Space Weather

FEATURE ARTICLE
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Key Points:
- Community colleges are important in the STEM pathway for underrepresented minorities and nontraditional students interested in STEM.
- Engaging community college students early in space weather research and activities increase their interest in space science and STEM.
- Using large geospace data sets in the classroom increase students’ computational, critical thinking, and data analytical skills.

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Abstract
Community Colleges provide a great opportunity to diversify the space sciences or other science, technology, engineering, and math (STEM) fields due to their large population of underrepresented students. However, since the primary mission of community colleges is teaching, there is a challenge to support undergraduate research training and promote undergraduate research opportunities. Undergraduate research experiences are one of the leading high-impact practices (HIPs) to encourage students to pursue STEM majors, graduate degrees, and careers. Space weather provides the opportunity to engage undergraduate students in real-world research due to the accessibility of space mission data sets within open access data repositories. Space weather’s impact on Earth’s geospace environment, life, and society also provides a compelling real-world hook to engage students in activities that have a number of impacts including (1) long-term integration of space weather into the undergraduate curricula; (2) experience in analyzing large geospace data sets, which increases students’ computational, critical thinking, and analytical skills, useful for any career; and (3) increase in students’ interest in and motivation to study STEM, as well as preparing them for choosing a career path in space science and related fields. The model presented below has the potential to increase the retention, graduation, and transfer rate of community college students to four-year STEM programs, as well as increase representation and inclusion in space sciences and other related STEM fields.

1. Introduction

Although many community college students have not heard of the term space weather, it has significant impact on an increasing technological society, making it relatively easy to connect to the internet and smartphone generation. Space weather is defined as “... any and all conditions and events on the sun, in the solar wind, in near-Earth space, and in our upper atmosphere that can affect space-borne and ground-based technological systems and through these, human life and endeavor (National Research Council (NRC), 2008).” These effects include among others: damage to satellites, damage to electric power transformers, degradation of the accuracy of Global Navigation Satellite System (GNSS) applications, and high-frequency communication (Lanzerotti, 2001). Interdependencies of the nation’s critical infrastructure and resources today can result in disruption with cascading effects. For example, the loss of power could also affect water, food, communication, banking, and finance. Students are familiar with the effects of natural disasters, including both economic and societal issues, which can help them understand the effects of space weather. In New York City for example, students were not immune to the impact of Hurricane Sandy and its cascading effects on critical infrastructure where the costs and consequences were severe: water, transportation including the availability of gasoline, and housing. The threat presented by space weather is severe enough to warrant it a spot as a natural disaster on the U.S. Department of Homeland Security ready.gov website. As society’s dependence on technology increases, so does the potential impact of space weather. As noted in the Solar Physics Decadal Survey Committee (Solar and Space Physics: A Science for a Technological Society, NRC, 2013), “... a thriving field of solar and space physics requires continued outreach to the general public and in particular to students who will become the next generation of space scientists.”
Initiated in spring 2015, the QCC Space Weather Research and Education Program (QCC SWREP) is a partnership between the Queensborough Community College (QCC), the Community Coordinated Modeling Center (CCMC), based at the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (NASA GSFC), and two 4-year colleges: The City College of New York (CCNY) and York College (York). QCC, CCNY, and York are constituent campuses of the City University of New York (CUNY) system—the nation's largest urban public university, with 274,000 students enrolled in 11 senior colleges, 7 community colleges, and 7 postgraduate institutions. CCMC is a multiagency partnership facility that supports and performs research and development for next-generation space science and space weather models. CCMC also supports education through the Space Weather Research, Education, and Development Initiative. CCMC staff consists of NASA civil servants, contractors, and postdoctoral fellows from various disciplines.

QCC SWREP's mission is to use space weather as a vehicle to interest, motivate, and retain students in STEM. QCC SWREP has promoted an interdisciplinary approach to training future generations of STEM students using mentors from both science and engineering disciplines. Through this unique partnership, students are engaged in a year-long research experience with two components: (1) during the academic year, students are enrolled in undergraduate research courses and contribute to the general body of knowledge of space weather and (2) during the summer, students are placed in research internships at partner institutions at either NASA GSFC, CCNY, or York. Educational materials are also developed that use real-time and archival data from both space-borne and ground-based instruments that enrich QCC physics curriculum for both STEM and non-STEM majors. Space weather research and education activities have a number of impacts, including (1) long-term integration of space weather research activities into the undergraduate curriculum, thus exposing students to research early in their academic careers; (2) experience in analyzing large geospace data sets, which increases students' computational, critical thinking, and analytical skills, useful for any career; and (3) increase in students' interest in and motivation to study STEM, as well as preparing them for choosing a career path in STEM. The program is anchored by evidence-based best practices (i.e., mentoring, financial support, professional development) that have proven successful at increasing the retention, transfer, and graduation rates of community college students (Cejda & Hensel, 2009; Kuh, 2008; Nerio et al., 2019). The model presented below has the potential to increase the retention, graduation, and transfer rate of community college students to four-year STEM programs, as well as increase representation and inclusion in space sciences and related STEM fields.

2. Undergraduate Research at Community Colleges: Opportunities and Challenges

The United States needs more STEM graduates in both number and diversity that can in the long-term impact the U.S. economy (Wilson, 2016). A 2012 report to the President, Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering and Mathematics (President's Council of Advisors on Science and Technology (PCAST), 2012), predicts that over the next decade, the U.S. workforce will face a shortage of one million college STEM graduates and calls for addressing the shortfall by increasing retention of college students in STEM. With a large population of untapped students, especially underrepresented groups (minorities, women, and first-generation students), community colleges represent a new source of talent that can increase the diversity of the U.S. STEM workforce (Rephann, 2007). The American Association of Community Colleges (AACC, 2019) reports that as of fall 2017, an estimated 7.7 million students were enrolled at a community college; about 4.5 million of them enrolled full-time; and that overall, community college students make up 41% of undergraduate students in the country. These large enrollment numbers highlight the increasing impact that community colleges have on postsecondary education in the nation. An increasing number of students in groups traditionally underrepresented in STEM also use community colleges as their entry point to higher education: about 41% of students are underrepresented minorities, about 51% are female, and about 36% are the first in their families to attend college (AACC, 2019). According to a National Science Foundation (NSF, 2017) study, 46% of STEM graduates reported having attended a community college. As shown in Figure 1, for example, through the transfer process, students can continue their education at four-year colleges or universities and subsequently earn higher degrees, including PhDs.
Students at community colleges face many factors that negatively affect their retention and persistence in the pursuit of the STEM degree. With many more students not prepared to do college work, community colleges address this problem with extensive remedial programs designed to make up for students' weak preparation, especially in math (Parsad & Lewis, 2003; Sparks & Malkus, 2013). Nationwide, about 59% of community college students take remedial math (Chen, 2016). Participation in remediation was more common among several demographic groups, including blacks and Hispanics, low-income students, first-generation students, and female students (Chen, 2016). Data from the National Center for Education Statistics (McFarland et al., 2019) show that only 13% of community college students graduate in two years, 22% within three years, and 28% within four years. This is partly due to the fact that ~62% of all community college students work either full-time or part-time to support themselves and family (AACC, 2019).

Several reports have recommended ways to improve the retention, persistence, and graduation rates of students (National Academies of Sciences, Engineering, and Medicine, 2016a; National Academy of Engineering and National Research Council, 2012; PCAST, 2012). One strategy in particular that is having some success is undergraduate research. The PCAST (2012) report recommends expanding opportunities for undergraduate research early in their academic careers. The report also states that the first two years of college, for both community and four-year colleges, are the most critical for recruiting and retaining students in STEM due to their high attrition rate (PCAST, 2012). Undergraduate research experiences are considered one of the leading high-impact practices (HIPs) that encourage students to pursue STEM majors, graduate degrees, and careers, and their positive outcomes have been documented by a growing body of research (see, for example, Hathaway et al., 2002; Hunter et al., 2007; Kuh, 2008; Lopatto & Tobias, 2010; Miller et al., 2011; Thiry et al., 2011; Simons et al., 2012; Damas, 2017a; Nerio et al., 2019). Undergraduate research experiences in the sciences provide a variety of benefits to students including sophisticated understandings of science and its nature, improved attitudes toward science, career awareness in the sciences, enhanced critical thinking, and improved self-efficacy and (Nagda et al., 1998; Lopatto & Tobias, 2010; Carpi et al., 2016).

Undergraduate research experiences are considered one of the leading HIPs to encourage students to pursue STEM majors, graduate degrees, and careers. However, since teaching is the primary mission of community colleges, there is a challenge to support undergraduate research training and promote undergraduate research opportunities. Hewlett (2018) wrote of several known barriers to integrating research into the student experience at community colleges such as “limited financial resources, incompatible faculty model (e.g., high teaching loads), limited student preparation, isolation from networks, marginalization from the science research endeavor, and limited administrative support.” While the main duty of faculty is teaching, a research culture has steadily developed at community colleges with the support of programs like the Community College Undergraduate Research Initiative (CCURI), a large-scale nationwide model of...
undergraduate research program for community colleges. CCURI provides support and resources to community college partners through faculty workshops, opportunity to build collaborations, and through conferences (Hewlett, 2018).

3. QCC SWREP: A Model for Undergraduate Research at a Community College

A literature review on best practices for increasing community college student participation in STEM provided guidance for the design of the QCC SWREP model. The program reflects strategies that offer community college students academic and financial support, and social integration (see, for example, Lopatto, 2004; Lopatto & Tobias, 2010; PCAST, 2012; National Academies, 2016a; Hewlett, 2018). A logic model (see Figure 2) is used to guide QCC SWREP's planning, evaluation, and overall management (MacLaughlin & Jordan, 1999; W.K. Kellogg Foundation, 2001). The model also illustrates how the desired program components, for example, inputs (resources), activities, outputs, outcomes, and impact, work together to achieve desired program results. In the next section, a brief overview of the program context is given. Following this, the program structure is presented using the logic model as a guide.

3.1. Program Context

QCC is one of the most diverse campuses in the nation with a fall 2018 student enrollment of 15,411. Hispanic students represent the largest group (29%), followed by Asian or Pacific Islander (28%), black (27%), white students (15%), and women (52%). QCC 2018–2019 Fact Book compiled by the Office of Institutional Research and Assessment (2019) indicates that at least 32.8% of incoming freshmen needed math remediation, much lower than the national average reported by AACC (2019). The majority of QCC students mostly commute by bus, which can take up to two hours, each way. They also work part-time, and have the outside demands of family, which leave very little time to pursue research activities outside their scheduled classes. These are all factors that can affect academic success, transfer persistence, and graduation. QCC SWREP was initiated to address the need to prepare and support motivated community college STEM students interested in a research experience.

3.2. Inputs

3.2.1. Partnership

The first crucial step in developing a research program such as QCC SWREP is to determine the types of resources that are needed to implement program. The program (QCC SWREP) provides the administration, coordination, and leadership to ensure that it achieves the desired results. The college (QCC) provides community college faculty, facilities, and funding to support faculty travel in the program. Partnership is another important resource. Amey et al. (2010) discuss the concept of partnership capital as an outcome of social capital (i.e., respect, trust) and organizational capital (i.e., resources, influence), which can have implications for partnerships. Community college faculty are marginalized from the science research endeavor, face isolation from scientific networks, and have limited resources to conduct research (Hewlett, 2018). These important issues should be discussed with prospective partners before establishing the partnership to ensure mutual respect and trust, as well as broadening partners’ attitudes toward community college faculty and students in general. Partners also have to buy into the program’s philosophy before they invest time to mentor community college students. Partnering with CUNY senior colleges and NASA GSFC provide more entry points and pathways to STEM degrees for community college students; encourages research collaboration; opportunities for summer internships; sharing of resources such as equipment and facilities; and through articulation agreements, create opportunities for students to transfer to four-year institutions (Fletcher & Carter, 2014; Williams et al., 2011; PCAST, 2012). The partnership also led to two funding opportunities to support QCC SWREP activities: one is an Early-concept Grant for Exploratory Research (EAGER) award through the National Science Foundation (NSF) and the second through the NASA Minority University, Research and Education Project Community College Curriculum Improvement (MC3I) Program. Table 1 lists the core partners, resources, and coordinators.

3.2.2. Financial Support

A study conducted by QCC’s Office of Institutional Research and Assessment (2019) found that 67% of students work at least part-time. This is in addition to the financial aid that they receive from the state and federal government. QCC students receive a stipend during the academic year to cover transportation, for example. In addition, the program supplies all students’ research needs. Although most students still work...
during the academic year, a few were able to cut their weekly hours to 10 or less or work only on weekends to remain engaged in research activities. Students that are accepted in the summer program receive a stipend and are not allowed to work during the week. However, some can work and are able to change their work schedules to weekends since they cannot afford to lose their jobs. Locals also receive additional funds to cover transportation and lunch. Since the bootcamp (see section 3.3.2) is required of all students, the program also pays for local students’ overnight travel for one week to NASA GSFC. For students who do their internships at NASA GSFC, lodging and transportation are covered. QCC SWREP also funds QCC faculty reassigned time to reduce their teaching loads, as well as pay summer salary to CUNY faculty mentoring students. Through a subcontract, the program also pays for three research scientists from The Catholic University of America that are residents at NASA GSFC to mentor student interns at CCMC.

3.3. Program Activities

3.3.1. Recruitment

Student recruitment is another crucial step in the program and in mentoring community college students. QCC SWREP recruits and supports students as early as their first year in college. Students do not need to have prior knowledge of space weather, and although university physics is not required, it is recommended. Recruitment of QCC students focused on STEM majors, specifically engineering science majors, who plan

| Inputs | Activities | Outputs | Outcomes |
|--------|------------|---------|----------|
| Resources needed to accomplish activities | Address problem (see problem context) | Evidence produced by activities | When accomplished, activities lead to changes in 3, 6, & 7-10 years. |
| **QCC SWREP**<br>- Administration & leadership<br>- Funding | - Student recruitment and selection<br>- Mentor recruitment and selection<br>- Year-long Research Experience (curriculum & research experience)<br>- Mentoring<br>- Learning Community<br>- Professional Development<br>- Student tracking (longitudinal) | **Student Participation:**<br>- # of CC Student participation<br>- # of women<br>- # of underrepresented minorities (URMs)<br>**Target Goals for students:**<br>- # of transfers to 4-yr STEM programs<br>- # of BS degrees in STEM<br>- # of students working in STEM fields<br>- # of published student-led abstracts<br>- # of presentation at conferences<br>- # of space weather forecasters<br>- # of students on LinkedIn | **Short-term (1-3 yrs.)**<br>- Increase in student retention & persistence<br>- Increase transfer to 4-yr STEM programs<br>- Increase confidence to do research |
| **Partners**<br>- Research collaboration<br>- Summer internships<br>- Transfer opportunities<br>- Time<br>- Facilities & equipment | **Intermediate-term (4-6 yrs.)**<br>- Increase desire to obtain BS degrees<br>- Increase desire to obtain advanced degrees<br>- Pursue space-related careers | **Long-term (7-10 yrs.)**<br>- Increased career prospects<br>- Well-trained STEM workforce with interdisciplinary training | |
| **Other**<br>Community College Undergraduate Research Initiative (CCURI) | | | |

**Assumptions:** Unique partnership and collaboration with NASA research scientists & CUNY senior faculty provide a novel training model for student learning and career preparation and benefits to community college (CC) faculty.

**External Evaluation:** project outcomes, goal achievements, student retention, academic performance, transfer & persistence.

Figure 2. Logic model of QCC SWREP. Model is read from left to right and illustrates how desired program components, that is, inputs (resources), activities, outputs, outcomes, and impact, work together to achieve desired program results.

| List of QCC SWREP Collaborators |
|-------------------------------|-----------------|-----------------|
| **Core partners** | **Key inputs** | **Coordinator(s)** |
| Community Coordinated Modeling Center (CCMC) | Collaboration, research mentors, time, facilities and equipment | Maria Kuznetsova, Chigomezyo Ngwira, Anna Chulaki |
| CUNY four-year colleges | Collaboration, research mentors, time, facilities and equipment | Ahmed Mohamed |

Table 1
on transferring to CCNY Grove School of Engineering. CCNY offers a doctorate program in engineering. There is a special emphasis on recruiting women in QCC SWREP since they make up less than 10% of students in QCC’s Engineering Science program. Going forward, to further increase the number of underrepresented groups, QCC SWREP is partnering with the CUNY chapters of the Society of Women Engineers, Society of Black Engineers, and the Society of Hispanic Professional Engineers. These organizations will provide workshops and peer-mentors to QCC students. Most students do not know about or are unaware of research activities on campus, including QCC SWREP, and various strategies exist to recruit them. Word of mouth, where current students and program alumni spread the word to others, is by far the most effective of the recruiting strategies. The personal approach where faculty members or colleagues identify promising students in their classes and invite them to join QCC SWREP is also very effective. QCC has a STEM academy that hosts weekly seminars, and a website devoted to undergraduate research that lists research opportunities such as QCC SWREP. In the past four years, as the number of research programs at QCC has increased and student academic readiness has been steadily decreasing, student recruitment has become challenging. There is much competition to recruit very good students, and the challenge is to identify students that are both promising and interested in research. For QCC SWREP students, curiosity, interest, grit, ability to work well with and help others, an independent spirit, and good math skills were found to be good predictors of success in research.

Selection of students for the academic year is done through an application process, and through an informal interview with faculty. Since most students are in their first year, faculty mentors looked for students with strong interest, desire, grit, and above all curiosity. QCC students who do well during the academic year are invited to participate in the 10-week paid summer internship program after going through an application and interview process with all partners. Non-QCC students interested in an internship at NASA GSFC must apply through its internship program gateway and selection of students is done by NASA GSFC and QCC.

Mentors at both CCNY and York are chosen based on whether their research projects have space weather applications. At CCNY, the program partnered with CCNY’s Smart Grid Interdependencies Laboratory—a research group focused on the rising interdependencies between the power grid and other critical infrastructures to study the effects of geomagnetically induced currents on the New York State Power System. At York, program partnered with the particle physics group and students work on space weather effects of cosmic rays. Mentors are also chosen based on their experiences with undergraduate students in their research groups.

### 3.3.2. Year-Long Research Experience

Research indicates that longer programs offer students more benefits than shorter programs such as a summer or a one-semester experience, including a greater understanding of research procedures and working independently on research projects (Adedokun et al., 2014). However, due to students work and family obligations, and non-QCC students, the program allows some flexibility for students not able to do both.

The year-long space weather research and education curriculum shown in Table 2 gives students two experiential learning opportunities anchored by evidence-based best practices that ensure student success in the program. During the academic year, students are enrolled in a two-semester credit-bearing, project-based research course, and work in a dedicated computer lab (Space Weather Lab) at QCC. The first semester course is an introduction to space weather that uses a system science approach, which views the Sun–magnetosphere–ionosphere–atmosphere complex as an integrated system that are not independent components or self-confined entities. Students learn the central physical concepts associated with space weather, including the Sun and its activities; solar flares, solar wind, solar energetic particles, coronal mass ejections, and their impacts; Earth’s magnetosphere; Earth’s upper atmosphere; auroras; and other topics.

During the second semester, students are introduced to the state-of-the-art models used to simulate the dynamic behavior of solar, heliosphere, and magnetosphere-ionosphere space plasma environments, and also learn how to use state-of-the-art modeling capabilities hosted at the CCMC to analyze space weather events. They work on research projects, which use case studies of geomagnetic storms that incorporate large geospace data sets to illuminate the process of science and discovery, and connect space weather hazards with economic, societal, and policy issues. Research projects are developed with partners and take into account diverse student levels and background, that is, academic and previous level of exposure to science. Each student keeps an electronic shared folder (e-folder) of all their artifacts (reports, research plan, posters, presentations, paper, etc.). They also lead at least one group discussion, give oral presentations to their peers
and faculty, and present a poster at QCC’s Undergraduate Research Day. Students invest their time primarily in the classroom and spend 4 hr/week on research activities. Since research activities are time intensive, class sizes are kept small, with no more than six students.

During the summer, highly motivated QCC students that have completed the academic year successfully are placed in a paid 10-week research internships at either NASA GSFC, CCNY, or York. During the first two years of program, only QCC students participated in the summer program. In summer 2017, the summer internship program was opened to all other community college students nationwide. Local community college students mostly intern at QCC, while the regional and national students intern at NASA GSFC. Students have a choice of three types of internships: (1) Space weather research at either CCMC or at a CUNY senior college, where students carry out research projects under the direction of a research mentor. CCMC also works closely with NASA GSFC Heliophysics Division scientists who also mentor students. In general, summer research projects are logical extension of the academic year research projects but need not be; (2) Space weather forecasting at NASA where students under the guidance of senior CCMC space weather team, learn how to provide space weather services to NASA missions using real-time simulations. Successful forecasting interns are certified as entry-level space weather forecasters. During the academic year, interns can continue as paid “forecasters in training” and can certify as level II-III forecasters (see Figure 7); and (3) Software development at NASA CCMC where students work on a variety of projects in support of its activities.

All participating summer interns attend the space weather bootcamp during the first week of summer on site at NASA GSFC, and work on tutorials that provide knowledge of space weather forecasting, and space weather applications. CCMC has made all bootcamp materials available online, including information about all their internship programs (https://ccmc.gsfc.nasa.gov/support/SWREDI/bootcamp/index.php). Since the bootcamp is also open to outside participants, including foreign scientists and students, all program interns get an opportunity to interact with a very diverse group of scientists.

As part of their internships, students keep a shared e-folder in which they upload their weekly progress reports, research plans, and final scientific papers. They also give oral presentations of their results to research scientists and their peers, present a poster at either NASA or CUNY Summer Intern Poster Session, and submit a student-led abstract to a national meeting or conference such as the American Geophysical Union (AGU), the American Meteorological Society (AMS), the American Society of Engineering Education (ASEE), or other related meetings and conferences. Students whose abstracts are accepted can present at a conference, and all travel expenses are paid by QCC SWREP. See Table 3 for examples of student research projects.

O’Reilly et al. (2017) have shown that exposing students to large data sets can lead to significant improvement in students’ use of large data sets to address scientific problems, and improved competence in using spreadsheet software. In the past few decades, the Internet has become the depository for large amounts of data with increasing frequency and resolution that are generated by small-scale distributed ground- and space-based systems that sample the geospace environment across multiple scales. These data sets are all in the public domain and are available freely on the Internet. These continuous measurements—such as for example real-time (and archival) data from NOAA’s GOES and DSCOVR satellites, NASA’s ACE, and STEREO—provide an unprecedented opportunity for students to ask real scientific questions and to answer those questions with real data. Students also learn how to download, analyze and interpret large data sets, and make use of data facilities such as the NASA/GSFC Space Physics Data Facility, which is a World-Wide-Web-based system for viewing essentially any NASA data produced in common Data Format, such as CDAWeb, the Coordinated Data Analysis (Workshop) Web. Data are used to inform knowledge, to
develop hazard assessments, to provide early warning, and as inputs to models. The analysis of these large data sets requires only a computer and basic software that is readily available, such as Microsoft Excel. Students also learn to use MATLAB and learn how to program in Python and IDL. In addition, the QCC campus has a Sudden Ionospheric Disturbance (SID) monitor (QCCSwxlab), which gives students the opportunity to collect their own data, share their collected data with the scientific community, and have hands-on experience troubleshooting electronic devices. The SID monitor tracks the Sun’s influence on the Earth’s ionosphere by detecting solar flares, Cosmic Rays, and other ionospheric disturbances. Very low frequency transmitters are scattered around the world, so SID monitors can be placed anywhere worldwide. Stanford University currently provides a centralized data repository (http://sid.stanford.edu/database-browser/) where students can deposit, share, and extract data. QCC students built their own antenna and the PC that are used to collect and analyze the data.

### 3.3.3. Mentoring

The goals of the mentoring program are to provide community college students with the skills, knowledge, and experience to prepare them to do research; transfer to four-year colleges and graduate with STEM degrees; and increase their persistence and career prospects. One positive aspect of a mentor’s role is that it can persist far beyond the duration of the research program. Students have access to a network of mentors from QCC, CUNY senior colleges, NASA GSFC, and receive a level of mentorship (experienced researchers to junior researchers, graduate students, and QCC SWREP alumni) that strengthens their research and education experiences. Mentoring programs have been shown to increase student performance and persistence (Damas, 2017a; Tinto, 1998). Several studies also show that the mentor-student relationship contributes to community college students’ reported sense of belonging to the institution and time spent in college (Damas, 2017a; Nagda et al., 1998; Nerio et al., 2019). Students undergo an orientation that involves in-depth conversations between them and mentors that explain the purpose of the program, and their individual roles. Mentors also meet with students individually 3 times during the semester to gauge students’ progress. They also advise students on courses, write letters of recommendations (for both current and alumni), and give advice on four-year STEM programs. QCC mentors obtain feedback from each student’s STEM instructors in order to track their progress and decide on the types of intervention students might need. At QCC, the Center for Excellence in Teaching and Learning hosts professional development workshops for faculty interested in starting a research program. The CUNY system also offer several workshops aimed at mentoring undergraduate students. Faculty mentors and some members of the CCMC team have also attended professional development trainings, such as American Geophysical Union’s “Establishing and Sustaining an Undergraduate research Program.”

Peer-led team learning is an instructional methodology that has been shown to be a highly effective mentoring strategy (Colvin & Ashman, 2010). QCC SWREP program alumni are recruited to serve as leaders of
peer-led teams to provide their insight into program logistics, to speak with and counsel new students, provide feedback on how to improve students’ research projects, and help with transfer issues. Peer mentors are trained through QCC’s Student Learning and Tutoring Center and program faculty. Students also maintain contact with each other through the QCC SWREP Group LinkedIn page (see section 4.2). Students ask each other for advice, as well as post their “likes” of activities that might be relevant to others. These include motivational speakers (both students and professionals), student accomplishments, and other topics.

3.3.4. Learning Community and Professional Development

QCC SWREP students are recruited together as a cohort, which encourages a learning community in which they bond and support one another. Although students in the same cohorts graduate at different times, on average, they spend 1.5 years in the program. Thus, there are always more experienced students available to orient and train the new students, and to help prepare them for their upcoming summer internships. Program alumni advising sessions are often combined with a visit to the alumni’s campus. Students’ development in QCC SWREP is enhanced through a series of team-building exercises and professional development activities. During the academic year, students’ activities focus on background material and developing research skills to conduct analysis and make inferences about physical parameters and physical processes involved in student research areas. These are achieved through a Research 101 course, taught by QCC’s Library staff, and skill-building workshops taught by faculty that focus on developing computational, critical thinking, and communication skills. Other workshops are offered on the transfer process, careers, time management, and other life skills. During the summer, the NASA GSFC Heliophysics Science Division with the support of NASA’s Office of STEM Engagement and CCMC staff developed a program to aid mentors in the transfer of knowledge and good scientific conduct, and to create a collaborative network of future scientists. The NASA 10-week summer internship program includes a calendar of events (seminars, workshops, field trips, etc.) for students and their mentors. In addition to the NASA CCMC Bootcamp, QCC and other CUNY interns also participate in several enrichment and professional development programs supported by CUNY NSF Louis Stokes Alliances for Minority Participation, CUNY NSF Research Experiences for Undergraduates programs, and the CUNY Research Scholars Program.

3.4. Program Outputs and Outcomes

Over the past four years, 46 students have successfully gone through QCC SWREP (see Figure 3). They include 39 community college students, of which 28 out of 39 (72%) are from QCC, and 7 are four-year college students, predominantly sophomores. The program’s student participants include 9 blacks, 9 Hispanics, 13 Asians, 11 whites, 4 undeclared, and 12 women, with 7 out of 12 (58%) of the women coming from underrepresented minority groups. Overall, women represent 26% and black and Hispanic students represent 20%, each of all total students. All (100%) blacks, (78%) Hispanics, and (75%) women are from community colleges. Over 50% of students are first-generation. The high percentage of Asian students (~24%) reflects their increasing enrollment at QCC. The high percentage of white students (~24%) in the program comes from four-year colleges, and from non-QCC community college students. White students also make up the majority of students that apply to NASA CCMC internships. NASA CCMC’s first cohort of community college student interns came from QCC. Figure 4 breaks down mentors by institution and race. Overall, there are 21 mentors in the program with almost 50% from NASA GSFC. Each mentor has two student mentees. There are four mentors from QCC and one from Prince George’s community college. Female mentors represent close to 50% with the majority 8 out of 10 (80%) coming from NASA GSFC.
minorities make up ~29% of mentors. Overall, the program has a diverse group of mentors and students. The program's strength lies in the diversity of talent and expertise that exist among participants.

QCC SWREP has already had a positive effect on all program participants (see Figure 5). Since the program began, about 28 out of 39 (72%) community college students have transferred, and of the 28 that transferred, 25 out of 28 (~89%) transferred with associate degrees, mostly in engineering science. One student, after her associates degree, took the civil service engineering exam at the New York State Department of Transportation, and currently works as an engineer. Table 4 shows the total graduation numbers for QCC's engineering science program per year. As can be seen from the table, overall, from 2014 to 2018, QCC SWREP students represented 10 to 25% of all Engineering Science graduates at QCC. The number of students graduating from the QCC's engineering sciences is about 10% per year of the total enrolled. QCC SWREP Engineering Science majors are more persistent than non-QCC SWREP participants at QCC.

The program started with 56 students; however, 8 out of 56 (14%) of the students left the program, and did so for various reasons including, work, health, and not enough time to devote to research. For the group of continuing students, 2 are transferring fall 2019, and the rest (7) spring 2020. QCC students generally bring about 30–40 credits into QCC SWREP, and on average take ~2.5 years to transfer/graduate from QCC. At QCC, 65 credits are required of engineering science majors to graduate. With 89% of QCC SWREP students transferring out with a degree, some ended up spending one extra semester and preferred to intern during the summer as opposed to taking classes.

In the past four years, of the 28 that transferred to a four-year program, 8 out of 28 (~29%) have finished their bachelor’s degree. One is in an Astronomy PhD program at the University of Illinois at Urbana Champaign, and one is in an Aerospace Engineering MS program. One is working for the New York City Department of Transportation. Two are working in aerospace industry as engineers: one at Colin Aerospace and the other at Northrup Grumman. Two are working as research associates at universities: one at CUNY’s Advanced Science Research Center and the other at The Catholic University of America. Another student is working with his family business and is studying for the GRE. These last three will be applying to graduate school.

Figure 4. QCC SWREP mentor demographic data (2015–2019). (a) Mentors by institutions and (b) by race. The ratio of students to mentors is ~2:1.
next fall. The time to degree completion for this group of students was about 2.25 years, as compared with a study by Van Noy and Zeidenberg (2014) that found that STEM major transfer students take about six years to graduate with a BS degree. Of the remaining students, 29% of them will graduate in 2020, and the rest in 2021.

From Figure 6, it can be seen that NASA is a big draw hosting more than half of all summer interns. The program does allow students to do a second internship, and ~35% of students have done so at both CCNY and NASA GSFC. Students have also obtained their own second internships independently of the program; however, the program does assist them. Three students applied and were accepted into University of Michigan Rackman Graduate School Summer Research Opportunity Program; one was accepted into an NSF Research Experiences for Undergraduates program at the New Jersey Institute of Technology, and three others found internships at different NASA Centers. Figure 7 shows other outputs such as the number of student-led published abstracts (21), posters presented at conferences (41), and the number of students that have received level I–III space weather forecasting certificates (8). Of the eight student forecasters, three are certified as level III, which is one step below expert level.

Table 5 summarizes the desired learning outcomes for the program and links them to the cognitive hierarchy contained in Bloom’s Taxonomy of Educational Objectives (Adams, 2015). The six major categories representing Bloom’s Taxonomy are also listed in Table 5. The short-term outcome is to increase student persistence and confidence in their ability to do research. While the intermediate outcomes are for students to persist when they transfer and pursue graduate school or careers in STEM. In the long term, with such preparation, their career prospects will increase. The program’s impact is to increase the diversity and inclusiveness of the U.S. STEM workforce with knowledge of space weather.

### 4. Program Evaluation

#### 4.1. Surveys and Focus Groups

The program evaluation assessed the impact of participation on student retention, academic performance, transfer, and persistence. Mentors communicate often to discuss student progress and share best practices. QCC SWREP uses the Summer Undergraduate Research Experience Survey III to assess student learning gains made during their participation. Summer Undergraduate Research Experience Survey III is a well-known survey instrument that has been used by more than 1,000 colleges nationwide (Lopatto, 2004, 2007; Lopatto et al., 2008). The mean self-reported gains made by QCC SWREP students across 21 learning gains are compared with students in other summer program nationally (see Figure 8). In all cases, QCC SWREP students’ self-reported learning gains were greater than the national average. In particular, QCC SWREP students reported high gains in “understand real problem,” “skills in interpreting results,”

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**Table 4**

| Year          | 2014–2015 | 2015–2016 | 2016–2017 | 2017–2018 |
|---------------|-----------|-----------|-----------|-----------|
| QCC SWREP students | 2         | 3         | 6         | 3         |
| QCC students  | 20        | 20        | 24        | 13        |

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*Scholars applying for graduate school next fall*

Figure 5. Diversity of pathways: transfer, bachelor’s degree, and post-bachelor’s degree outcomes for the 38 QCC SWREP community college students (2015–2019). (a) Number of QCC SWREP community college (both QCC and non-QCC) students that have transferred, left the program, or continuing their associate degrees. (b) Number of transfer students that have finished bachelor’s degree. (c) Post-bachelor’s degree outcomes for QCC SWREP students. More than 60% of students are working in STEM fields.
and “readiness for more research.” Half of the students surveyed also participated in the QCC SWREP year-long program. Some of the respondents indicated that they saw an advantage to the summer experience as expressed in the following statements (Lopatto & Jaworski, 2017):

“I am very satisfied that I was given the opportunity to carry out space weather research. It has taught me valuable things, such as how to perform research, present a slideshow, write an abstract and research paper, etc. In addition, it has prepared me for future work and has encouraged me to do more research internships.

All in all, this summer research experience made me learn so many positive things about being a scientist. It cleared up a lot of misconceptions that I had about scientists and the science community. It taught me what scientists do on a daily basis and gave me more confidence to see myself as one. Also, I loved how so many scientists use free data on the internet. I have heard that science is a very open field, but I didn’t realize how open it was. It was great to learn because I used to think that science is very competitive and not many would want to share much, but now I see I was wrong. I learned that they work with others around the world, have groups that they work with for years, get to travel around the world, etc.

Focus groups were also conducted with QCC students during the academic year. When asked if there are any gains derived from participating in the program on a personal level, students gave the following responses (Damas, 2017b):

“The responsibility made me try harder. I was committed to the work associated with this course/project for myself as well as for others.”

“I feel like a professional in the sense that I am/we are doing what professionals do.”

“I am gaining teaching skills in the process of helping each other out. It will be better next semester after I mentor younger students in the program.”

“... [I] got a shot back in QCC when I hadn’t shown anything that I deserved it, and that was the beginning for getting me on the path into grad school.”

4.2. Longitudinal Tracking of Alumni

A LinkedIn page was created for QCC SWREP students to network and “connect” to each other virtually as they transition from their academic to professional career. As students transfer to different schools, the “physical” learning community becomes the “virtual” learning community through LinkedIn. Students connect not only to each other but also to other professionals. All 46 students were sent invitations and 34 out of 46
Students organize their education, achievements, and professional experiences on their profile pages that are available to all of their connections. The LinkedIn page is used to track program alumni longitudinally and is only available to QCC SWREP participants. Follow-up surveys are also administered yearly to all program alumni to gauge both their academic and professional progress.

5. Lessons Learned

Running a research program for undergraduate students is very time and energy intensive. Although a faculty’s teaching load may be reduced due to reassigned time, other duties (committee work for the college, etc.) are not. In addition, there are also administrative duties associated with running the program itself (reports, meetings, etc.) and in managing the funds that support the program (stipends, salaries, travel, etc.). Community college faculty also spend a huge amount of time managing both students (advising, tutoring, etc.) and their research projects. The program uses QCC’s extensive support services, such as the Office of Advising, the Student Learning Center, the Office of Transfer, and the STEM Academies to help both students and faculty with some of the logistical issues. Faculty are then able to spend more time with students on their research projects. Increasingly, community colleges like QCC are requiring their faculty to engage in scholarly work and to publish in prestigious journals, even with limited resources provided by the college. Publishing with community college students is a big challenge. This is due to limited student preparation (especially math), and limited time to do research during the academic year, which tends to be divided between other courses, work, and family. This might dissuade some nontenured community college faculty to work with community college students on research projects, thus depriving students of a very rewarding opportunity. One strategy is to have students spend more of their time working on their research projects in the classroom. Even with all of these challenges, working with students is beneficial not only to the students but also to the mentors, their partner institutions, and the college.

While funding is beneficial to both students and mentors, it is the least sustainable of the resources. QCC SWREP partnered with several other CUNY programs and has been able to leverage funding and other

| Program learning outcomes                              | Bloom’s taxonomy |
|---------------------------------------------------------|------------------|
| Fundamentals of Swx, research methods, etc.             | Knowledge        |
| Independent thinking                                    | Comprehension    |
| Applied technology (e.g., SID monitor)                  | Application      |
| Group work and interdisciplinary teams                   | Analysis         |
| Dealing with ambiguity and complexity (large data sets)  | Synthesis        |

Figure 7. Other program outputs. Poster presentations at meetings and conferences, student-led abstracts, students on LinkedIn, and the number of students that are certified as space weather (Swx) forecasters. Level III is one level below expert.

Table 5

QCC SWREP Learning Outcomes Paired With Associated Level of Bloom’s Taxonomy
resources. QCC SWREP students have received funding from the Space Grant Community College Partnership Program, CUNY’s NSF Research Experiences for Undergraduates programs, the CUNY Research Scholars Program for community college students, which is funded by the Office of the Mayor of New York City, and many other programs. In addition, students also benefit from several resources offered by the CUNY NSF Louis Stokes Alliances for Minority Participation. The NASA Pathway Program is also another opportunity known to students, and one QCC student, after finishing his B.S. degree, applied and was offered a semester long internship at NASA GSFC. Students are also sent a list of internships, including those from The Institute for Broadening Participation (PathwaystoScience.org), which has many useful tips for obtaining internships. QCC SWREP keeps a database of the opportunities.

6. Looking Forward

As prospective engineers, QCC SWREP students have expressed their desire for the program to also focus on engineering projects. The program is expanding to include Cubesat training projects that can expose students to challenges of real-world engineering design (National Academies of Sciences, Engineering, and Medicine, 2016b). In the past few years, Cubesats have started playing a larger role in NASA’s technology demonstrations, scientific research, and exploration, as demonstrated by NASA’s recent successful Insight Mission (NASA, 2018). QCC SWREP is partnering with NASA GSFC’s Mission Engineering and Systems Analysis (MESA) Division of the Engineering and Technology Directorate. This partnership, which also includes the Atmospheric & Space Technology Research Associates (ASTRA), a private space technology firm, has also led to a NASA Minority University, Research and Education Project Innovations in Space Technology Curriculum (MISTC-2) funding opportunity for the next two years for QCC and other community college students to work on a Cubesat mission slated to launch from the International Space Station in 2021. A space systems curriculum is being developed at QCC that will provide students with application-oriented experience covering space science, engineering design, and project management. Courses and summer research experience at MESA and ASTRA will challenge students to understand applied science and engage them in various phases of small satellite missions. QCC SWREP is also partnering with other community colleges interested in emulating the space weather research and education program, as well as with other CUNY four-year colleges, and non-CUNY colleges that offer degrees in aerospace engineering.

Research with undergraduate students is an opportunity to shape young minds and train the next generation of scientists and engineers. Research programs such as QCC SWREP give students a glimpse into their future careers as STEM professionals. They know what to expect and can decide whether this is the right path for them. Various institutions can work together to offer diverse pathways in STEM to community college students.
students so that they can persist, transfer, graduate, and contribute to the diversity of the nation’s STEM workforce, necessary for a thriving economy.

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