five key recommendations to help in addressing the nation's STEM plight: (1) catalyze widespread adoption of empirically validated teaching practices, (2) advocate and provide support for replacing

standard laboratory courses with discovery-based research courses, (3) launch a national experiment in postsecondary mathematics education to address the mathematics-preparation gap, (4) encourage partnerships among stakeholders to diversify pathways to STEM careers, and (5) create a Presidential Council on STEM Education with leadership from the academic and business communities to provide strategic leadership for transformative and sustainable change in STEM undergraduate education. Yet these concerns are not new. In 1980, Congress first mandated the National Science Foundation (NSF) through the Science and Engineering Equal Opportunities Act to diligently seek to develop the STEM talents of the country's citizenry irrespective of gender, ethnicity, race, and economic background. This 30-year-plus battle to combat poor STEM performance among students and to diversify and increase the STEM workforce began last century, and it rages on today. With many—if not most—of the 21st-century STEM challenges coalescing around the geosciences (Earth, atmospheric, and ocean sciences), solutions to intricate and complex STEM challenges will require a new scientific workforce armed with innovation and a skill set that engenders technological sophistication and interdisciplinary thinking. Therefore, it is critical to train and to engage a diverse workforce in the geosciences and to educate the nation's citizenry—with its inherent diversity—about basic geophysical concepts and impacts. All demographic studies indicate that the country's current minority population will this century become its majority. Yet underrepresentation of minorities continues in STEM disciplines in general and in the geosciences in particular. For example, an NSF (2009) report documented that 22.7% of the traditional college-age students (18–24 years of age) in the United States are from

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<sup>1</sup>Physics Department, New York City College of Technology, 300 Jay Street, Namm 811, Brooklyn, New York 11201, USA

<sup>2</sup>Mathematics Department, New York City College of Technology, 300 Jay Street, Namm 711, Brooklyn, New York 11201, USA

<sup>3</sup>NSF CREST REU Program, City College of New York, 140th St and Convent Avenue, New York, New York 10031, USA

<sup>a</sup>Author to whom correspondence should be addressed. Electronic mail: rblake@citytech.cuny.edu. Tel.: 718-254-8582. Fax: 718-254-8595

underrepresented minority (URM) groups. However, they earn only 13.7% of all bachelor's degrees in the STEM disciplines. The American Geological Institute (2009) reported that compared to other science and engineering fields, the geosciences confer the lowest percentage of bachelor's degrees to URMs. The study also reported that the percentage of geoscience degrees earned by Hispanics and African Americans is only approximately 2%. A timely study by Gates and Mirkin (2012) further highlights the dismal national STEM landscape; it also offers recommendations and ideas that are useful and practical for ameliorating the national STEM crises.

A STEM gender gap also exists, and to close this gap, President Obama's *Educate to Innovate* initiative (Obama, 2009) stressed the importance of including women and girls in the current and future expansion of STEM education and career opportunities. Moreover, the U.S. Department of Commerce's Economics and Statistics Administration study (2011) highlighted that even though women make up approximately 50% of the U.S. workforce, they only comprise 24% of the STEM workforce. Therefore, to achieve general workforce parity, twice as many women need to be employed in STEM careers as are currently employed. In a study titled *Women, Minorities, and Persons with Disabilities in Science and Engineering*, the NSF (2013) found that although more women than men graduate from college with bachelor's degrees, men dominate the degrees earned in the STEM fields. The study further highlighted that the STEM workforce is largely white and male and that minority women make up less than 10% of it. In light of these alarming STEM gender inequities, program initiatives with an intentional recruitment strategy can be used as mechanisms to help redress and ameliorate this plight.

## ACADEMIC AND SOCIAL SUPPORTS FOR URMS THROUGH UNDERGRADUATE RESEARCH

A plethora of recent reports and studies have highly endorsed several recommendations to promote success in STEM for underrepresented minorities. For example, the National Academies (2011) advocate that programs should engage students in strong STEM communities to increase and enhance the students' identification and success with STEM. The report stressed that such programs need to provide academic, social, and financial support to students and that the programs need to support student transitions from undergraduate to graduate apprenticeship through research assistantships. The President's Council of Advisors on Science and Technology (2012) recommended support for early engagement of students in research, because faculty research projects are a direct way for students to experience innovation and discovery. Moreover, Toldson and Esters (2012) conducted a study on behalf of the Minority Males in STEM Initiative under the auspices of the Association of Public and Land-Grant Universities, surveying 1,443 STEM students during the fall 2011 semester. They concluded that high-achieving minority males in STEM disciplines require faculty engagement, involvement in undergraduate research, and financial support.

While research experience is one of the paramount interventions to retaining undergraduates in the STEM disciplines, its impact is even more significant for students

from URM groups. Previous research has investigated this type of exposure from many standpoints and has almost unanimously proclaimed the ample benefits of the undergraduate research experience. In a long-term study, Lopatto (2007) found that undergraduate research enhances the educational experience of science undergraduates, attracts and retains talented students to careers in science, and acts as a pathway for minority students to begin science careers. In a later study, Lopatto (2010) reported that results from the Summer Undergraduate Research Experience survey indicate that most research experiences not only enhance intellectual skills, such as inquiry and analysis, but also promote communication and teamwork. Gasiewski *et al.* (2010) reported that creating networks and informal connections through research programs, specifically for URM students, can eradicate racial isolation and positively affect the students' ability to successfully persist in STEM. Newman (2011) found that African American engineering students' involvement in faculty research laboratories supplied them with the much-needed practical application and relevance that gave meaning to their coursework.

Recent studies have also shown that identification with a group of STEM scholars may increase persistence and decrease departures from STEM fields (Estrada *et al.*, 2011). Espinosa (2011) reported that women of color who persisted in STEM had developed meaningful relationships with faculty and peers both in research laboratories and in robust STEM communities. The Toldson and Esters (2012) study mentioned earlier reported that successful minority male STEM students benefitted from being engaged in not only undergraduate research but also relationships with mentors who "understand their culture." Junge *et al.* (2010) found that their Summer Undergraduate Research Experiences program enhanced research skills and interest in academic research careers. Their data indicate that participation in their summer research program significantly increased both the number of science courses taken and the overall grade point average (GPA) of the students. This was found to be particularly true for women and minorities.

In general, therefore, undergraduate research experiences provide (1) motivation to persist in science; (2) increased postsecondary attainment in a STEM discipline; (3) a supportive community of scientists and peers; (4) a comprehensive mentoring experience, especially in diversified research teams; (5) paid research internships for the summer, academic year, or both; (6) strong preparation for graduate school studies; (7) an enhancement of research proficiency; (8) an academic enrichment involving learning new concepts, tools, and skills; and (9) opportunities to share and gain knowledge at conferences and seminars.

## NSF RESEARCH EXPERIENCES FOR UNDERGRADUATES IN SATELLITE AND GROUND-BASED REMOTE SENSING

### Mission of the NSF Research Experiences for Undergraduates Program

As noted earlier, early and continual research engagement remains a most effective means of attracting and retaining undergraduates in STEM disciplines and in preparing them for STEM careers. However, opportunities for undergraduates to participate in STEM research experi-

ences are still few and limited, particularly for URM students. To address this imbalance and to meet this need, the NSF uniquely designed and instituted its Research Experiences for Undergraduates (REU) program. Annually, the NSF REU program creates opportunities and supports thousands of undergraduates to actively participate in STEM research. The REU program engages undergraduates in meaningful, goal-oriented research projects that provide transformative experiences that incubate and prepare students for the next level of academic growth, participation, and development. Directors of REU programs are encouraged by the NSF to seek, include, and increase the STEM research participation of underrepresented minorities, women, and people with disabilities.

### **New York City College of Technology's NSF CREST REU Program**

To assist in ameliorating the national STEM plight, New York City College of Technology (City Tech) designed its recently awarded NSF REU program in satellite and ground-based remote sensing to target URM students. The REU site is the Cooperative Remote Sensing Science and Technology (CREST) Center located at The City College of New York, City Tech's sister City University of New York (CUNY) institution. CREST is a National Oceanic and Atmospheric Administration (NOAA) research facility that specializes in satellite and ground-based remote sensing research. CREST partners with City Tech in this critical REU venture by providing resources, equipment, expertise, space, and other tangible access and opportunities to the REU scholars. REU scholars participate in remote sensing research projects that focus on the application of satellite and ground-based remote sensing to the study of the Earth's atmosphere, hydrosphere, cryosphere, biosphere, and lithosphere. Therefore, they are actively engaged in a range of STEM research projects that includes the study of hurricanes, atmospheric water vapor distribution, soil moisture, vegetation, sea ice, air quality, coastal waters, and climate change.

### **Project Goals**

The overall goal of the City Tech NSF REU site program at CREST is to continue to provide state-of-the-art satellite and ground-based remote sensing basic research experiences and STEM academic and research advancement opportunities primarily for students at the CUNY who are traditionally underrepresented in STEM. Its purpose is to promote research careers, to establish a community of scholars, to provide students with an opportunity to pursue master's and doctoral graduate programs in STEM, and to equip students with the tools necessary for the 21st-century STEM workforce.

### **REU Scholars**

The REU scholars were solicited and selected from CUNY's 23 individual institutions. The requirements for the candidates were the following: a STEM major, preferably in their junior year; U.S. citizen or permanent resident; and a GPA of 3.0 and above. Each candidate completed an application and was interviewed. Since the inception of the REU program in 2008, 47 REU scholars—39 (83.0%) of whom are underrepresented minorities (including women) in STEM—have completed or are continuing their STEM research or are pursuing their STEM endeavors (graduate

school or STEM workforce). Among the 47 students, 51.1% identify themselves as African American (non-Hispanic), 14.9% as Hispanic, 19.1% as Asian American or Pacific Islander, 12.8% as Caucasian, and 2.1% as other. They consist of 33 (70.2%) males and 14 (29.8%) females, and efforts to recruit more females, specifically URMs, into the REU program are being continued. The majors of the REU scholars encompass the disciplines of environmental science, applied mathematics, physics, computer science, civil, electrical, mechanical, and environmental engineering. Of the 47 REU scholars, 10 are "leveraged" students who wanted to benefit from this rich NSF research experience. These leveraged students (some from other universities, but most from CUNY) were not directly or completely funded by the NSF REU program. Primary funding for leveraged students came from other programs or sources. Almost all students (formal and leveraged) in the program were recruited from the 23 campuses that comprise CUNY (the largest urban public university in the nation, serving nearly 500,000 students), so these students are mostly within the same interconnected New York City area. The proximity of their institutions allows them to continue their research experience with the REU program during the academic year, which is a distinctive facet of the program. The few leveraged students who are non-CUNY REU scholars return to their home institutions after the summer has ended, and they are encouraged to remotely continue their research experience via collaborations with the REU mentors assigned to them during the summer. Some of them have done so.

## **NSF CREST REU PROGRAM DESIGN**

The NSF CREST REU program is designed to provide the academic and social supports (specifically for URMs) that the recent literature identifies as best practice. The program is composed of the following three primary components: (1) *Structured Learning Environments: Preparation and Mentorship*, (2) *Student Support and Safety Nets*, and (3) *Vision and Impetus for Advancement*. These three synergistic components are highlighted in Fig. 1.

### **Component 1: Structured Learning Environments: Preparation and Mentorship**

The *Structured Learning Environments: Preparation and Mentorship* component provides the REU scholars with a research experience that trains and advances them with the skill sets necessary for proficiency in satellite and ground-based remote sensing research and with a structured mentoring program that supports and enhances student success.

### **The REU Program Design**

The year-round academic program engages students for 9 weeks in the summer, 3 weeks in the fall semester, a wintermester, and 3 weeks in the spring semester. During the summer, students are immersed in research full time. During the fall and spring semesters, when course work takes precedence over research, the commitment to the research project is spread over the entire semester and is scheduled each week on Fridays for 4 hours.



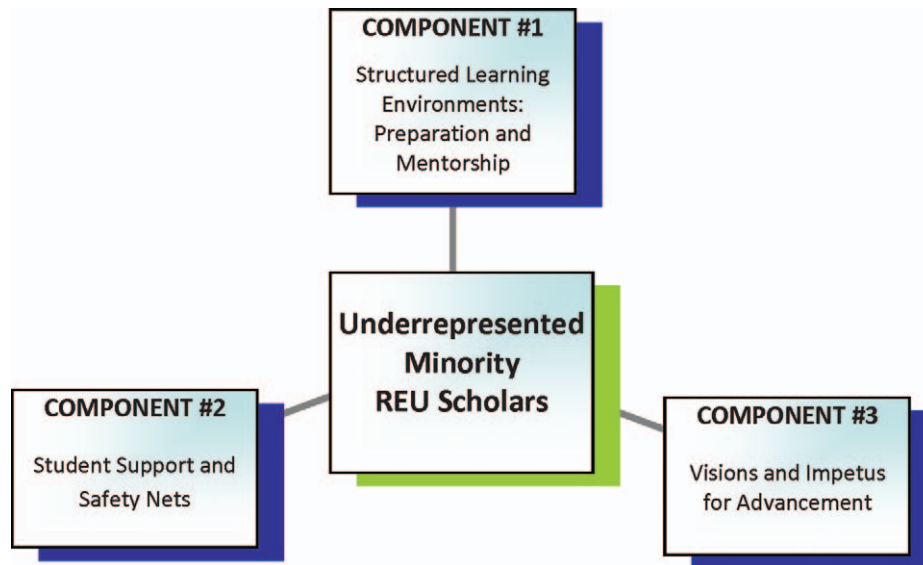


FIGURE 1: NSF CREST REU program design.

### *Summer Research Program: 9 Weeks*

#### *Orientation*

The summer research experience of the REU program begins in June with a REU kickoff meeting that is attended by all REU scholars, NOAA-CREST research scientists, postdoctoral fellows, and graduate student mentors. The 3-week orientation provides a comprehensive overview of the REU program. During the first week of orientation, NOAA-CREST scientists, researchers, and doctoral students present the spectrum of satellite and ground-based remote sensing research that is conducted at NOAA-CREST. After this first week, the REU scholars select a remote sensing research area that they are most interested in. The second and third weeks of orientation consist of providing them with the tools and the skills necessary for research. During this time, the REU scholars are enrolled in three minicourses: MATLAB, Remote Sensing, and Geographic Information Systems (GIS). After the orientation period, each REU scholar is placed in a research team composed of one or two NOAA-CREST faculty mentors, a NOAA-CREST research scientist, a postdoctoral fellow, a graduate student, and one or two high school students. The REU scholars then spend the next 6 weeks engaged in satellite and ground-based remote sensing research.

#### *Research Symposium*

The summer component of the REU program concludes with a major 1-day research symposium in early August. This summer-ending research summit is a culminating event for the many federally funded summer research internship programs in and around the New York City tristate region. Approximately 300 students who receive funding from NSF, National Aeronautics and Space Administration, and NOAA participate in this summit with both poster and oral presentations. The summit is organized, administered, and managed by CREST and by the principal investigators of programs funded by the federal agencies listed earlier. Program managers and program directors from these federal agencies participate in the summit by making oral presen-

tations and by availing themselves to students and faculty thereafter to discuss funding, scholarships, internships, and other scholastic and research opportunities. The summit is a highlight of the summer research experience, because it brings together a rich, diverse pool of students, researchers, faculty, and federal administrators to celebrate student achievement and to motivate students to continue on the pathway toward graduate school.

#### *Fall and Spring Semesters: 6 Weeks*

During the fall and spring semesters, the REU scholars continue to work with their mentors and their research teams, albeit at a reduced pace. Primarily in the fall and spring periods, the students showcase their fine-tuned summer research projects at the numerous national, regional, and local conferences at which they are mandated to present.

#### *Wintermester*

The REU program remains active throughout the month of January, when CUNY is on winter break and classes are not in session. REU scholars use this time to complete unfinished fall research commitments or to advance their research projects. At the end of January, they present their updated research findings and most recent scholarly accomplishments. These presentations are made to members of the NSF CREST REU program community. In addition, the REU scholars participate in a 2-day NSF CREST REU program-sponsored Ethics in Science workshop that is taught by an expert in research ethics. The workshop covers major research ethics topics, such as the applicability of ethical concepts to science, the philosophical and historical underpinnings of research ethics, ethical principles as they apply to research, issues of misconduct, conflict of interest, intellectual property and patents, authorship, mentorship, and peer review. The workshop brings awareness to the many ethical issues that must be adhered to when conducting research and writing research papers.

Therefore, a rich calendar-year research experience in satellite and ground-based remote sensing, from June to the

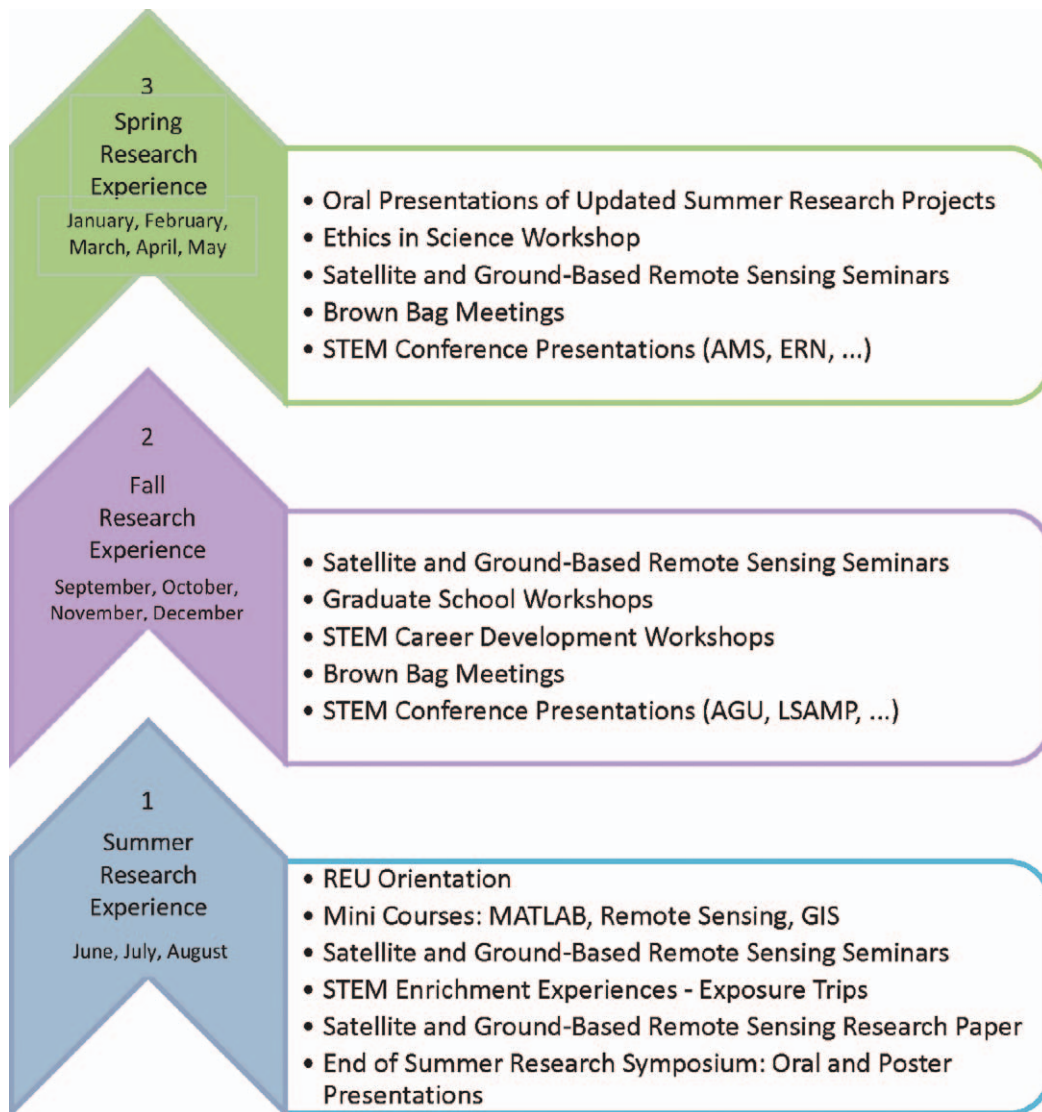


FIGURE 2: One-year timeline of NSF CREST REU program activities.

following May, is provided to the REU scholars. Figure 2 highlights the REU program activities.

### Minicourses

REU scholars come from diverse educational backgrounds, and they often do not have the necessary knowledge or skills for research. To prepare and equip the students with the tools needed for satellite and ground-based remote sensing research, the REU program sponsors three essential minicourses: MATLAB, Remote Sensing, and GIS.

### MATLAB

The MATLAB short course is designed to introduce students to the basic functionality and programming environment of the matrix laboratory programming language. The MATLAB computing environment has become an industry standard in science and engineering due to its versatility and relatively simple syntax. Throughout the course, students are exposed to basic programming tools and their applications to remote sensing. Moreover, basic

statistical, graphics, and mapping tools critical for data analysis and visualization are emphasized. Students are provided exercises and assignments to analyze real data sets from both satellite and ground-based measurements.

### Remote Sensing

In the Remote Sensing minicourse, students are given a basic, fundamental introduction to remote sensing and its many geoscience applications. The course provides the REU scholars with a physical understanding of measurements from space and of the various platforms that are used for remote sensing applications. Polar orbiting satellites, geostationary satellites, active and passive systems, the atmosphere and atmospheric sounding techniques, interferometric and light detection and radar systems, image processing, and radiative transfer are introduced in this course. At the end of the course, the REU scholars are exposed to the many techniques used to parameterize and transform remote sensing backscatter into useful estimates of environmental quantities.

## Geographic Information Systems

The final minicourse covers fundamental GIS concepts. It includes querying of a GIS database, manipulating tabular data, editing spatial and attribute data, and presenting data clearly and efficiently using maps and charts. Students learn the concepts of data sets, map layers, area measurement, scale, and symbology. These skills allow the REU scholars to confidently use GIS tools and to make maps relevant for remote sensing applications.

## Seminars and Workshops

### Seminars

Each week during the summer, at least one seminar is conducted by faculty from NOAA-CREST, and it is mandatory that all REU scholars attend. NOAA-CREST also has a fall and a spring weekly seminar series, and REU scholars are mandated to attend at least two of these seminars during each of the semesters. The seminar series serves as a tremendous catalyst to motivate the REU scholars. Through these seminars, the REU scholars have been exposed to all aspects of satellite and ground-based remote sensing, because experts from all over the nation and the world participate in this rich forum.

### Career Development Workshops

Workshops conducted throughout the REU program focus primarily on STEM careers. These workshops are conducted by employees from NOAA line offices and NOAA-CREST industry partners. These industry partners use NOAA-CREST as part of their career-worker recruitment program and frequently hire NOAA-CREST graduates. Moreover, a major goal of this program is to diversify and replenish this nation's STEM workforce in general and NOAA's workforce in particular. The REU scholars receive ample encouragement to seek academic paths that lead to STEM careers.

## Multitiered Mentoring

The REU program embeds a multitiered mentoring segment that mirrors a community of practice. According to Wenger (2006), "Communities of practice are formed by people who engage in a process of collective learning in a shared domain of human endeavor." Each REU scholar is a member of a team that consists of faculty mentors, research scientists, postdoctoral fellows, graduate students, and high school students. The faculty mentors are the NOAA-CREST research scientists who design the research projects for the REU scholars. These faculty mentors typically have postdoctoral research scientists and graduate students working in their laboratories. These advanced students are trained and guided by the faculty mentors. They become a valuable resource in the mentorship chain as they share their experiences and expertise with the REU scholars. Therefore, the REU scholars become integral participants within a community of learners. In addition to being mentored by experts and advanced students in the field, they are expected to provide guidance to the high school students involved in the program, many of whom are also from underrepresented groups.

## Component 2: Student Support and Safety Nets

The *Student Support and Safety Nets* component integrates REU scholars in a learning environment in which they

are never isolated or unsupported. These structures support a culture of a professional partnership and enhance the quality of the research experience. Through networking sessions, brown bag meetings, social events, graduate school workshops, and counseling, these mentor and peer interactions sustain and promote the successful accomplishments of the REU scholars.

## Networking Sessions

Monthly special networking sessions with research scientists, postdoctoral fellows, and graduate students are organized so that REU scholars are provided with the opportunity to expand their professional community. Often taking place outside of the college environment, the informal setting encourages new contacts and fosters an exchange of ideas beyond the research laboratory setting. The engaging discussions that stem from these sessions stimulate the students' passion, knowledge, and understanding of their projects and strengthen their involvement and enthusiasm of the research process.

## Brown Bag Meetings

During the summer, weekly mandatory brown bag meetings provide students with a free-flowing open forum to discuss issues related to their research and to be surrounded by like-minded peers. These sessions are led by senior NOAA-CREST research scientists, graduate students, or both. The discussions focus on a variety of issues ranging from research, to graduate school success, to politics or baseball. During the fall and spring semesters, REU scholars meet monthly to provide an update of their research projects and learn about opportunities to foster their research development.

## Social Events

REU scholars spearhead the planning and the execution of the program's annual summer picnic. The picnic is a success because it not only gives them an opportunity to forge lasting friendships outside of the research venue but also affords them a chance to interact with research scientists, faculty, postdoctoral fellows, graduate students, and their peers in an informal atmosphere. Engaging in sports and games with the scientists has become a valuable social experience.

## Graduate School Workshops

One of the goals for this REU program is to create an undergraduate pipeline to graduate school. REU scholars are strongly encouraged to continue their research experience with the REU program at the graduate level. Graduate school support is provided by offering free Graduate Record Examination preparation courses. These courses are usually cost prohibitive for many URM students. Workshops on the graduate school application process, scholarship and fellowship applications, writing personal statements, and constructing resumes are also given during the academic year.

## Counseling Support

A partnership with the Counseling Services Center at the college was established to provide the REU scholars with services pertaining to their educational, psychological, and career development. Many of them are first-generation college students who are often faced with issues that can



impede and even cripple their academic progress. Accessibility to counseling services plays a pivotal role in maintaining emotional, social, and academic health and success of these students.

### Component 3: Vision and Impetus for Advancement

The *Vision and Impetus for Advancement* component allows REU scholars to see themselves as STEM scientists and STEM workforce professionals. Through national, regional, and local conferences and STEM enrichment experiences, the REU scholars are exposed to cutting-edge technology, state-of-the-art equipment, prominent scientists, and people in the forefront of STEM advancement.

### STEM Enrichment Experiences

STEM exposure events provide REU scholars with an opportunity to meet scientists working in industry and to talk with them about the requirements and the rewards of STEM careers. These field trips motivate and inspire the students to keep aspiring toward STEM success, and they provide the students with a vision of who they can become after formal academic training is complete.

STEM exposure events include the following locations:

- *The Brookhaven National Laboratory*—Weather balloon launches at the National Weather Service are observed. Weather camps and meteorological workshops are also provided.
- *The National Center for Weather and Climate Prediction*—REU scholars are provided with lectures and tours. Opportunities to interact with the operational scientists who are on duty monitoring and predicting atmospheric and oceanic dynamics provide an engaging experience.
- *The American Museum of Natural History*—Climate change and astronomy exhibits are highlighted at the museum.
- *The Cary Institute of Ecosystem Studies*—Forums on translational ecology are provided.
- *The Solar Panel House*—Demonstrations of how solar energy can be used to provide 100% of the energy needs of a house are presented.

### STEM Conferences

At professional organizational meetings, REU scholars embrace a vision of themselves in a greater academic society, consequently providing them with a motivation to continue in their STEM areas of study as highlighted by Mabrouk (2009). They present their research and participate at national, regional, and local conferences sponsored by the American Geophysical Union (AGU), the American Meteorological Society (AMS), the NOAA Educational Partnership Program, the Louis Stokes Alliance for Minority Participation (LSAMP), the National Organization for the Professional Advancement of Black Chemists and Chemical Engineers, the NSF Emerging Researchers National Conference in STEM (ERN), and the Mathematical Association of America.

These crucial activities open a new vista of the research world to them. The benefits they gain from preparing and presenting their research projects, from being exposed to recent developments in the field, and from the many opportunities to network and to discuss research projects

and interests with their peers and other scientists are invaluable. Moreover, some national conferences provide workshops about the graduate school application process, and they offer sessions in which undergraduates meet and speak with representatives from various universities and graduate programs. Traveling away from home to these conferences (for some REU scholars, these trips afford them their first opportunity to travel on an airplane or outside of New York City and away from their local communities) builds camaraderie among the REU scholars. These scholarly activities help to develop and cement a tightly knit community and forge strong, lasting friendships.

Besides presenting at conferences, REU scholars have represented the REU program as STEM ambassadors at several local events. They are usually solicited to discuss their research experiences at the institution's freshmen orientations, bridge programs, research mixers, internship and fellowship seminars, and geoscience events.

### PROGRAM OUTCOMES

The outcomes from the NSF CREST REU program have been exceptionally positive. Of the 47 REU scholars who have or who are participating in the program, 25.5% (12) are in graduate school in the STEM disciplines, 4.3% (2) have completed a master's degree and are now employed in the STEM workforce, 21.3% (10) have completed a bachelor's degree and are now employed in the STEM workforce, and 48.9% (23) are persisting in their STEM majors. Moreover, 3 of the REU scholars won first place recognition for their research, and 3 other REU scholars are coauthors for two peer-review publications and one book chapter. In addition, recent survey results show that 84% of the REU scholars now indicate interest in pursuing master's degrees in STEM, and 75% indicate an interest in pursuing doctoral degrees in STEM. The REU program boasts a 100% STEM retention rate for its REU scholars.

### STUDENT TESTIMONIALS

The following are quotes from REU scholars about the effectiveness of the program and how it has helped to transform their academic lives.

*"Already my work with the NSF CREST REU program has helped to shape my understanding of environmental issues. This research using satellite remote sensing of the Earth and its processes has given my studies at City College a new direction with deeper meaning."*

*Avani Ogwaro, Environmental Engineering major, junior*

*"Participating in the NSF CREST REU program was more than just an eye-opener; it exposed me to the scientific community, allowed me to present my work at a number of conferences in the United States, led me to a series of new opportunities, and compelled me to expand my career goals. In fact, it was this program that made me realize that a career in research was what I wanted, and my pursuance of a Ph.D. in engineering or science was no longer optional—it was essential. Upon graduating from the City College of New York, using the multidisciplinary experience that I've acquired through both my research and curriculum, I hope*



*to shift my focus of research towards environmental sustainability and help to revolutionize engineering designs and strategies.”*

*Adam Atia, Earth System Science & Environmental Engineering major, senior*

*“My undergraduate research experience helped me to acquire key knowledge of remote sensing from basic light/matter interactions in the atmosphere to the signal processing required to gain representative information about the environment. Because of this, I was awarded a scholarship to a master’s program.”*

*Abdul Jollah, graduate student*

*“My research experience at the REU program helped me to appreciate the pleasures and the hard work associated with doing research at the graduate level. In July 2009, I had the opportunity (via the NSF CREST REU program) to be part of a group of dedicated students and scientists from across the country to investigate cross-Atlantic Saharan aerosols. During this month, we worked different shifts and late hours for the different projects we were assigned to. It was during this month that I also nurtured and developed the hard-working attitude that I summoned at the graduate level. In September 2009, I joined NOAA-CREST as a CREST scholar, where I had the privilege to work with great professors at City College doing research in satellite remote sensing. The REU experience, to a great extent, made my master’s degree research experience so much more enjoyable; it allowed me to develop the set of skills required to do research at a graduate level. Today, I am a new hire at the United States Patent and Trademark Office (USPTO), and I am so grateful for the opportunity I was given to do research as an undergraduate and later as a graduate student because the experience prepared me to better do my job at USPTO.”*

*Ibrahim Siddo, master’s degree graduate, STEM workforce*

*“The REU program continues to impact my career and my professional growth. I am very happy to be a part of this research program that collaborates with the faculty and students. The program has taught me how to analyze data, write a technical paper, [and] prepare and make both oral and poster presentations. I was able to participate in fieldwork studies in Chesapeake Bay with my coastal remote sensing research team, and that was a tremendous bonus for my experience. In addition, being affiliated with this REU program provided me with the opportunity to make presentations at prestigious conferences such as AGU, AMS, LSAMP, and ERN. I am excited to network with other professionals around the nation and to present my work in those conferences. Overall, I am very grateful for having the REU program prepare me, as an undergraduate student, for graduate school and for the STEM workforce through its many rewarding activities and events.”*

*Lena Lai, Earth and Atmospheric Sciences major, junior*

These testimonials are evidence of the impact the NSF CREST REU program has had on the lives of its REU scholars. Many of these minority students would not have

pursued advanced degrees were it not for the training and the rich experience that they were given through this program. The program helped to mature the REU scholars even in their undergraduate scholarship. The NSF CREST REU program gave them the tools, the skills, the confidence, the assurance, and the comprehensive, holistic perspective needed to better understand the underlying complexities of geoscience and the role that they must play in unraveling these complexities.

## CONCLUSION

As our nation wrestles with a deepening STEM crisis that is exacerbated by diversity and gender issues, programs like the one described here are more needful. This NSF CREST REU program model is one example of how the next generation of scientists may be cultivated, nurtured, and inspired. The program underscores and emphasizes that advancement, success, and preparation of undergraduate students in STEM (and particularly in the geosciences) must coalesce around rich, transformative STEM research experiences. The City Tech NSF CREST REU program offers an effective model of student engagement and training that is portable, sustainable, and practical. The program is built on the three fundamental pillars of (1) *Structured Learning Environments: Preparation and Mentorship*, (2) *Student Support and Safety Nets*, and (3) *Vision and Impetus for Advancement*, and it derives its success from overall activities (research and otherwise) that are proactive, intrusive, and student centered. It provides intentionally targeted academic and cultural (diversity awareness or multicultural sensitivity programs) support services and actively engages a diverse cohort of REU scholars in state-of-the-art satellite and ground-based remote sensing at the premier NOAA-CREST remote sensing facility. This comprehensive, holistic approach to the acquisition of geoscience knowledge has the added value of transforming undergraduates into a unique and vibrant community of learners while concurrently helping to replenish the nation’s STEM workforce. We believe that the following six programmatic nuggets are essential for inclusion in programs that may seek to replicate and emulate the one described here:

1. Providing a well-resourced, active research site like CREST that not only is engaged in state-of-the-art, transformative research projects but also has an abundance of research faculty and graduate students who take seriously the mission of training and preparing undergraduate students.
2. Adequately preparing the undergraduates before beginning research. Many of the students come to the program lacking the knowledge and skill sets necessary for a fruitful research experience, so providing preresearch preparation, like the mini-courses offered in this program, is tremendously helpful.
3. Implementing an active mentoring system that ensures student research support and that builds a community of learners. Students should not be isolated; rather, they should genuinely feel and know that they are part of a larger community that is nurturing and supportive.

4. Acknowledging and embracing of both racial and gender diversity. These help to promote sharing, partnering, and peer mentoring among the students, because they break down cultural and gender barriers and encourage students to build sustained scholastic relationships and friendships. They also create scholastic communal bonds that make for a richer research experience.
5. Providing outlets for students to showcase their work and to participate in the wider community of scholars. Having students present their research at national, regional, and local conferences and publishing their work in peer-reviewed journals as authors or coauthors is highly motivating for the students.
6. Offering STEM and geoscience exposure events that help to inspire students to see themselves as part of the future STEM workforce.

This undergraduate research program and project will be sustained and institutionalized at City Tech through the formation of a new geoscience center—The Center for Remote Sensing and Earth System Sciences (ReSESS). ReSESS will be a satellite program of CREST, and it will be intricately connected to CREST through joint research activities, programmatic initiatives, and a shared vision. ReSESS aims to embrace the creation of a viable and vibrant undergraduate research program. The center plans to recruit, retain, support, and challenge a diverse population of students, particularly those who are underrepresented minorities in STEM. These efforts should support the nation's need to build and to maintain a strong 21st-century STEM workforce.

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## Errata

In the article by Reginald A. Blake, Janet Liou-Mark, and Chinedu Chukuigwe, “An Effective Model for Enhancing Underrepresented Minority Participation and Success in Geoscience Undergraduate Research,” which appeared in

the *Journal of Geoscience Education*, 61(4) on pages 405–414, incorrect received and revised dates were inserted during production. The received date should have been 31 December 2012 and the revised date should have been 23 August 2013. We apologize for these errors.