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Programs to build capacity in geosciences at HBCUs and MSIs: Examples from North Carolina A&T State University

Solomon Bililign

Department of Physics, North Carolina A&T State University, Greensboro, North Carolina 27411

ABSTRACT
Increasing diversity in the geosciences has remained a challenge, despite large investments made by federal agencies in minority-serving institutions (MSIs) and historically black universities and colleges (HBCUs). With increasing challenges associated with climate and environmental change and severe and frequent natural disasters that disproportionately affect underrepresented minorities, HBCUs and MSIs are primed to lead the creation of a diverse workforce responding to these challenges. In this article, I use as examples the outcomes, successes, and challenges of two federally funded programs to increase diversity in the geosciences at an HBCU: North Carolina Agricultural and Technical State University (NCAT). The lessons learned from these programs and best practices and strategies that could be applied to build and sustain geosciences programs at HBCUs and MSIs are presented. The programs were the National Oceanic and Atmospheric Administration (NOAA) Educational Partnership program (EPP)-funded NOAA Interdisciplinary Scientific Environmental Technology Cooperative Science Center (ISETCSC) involving two HBCUs and three MSIs and the National Science Foundation (NSF)-funded Opportunities for Enhancing Diversity in the Geosciences (OEDG) Track I at an HBCU and Track 2 involving two HBCUs and two MSIs. One of the successfully accomplished goals of the ISETCSC was increasing research capacity in NOAA-relevant STEM areas at HBCUs and MSIs and building sustained research and educational capacity in the atmospheric sciences at NCAT. The OEDG Track 1 program, however, failed to develop a sustained geophysics program at NCAT. These experiences showed that one-time funding might not be enough to grow programs to be self-sustaining at these institutions, unless the programs are incorporated in their long-term strategic plans. Furthermore, when institutions apply for and receive grants for new program development in the geosciences, they need to be accountable in fulfilling the commitments and promises expressed in acquiring the funds.

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Introduction

As the United States becomes a minority-majority nation, the science, technology, engineering, and math (STEM) workforce will increasingly have to come from the nation's underrepresented minority (URM) groups (including African Americans, Hispanics, and Native Americans; NSB, 2006, 2018). By 2044, more than half of all Americans are projected to belong to a minority group (any group other than non-Hispanic white); by 2060, nearly one in five of the nation's total population is projected to be foreign-born (Colby & Ortman, 2015). Despite considerable progress over the past two decades, the educational attainment gap separating URMs from whites and Asians remains wide, with only 4.5% of doctoral students and 17.8% of all graduate students being URMs (Crisp & Nuñez, 2014; NAS, 2011). Although current data show an increase in the number of degrees earned by URMs and women, this growth did not keep pace with population growth, undergraduate enrollment, overall bachelor's degree attainment, and projected STEM labor market growth rates (NSF, 2017).

According to a report by the Department of Commerce (DoC, 2017), STEM employment in the United States continues to grow at a faster pace than employment in other occupations, and STEM workers command higher wages than their non-STEM counterparts. However, not all Americans have equal access to STEM education (NSF, 2017), in which underrepresented racial and ethnic groups make up 27% of the population but comprise only 11% of the STEM workforce (NSB, 2018).

CONTACT Solomon Bililign Bililignsol@gmail.com Department of Physics, North Carolina A&T State University, 1601 E Market Street, Greensboro, NC 27411, USA.

According to NSF statistics, between 2000 and 2014 (NSF, 2009, 2015, 2017), URMs earned 16% to 17% of STEM degrees but only 5% to 7% of geoscience degrees. Using data provided by the Bureau of Labor Statistics, the American Geosciences Institute (AGI) identified a total of 324,411 geoscience jobs in 2014 (Wilson, 2014). This number is expected to increase by 10% by 2024 to a total of 355,862 jobs. Approximately 156,000 geoscientists are expected to retire by 2024; however, over the next decade, only approximately 58,000 students will be graduating with their bachelor's, master's, or doctoral degrees in the geosciences. According to the *AGI: Status of the Geoscience Workforce 2016*, given minimal nonretirement attrition from the geoscience workforce, there is expected to be a deficit of approximately 90,000 geoscientists by 2024 (Wilson, 2016). According to the AGI data, the proportion of African Americans in atmospheric sciences occupations was only .4% in 2006 and 2.7% in 2013 (Merner & Tyler, 2017). In 2018, an increase to 4% was reported, but the percentage includes atmospheric and space scientists and does not tell if there was an increase in number of atmospheric scientists (Funk & Parker, 2018).

The National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), and the National Oceanic and Atmospheric and Administration (NOAA) contribute significantly to URM education and training in the geosciences via multiple research and educational programs at historically black colleges and universities (HBCUs) and minority-serving institutions (MSIs). Despite these continued efforts, the geosciences community still has difficulty recruiting and retaining students from underrepresented groups (Martínez-Sussmann Carmen & Levine, 2009), and there are few geoscience programs at MSIs (Rossbach & San Juan, 2016). Capacity-building federal grants have helped initiate geoscience programs at MSIs, but there has been little to no improvement in the overall number of URMs matriculating in the geosciences over the past four decades, despite ongoing investments by NSF, NOAA, and NASA (Bernard & Cooperdock, 2018).

In this article, I argue that enhancing and increasing diversity in the geosciences and MSIs can best be accomplished not only by providing funding to build capacity (infrastructure and support for personnel) and programs in the geosciences but also by ensuring that building and sustaining such programs is incorporated into those institutions' strategic planning and implementation. The geosciences provide solutions to issues of societal relevance and are inherently interdisciplinary. They should be developed as interdisciplinary programs to overcome the low enrollment problems of individual geoscience degree programs.

Role of HBCUs in diversity in STEM

HBCUs have helped increase the number of African Americans graduating in STEM (Gasman & Nguyen, 2016). Many African American undergraduates are first-generation college students. HBCUs enroll a substantial fraction of these students. For example, HBCUs make up just 3% of higher education institutions in the United States, but they produce 27% of African American students with bachelor's degrees in STEM fields by implementing proven practices to assist students in STEM fields (DoE, 2016; Gasman & Samayoa, 2017).

Beyond producing graduates with baccalaureate degrees, HBCUs are the institution of origin for almost 30% of African-Americans who earn doctorates in STEM (NSF, 2017). Twenty-one of the top 50 institutions for educating African American graduates who go on to receive their doctorates in science and engineering are HBCUs (Fiegener & Proudfoot, 2013; NASEM, 2018). Increasing diversity in the geosciences is therefore best accomplished by building capacity in the geosciences at HBCUs and MSIs.

Geoscience programs at North Carolina Agricultural and Technical State University (NCAT), an HBCU, were initiated and built via external funding from federal and private organizations; as a result, their survival is dependent on sustained and uninterrupted external funding, because building capacity in the geosciences and developing such programs has not been part of most HBCUs' long-term strategic plans (Schexnider, 2017). Also, many HBCUs are having financial difficulties due to low endowment and dependence on state appropriations, and they cannot afford to create majors with low enrollment (AGB, 2014; Schexnider, 2017). For HBCU administrators, offering high-enrollment majors and providing courses in more traditional STEM and non-STEM areas that have broader alumni support (JBHE, 2004) appears to be safer than experimenting with something new, regardless of how important those new or innovative majors or courses might be to the country's science and engineering priorities. Although federal funding can initiate and help grow programs in the geosciences at HBCUs, these programs cannot be sustained with federal funding alone. Sustaining these programs may require HBCU leadership to clearly understand the societal benefits of such programs and how they impact the communities they serve and commit to taking risks—for example, finding innovative and cost-effective ways of building a program that will have low enrollment but will help the country meet its geosciences workforce needs.

Descriptions of the programs

The NOAA- Educational Partnership Program with MSIs (NOAA-EPP; NOAA, 2019) and the NSF Opportunities for Enhancing Diversity in the Geosciences (OEDG; NSF, 2010) programs were designed to address the severe underrepresentation of minorities in the geosciences by building infrastructure and human capacity in the geosciences at MSIs and HBCUs (Morris et al., 2007; Robinson, Rousseau, Mapp, Morris, & Laster, 2007). This article provides a critical commentary on the successes and the challenges of two geoscience programs initiated at NCAT through the two federal funding programs: the NOAA-EPP-funded Interdisciplinary Scientific Environmental Technology Cooperative Science Center (ISETCSC) and the NSF-OEDG-funded efforts to develop a geophysics program. Based on the experiences of these programs, lessons learned, best practices, and recommendations to build, grow, and sustain geoscience programs at HBCUs and MSIs will be presented.

NOAA ISETCSC center

ISETCSC, which operated from 2006 to 2011, was led by NCAT and was a collaboration of 37 scientists and engineers representing seven academic disciplines at six academic partnering institutions. The MSI and HBCU partner institutions were the University of Alaska–Southeast (UAS), California State University–Fresno (CSU–Fresno), City College of the City University of New York (CUNY), and Fisk University (Fisk). The majority-serving partners were North Carolina State University (NCSU) and University of Minnesota (UM). The selection of partner institutions was intended to maximize the ethnic and geographic diversity of MSIs. The majority-serving institutions were selected based on availability of strong programs relevant to the center's research and educational goals. In addition, ISETCSC was aligned with the NOAA Office of Atmospheric Research (OAR) and collaborated with four federal labs—the Earth System Research Lab (ESRL), National Climatic Data Center (NCDC), National Severe Storm Lab (NSSL), and the National Center for Atmospheric Research (NCAR)—to provide undergraduate and graduate students with experiences in field and laboratory research and opportunity to work with scientists at those labs.

ISETCSC was organized in three research areas: (a) sensor science and technology development of meteorological, oceanographic, and chemical (particulate) sensors; (b) global observing systems for the analysis of global observing systems and numerical and physical modeling; and (c) information technology applications to develop observational and information technology systems for data mining, fusion, collection, assimilation, and computing techniques. These areas supported NOAA's efforts to "understand and describe climate variability and change to enhance society's ability to plan and respond" (NOAA, 2005).

ISETCSC education objectives were to (a) expand university educational programs to develop future workforce needs for NOAA, (b) leverage ongoing K–12 education programs for targeted teacher development activities to increase NOAA-related content in school curricula and outreach programs to promote weather and climate literacy, (c) expand student and faculty exchanges between NOAA facilities and academic partners, and (d) develop degree programs in the atmospheric sciences and other relevant courses that support the Centers research areas at all partnering institutions.

NSF-Funded geophysics activities

The NSF-OEDG Track 1 project—titled "Collaborative Research: Enhancing Diversity in the Geosciences in North Carolina"—was funded for the period 2003–2007 in collaboration with the Department of Marine, Earth, and Atmospheric Sciences at NCSU. A "concentration" in geophysics and geophysics-related research infrastructure was developed in the Department of Physics at NCAT. From 2005 to 2009, NCAT partnered with Pennsylvania State University (PSU) on the NSF-funded Partnership for International Research and Education (PIRE), and NCAT became an AfricaArray participant. AfricaArray is an innovative program aimed at promoting, strengthening, and maintaining a workforce of highly trained African geoscientists and researchers for Africa (Webb et al., 2015). The PIRE program provided (a) support for a teaching postdoc that enabled offering introductory geophysics courses at NCAT, (b) funding for K–12 teachers' workshops in geophysics in collaboration with the Incorporated Research Institutes of Seismology (IRIS), and (c) funding for NCAT students to participate in summer international field research experiences in South Africa and at PSU. This geophysics project was further enhanced through the NSF-OEDG Track II award from 2009 to 2013 in collaboration with PSU, which, through AfricaArray (Nyblade, Hanson, Bililign, & Bralower, 2010), helped NCAT and participating institutions that included Fort Valley State University (FVSU), the University of Texas El Paso (UTEP), and California State University Northridge (CSUN) to develop a pre-eminent and sustainable pipeline program for increasing the representation of URMs within the geosciences (Webb et al., 2015). The proposed activities/interventions within the Alliance partners included (a) a summer workshop for high school teachers and students in geophysics, (b) a summer field course in Africa, and (c) scholarship funds to support undergraduate students planning to pursue geophysics as a major.

The AfricaArray program continues to partner with FVSU, UTEP, and CSUN in providing undergraduate research experiences to students. The most successful collaboration is the dual degree program through which FVSU students continue their graduate studies in geoscience at PSU (Crumbly, Hodges, and, & Rashidi, 2015). This success can be attributed to the commitment of the FVSU administrators to the program. The collaboration with NCAT ended after 2013.

Program activites and outcomes

NOAA-ISETCSC and the atmospheric sciences programs

Atmospheric science programs generally have very low URM student enrollment. However, the ISETCSC used established best practices for recruiting and retaining URMs in atmospheric sciences (Adetunji et al., 2012; Burt, Haacker, Batchelor, & Denning, 2016; Ernst, 2008; O'Connell & Holmes, 2011; Pandya, Henderson, Anthes, & Johnson, 2007; Stassun et al., 2011; Stokes, Levine, & Flessa, 2015). A diverse set of approaches was chosen to reach students at all applicable levels, from those transitioning from high school to college to those seeking graduate training. All ISETCSC recruiting efforts emphasized the atmospheric sciences as a viable socially and culturally relevant career option. ISETCSC high school outreach and recruitment programs used dedicated personnel who could communicate the cultural relevance of the geosciences (Morris et al., 2007; Riggs & Alexander, 2007; Robinson et al., 2007).

NCAT and some MSIs tend to be less selective, with higher proportions of open admissions, and tend to enroll larger percentages of low-income students (Li, 2007). These factors affect incoming students' (particularly URMs') preparedness for STEM fields. For example, barriers to participation in the geosciences for most African Americans include a poor mathematical background, learning environments that have offered or offer no motivation or support, lack of role models (Anderson & Kim, 2006; Russell & Atwater, 2005; Scholz, Steiner, & Hansmann, 2004), and belonging uncertainty (Walton & Cohen, 2007). As a result, many URM students who are admitted to STEM programs, even those with sufficient high school grade point averages, fail in their first science and math courses—which prevents them from making progress in their major and their retention in the program. Too often, fearing the rigor of the math and science courses, many students change majors even before attempting courses in their majors (Drew, 2011). It has also been shown that some URM students who take a geoscience course have a decreased interest in geosciences at the end of the course (Keilson, 1998; Riggs & Semken, 2001). To address these issues and barriers, ISETCSC provided mentoring for at-risk incoming freshmen that was designed to address the common challenges faced by such students (e.g., math skills deficiencies, computer skills deficiencies, self-discipline issues, language and communications skills issues, etc.).

ISETCSC's education plan used best practices for engaging URMs (Robinson et al., 2007). Engaging students was accomplished through a cohort-based approach, because STEM persistence improves when students are engaged in key academic experiences in groups (Chang, Sharkness, Hurtado, & Newman, 2014) such as studying with others, participating in undergraduate research (Judge, Pollock, Wiles, & Wilson, 2012), and being involved in academic clubs or organizations (Chang et al., 2014). Increasing diversity in the geosciences can also be achieved through careful attention to building trustworthy professional relationships (Callahan, Libarkin, McCallum, & Atchison, 2015; Lopez, Nandagopal, Shavelson, Szu, & Penn, 2013). Lopez and colleagues (2013) found that cohort-based approaches applying peer learning strategies improve STEM academic performance, which confirms Espinosa's (2011) finding of the importance of building strong social networks of peers among STEM majors. Developing the feeling and the knowledge that URM students belong in the sciences is a critical aspect of persistence for URMs (Johnson et al., 2007; Matsui, Liu, & Kane, 2003; Strayhorn, 2012; Walton & Cohen, 2007). ISETCSC organized small cohorts of students with similar academic goals both at NCAT and at partnering institutions. Larger cohorts connecting all ISETCSC-supported students across all partnering institutions were also formed.

ISETCSC's main pedagogical approach was mentoring (peer, faculty, and NOAA) that incorporated advising—that is, one-on-one guidance in, about, and across academic settings and use of a multiple-mentor mode (Huntoon & Lane, 2007; Riggs & Alexander, 2007; Robinson et al., 2007). Mentoring relationships have been shown to positively impact student success and retention (Garringer, Kupersmidt, Rhodes, Stelter, & Tai, 2015; George, Neale, Van Horn, & Malcom, 2001). For URM students, peer mentors are more than a source of tutoring or advice on course selection. They also serve as role models with whom students can identify, supporting increased opportunities for success (Gomez Riquelme, 2012; González & Ballysingh, 2012; Ovink & Veazey, 2011; Ramirez, 2012; Salas & Cannon-Bowers, 2001). ISETCSC students were mentored by a team of researchers and senior program participants to equip them with the skills to be active in NOAA mission-critical fields (Ernst, 2008; Pandya et al., 2007; Robinson et al., 2007). ISETCSC also created a culturally sensitive learning environment (Huntoon & Lane, 2007; Riggs & Alexander, 2007; Robinson et al., 2007).

Other best practices ISETCSC employed included (a) enhanced hands-on curriculum and evidence-based teaching methods that engaged students in "active learning" by providing opportunities for participation in field studies (Fuentes, Fuentes, Doughty, Demoz, & Mitrea, 2012; Haeger & Fresquez, 2016; Judge et al., 2012; McIntyre, 2001; Olson & Riordan, 2012; Smith, Sheppard, Johnson, & Johnson, 2005; Vos & de Graaff, 2004); (b) financial support (Bernstone & Dahlin, 1999; Ernst, 2008; Robinson et al., 2007; Serpa, White, & Pavlis, 2007; Velasco & de Velasco, 2010); (3) culturally relevant pedagogy that recognized students' experiences, cultures, and traditions (Denson, Avery, & Schell, 2010; Ladson-Billings, 1995; Lee, 2008; Lipman, 1995; Nelson-Barber & Estrin, 1995; Roehrig, Campbell, Dalbotten, & Varma, 2012; Rolón, 2003; Shujaa, 1995); and (d) formative and summative assessment and evaluation to determine the project's overall levels of success and effectiveness (Tridane, Belaaouad, Benmokhtar, Gourja, & Radid, 2015). This final practice provided data regarding which interventions are most critical in recruiting and retaining URMs in NOAA-relevant disciplines.

ISETCSC focused on student skills development in several areas to address NOAA mission-critical workforce development needs, including data analysis skills; research skills, including reviewing the existing literature; and proposal writing and communication skills (Walton & Cohen, 2007). Because most of the ISETCSC science projects involved a team of faculty from multiple disciplines, students had opportunities to work in interdisciplinary teams. Students were trained to translate research results to nonspecialists. In addition, designing projects with relevance to real-world and societal needs is critical to retention of students in STEM areas (Golding, 2009; NAS, 2005; NSB, 1986). ISETCSC used field courses and research opportunities as mechanisms to attract and recruit students into the geosciences (Gilligan et al., 2007; Morris et al., 2007; Pandya et al., 2007; Serpa et al., 2007; Williams, Morris, & Furman, 2007; White, Reddy, Liu, Williams, & Shoemake, 2013).

The ISETCSC education plan was designed to support development of the whole student: Participants' academic, social, and psychological states were monitored. Through exposure to role models, coordinated social support, awareness of factors that produce stress and anxiety among African Americans, and increasing students' sense of belonging (Huntoon, Tanenbaum, & Hodges, 2015), it is possible to increase diversity in the geosciences (Baber, Pifer, Colbeck, & Furman, 2010; Ellins & Olson, 2012). Development of extended networking opportunities to combat marginalization and alienation in professional meetings, in organizations, and across the larger scientific community was handled via collaborative partnerships between academic institutions and URM communities (Williams et al., 2007). The ISETCSC education plan included developing noncognitive aspects to student learning, such as establishing goal setting, persistence, and delayed gratification—all of which were recognized to be as important as the cognitive skills in learning (Blackwell, Trzesniewski, & Dweck, 2007; Dweck, 2006; Dweck & Leggett, 1988; Dweck & Leggett, 1999; Yeager & Dweck, 2012).

To promote high rates of retention, when students became ISETCSC members, they worked with their advisors to develop individualized development plans (IDPs; Clegg & Bufton, 2008; Hunt, Langowitz, Rollag, & Hebert-Maccaro, 2017; Kneale, 2004) that included milestones related to their educational and professional goals along with means of tracking progress toward those milestones. Progress was monitored via end-of-semester progress reports and annual reviews. Retention is enhanced by an active

Table 1. Summary of ISET Accomplishments based on education performance metrics, from final report submitted to NOAA (Bililign, 2012).

Educational metric	Accomplishment
Number of students financially supported by ISET across all institutions (**93% MIs at NCAT, 74% MIs overall, 36% female)**	342
Number of PhD students	36 (17 at NCAT, includes leveraged students)[a]
Number of MS students	69 (includes leveraged students)[a]
Number of undergraduate REUs	128
Number of BS graduates[b]	452
Number of MS graduates	38
Number of PhD graduates	12
Number of student trips for summer research at NOAA labs (42 students participated some twice or three times)	60
Number of students who participated in summer research at industrial partners	5
Offer summer camps for K-12 at NCAT and most partners	Over 250 teachers at NCAT, 40 at Fresno attended summer workshops, and 60 high school students at NCAT, 32 at Fresno and 20 at CUNY attended summer camps every year since 2006.
Develop ISET colloquium series in NOAA sciences. Colloquium series since Jan. 2007; most broadcast to partner institutions	104 (28 NOAA scientists, some visited more than once, 9 from NCAR)
Number of NOAA scientists appointed as adjunct faculty at NCA&T	21
Students at NOAA field work	2

[a]Leveraged students are students funded by other grants/funds working on ISETCSC projects.
[b]Includes students who participated in NOAA-ISET activities but not financially supported.

participation of the student in the learning process (Pandya et al., 2007).

A strength of the ISETCSC model is the use of existing national laboratories, industry, and university partnerships to provide cutting-edge research experiences, participation in major multi-university and multi-agency field campaigns, and educational and professional development opportunities for graduate and undergraduate students, postdocs, and faculty. For ISETCSC, this led to expanded student and faculty exchanges among NOAA, NCAR, and academic partners, including summer experiences for students at NOAA labs, faculty visits to NOAA facilities, and NOAA scientists' visits of up to a week to university partners. Additionally, NOAA scientists served on student thesis and dissertation committees, offered short courses, guided laboratory development, and presented seminars. The partnerships contributed to the success and steady enrollment and graduation of students in NCAT's graduate program in atmospheric sciences. Annual center-wide meetings brought together students, faculty, and NOAA scientists with the NOAA and industrial advisory committee members and external evaluators to assess the project's successes and needs for further improvement.

ISETCSC educational accomplishments

Table 1 provides the data for educational accomplishments provided to NOAA as part of the final ISETCSC report (Bililign, 2012). In 2007, ISETCSC helped to facilitate a new degree program in environmental science and establish the Institute of Climate Change, Oceans, and Atmosphere at CSU–Fresno. ISETCSC led the establishment of a BS program in atmospheric sciences and meteorology (ASME) at NCAT in 2008—only the second BS program in meteorology in the country at an HBCU. An NCAT PhD in Atmospheric Sciences was also developed through the Energy and Environmental Systems PhD Program in 2009. NCAT MS students in other STEM areas obtained MS degrees in their respective disciplines while working on thesis projects in the geosciences. In 2010, a new Alaska-wide bachelor of science in environmental resource studies was co-offered at UAS. Between 2008 and 2011, 18 undergraduate and 14 graduate courses in atmospheric sciences were created at NCAT, and 15 other new courses were developed at CUNY and UAS to support the new research activities initiated by ISETCSC. Additionally, in 2010 and 2011, through collaborations established by the ISETCSC, a graduate course in atmospheric chemistry was offered by seven NCAR scientists to NCAT graduate students via videoconferencing. The course material has been made available via the NCAR web page since 2011(NCAR, 2011).

More than 350 graduate and undergraduate students (see Table 1) received two to six years of financial support between 2007 and 2012 through the NOAA funding and later though leveraged funds from NSF, NASA, and other federal agencies. Graduate students (36 PhD and 67 MS) were supported throughout the center. Some of the students began as undergraduates with ISETCSC funding and pursued advanced graduate degrees in STEM areas.

Table 1 also shows the number of summer research participations at NOAA laboratories (Bililign, 2012).

Table 2. Student respondents report engaging in multiple strategies designed by NOAA ISETCSC personnel to improve students' research-related skills/competencies.

	Undergraduate	Graduate	Frequency	%
Research experiences on campus	19	19	38	88.4%
Attending seminars and/or conferences	15	20	35	81.4%
Presenting at seminars and/or conferences	11	16	27	62.8%
Mentoring (by a NOAA ISET professor)	11	14	25	58.1%
Research experiences at NOAA labs	7	10	17	39.5%
Web-based tutorials	1	7	8	18.6%
NOAA ISET courses	1	7	38	18.6%
Field study experiences	5	1	35	14.0%
Industrial internship experiences	3	0	27	7.0%

Note. Table shows respondents' engagement in strategies designed to improve research-related skills/competencies. Number of respondents, $n = 43$. In terms of differences between undergraduates and graduates, more graduate students are engaged in web-based tutorials and NOAA ISETCSC courses, whereas undergraduates are more actively engaged in field study experiences and industrial internships.

A total of 42 students from ISETCSC partner institutions were selected to conduct summer research with NOAA scientists who were already collaborating with ISETCSC faculty members between 2007 and 2012. It is worth noting that 64% of the 42 students who conducted research in NOAA labs were retained by their universities to pursue MS and PhD degrees in the atmospheric sciences. Also, 90% of the students came from traditional STEM disciplines but were exposed to career opportunities in the geosciences in which they could apply their disciplinary expertise to address interdisciplinary problems.

ISETCSC research accomplishments

One of ISETCSC's successfully accomplished goals was increasing new research infrastructure and human capacity in NOAA-relevant STEM areas at MSIs. Research accomplishments resulted in 92 refereed journal articles and 475 oral and poster presentations by students and faculty in all partner institutions. These successful research accomplishments were also used to leverage over $30 million in additional grants from several federal agencies, including NASA, NSF, Department of Defense, Environmental Protection Agency, and Office of Naval Research (Bililign, 2012).

At NCAT, the ISETCSC developed significant NOAA-related research infrastructure that has included fully functional labs for atmospheric chemistry and physics research and a computational facility for weather/climate modeling research. At Fisk, ISETCSC established ongoing research capabilities in image processing, pattern recognition, Earth information systems, environmental science, and grid computing.

ISETCSC's final external evaluation reports

To better understand the degree to which the NOAA ISETCSC program supports students' development of research-related skills and competencies, a formative evaluation was conducted by an external evaluator company (Evalworks) that provided annual evaluation results (Bililign, 2012).

A total of 43 students (22 graduate and 21 undergraduate, with 77% URMs) and 21 instructors responded to the NOAA ISETCSC Student and Instructor Surveys, including 21 NCAT students. The summary of the final report in 2012 is presented in Tables 2–4 (Germuth, 2011). It provides critical findings of student and faculty opinions on strategies designed to improve students' research-related skills/competencies and developed skills.

These strategies had the desired impact in that they helped increase student skills and competencies in multiple areas. Students indicated that they had gained the most skills related to networking and knowledge of their research area, with research experiences and mentoring being the strategies that supported the development of the most skills.

Qualitative findings from the student survey and from student interviews suggest that students were satisfied with the many opportunities provided to them as part of the NOAA ISETCSC program. For example, students reported that the program helped them identify their interest areas while providing hands-on experience as researchers, presenters, and audiences. However, students did report additional needs that appeared to differ by their program year, including the need for more mentoring of and communication with freshmen and new ISETCSC students and more pay for graduate students, along with more space and computer resources for all.

The geophysics program

To support geophysics curriculum, four new undergraduate geophysics courses were developed:

Table 3. Students asked to identify which strategies had the greatest impact on which skill competency, or knowledge areas.

	Strategy									
Skill/competency/knowledge area	Research experiences	Mentoring	Attending seminars and/or conferences	Research experiences at NOAA labs	Presenting at seminars and/or conferences	Field study experiences	Web-based tutorials	Industrial internship experiences	NOAA ISET Courses	Total
Networking	19	24	36	21	24	14	5	14	7	164
Knowledge of research area	35	25	25	18	16	16	7	10	10	162
Technical presentation	21	16	26	14	32	7	10	7	6	139
Data analysis and presentation	28	21	19	18	19	8	10	8	8	139
Scientific method	31	19	13	19	9	15	9	7	9	131
Research ethics awareness	25	16	17	14	9	15	10	8	7	121
Knowledge of NOAA	15	22	24	16	9	4	5	5	12	112
Career planning	18	21	18	13	8	10	5	9	5	107
Creativity	20	15	13	13	13	11	8	8	6	107
Technical writing	16	16	11	9	17	9	10	4	9	101
Independence	25	14	5	15	11	11	3	10	2	96
Computer software	27	14	9	16	5	6	7	7	4	95
Literature review	23	19	11	8	9	3	8	4	8	93
Leadership/Mentoring	18	22	5	9	9	8	3	4	5	83
Teaching	11	14	9	4	10	5	6	1	5	65
Hardware troubleshooting	17	11	1	12	1	5	5	4	1	57

Note. The table shows that, overall, strategies had the greatest impact on students' networking abilities/opportunities, knowledge of their research area, technical presentation skills, and data analysis and presentations. Number of participants is 43 students.

introduction to geophysics, applied geophysics, geophysical data analysis, and structural geology (NCAT, 2019). The program also used existing Earth science courses at NCAT in the Department of Natural Resources and Environmental Design in the School of Agriculture and Environmental Sciences. The program was designed so that students spend their final semester at NCSU to take advanced geophysics courses. Between 2004 and 2007, three students were enrolled and received a BS in geophysics; one later pursued an MS degree at PSU.

The NSF-OEDG-funded program collaborated with other STEM education/training and several NSF-funded programs to offer undergraduate research training in the geosciences. These activities included (a) hands-on experience with geophysics research equipment and geophysical data collection; (b) seminars and workshops on geosciences; and (c) development of scientific, technical, and computer skills. In addition, from fall 2003 to summer 2007, a total of 28 undergraduate students, five graduate students, and one high school student were engaged in research training in the geosciences (Tang, 2007). The OEDG project at NCAT cosponsored the 2004 Summer Research Experience for Undergraduates (REU) Program in the geophysical sciences from May 24 to July 31, 2004, and the 2006 summer REU Program in geospatial analysis and remote sensing technology from May 22 to July 14, 2006.

The geophysics course offerings were made possible because of the NSF-PIRE/AfricaArray program that provided support for a teaching postdoctoral fellow. The NSF-PIRE program provided international field research opportunities in 2005–2009 for 16 NCAT students. One of the barriers to participation of African American students in the geosciences is lower involvement in outdoor activities, lower perceived knowledge of the geosciences, and lower family support to pursue the geosciences (O'Connell & Holmes, 2011). The field course was successful in helping students start on realistic projects involving planning, collecting, processing, interpreting, integrating, and writing up a practical project. Because the students ran all the instruments and collected and processed all the data, they developed confidence in their abilities to initiate field programs and to quickly become familiar with the equipment (Webb et al., 2015).

OEDG Track II (2009–2013) focused on outreach and teachers' workshops (Bililign, 2013a). These workshops have been offered since 2005, initially through the NSF-PIRE AfricaArray grant (2005–2009) and then as a joint effort between NSF and the NOAA-

Table 4. Instructor ratings of student competencies ($n = 18–20$).

	n	Min. rating	Max. rating	Mean rating	SD
Technical presentation	20	2	5	3.80	.768
Literature review	20	2	5	3.70	.865
Data analysis and presentation	20	1	5	3.65	1.182
Knowledge of research area	20	2	5	3.65	1.137
Scientific method	20	2	5	3.60	.995
Career planning	19	2	5	3.58	.902
Research ethics awareness	20	2	5	3.55	.826
Independence	20	1	5	3.45	.945
Knowledge of NOAA	20	2	5	3.40	.883
Leadership/mentoring	19	1	5	3.37	1.116
Technical writing	20	2	5	3.35	.875
Creativity	20	1	4	3.30	.865
Networking	18	1	5	3.28	.895
Computer software	19	1	5	3.26	1.046
Teaching	18	2	4	3.06	.639
Hardware troubleshooting	19	1	5	2.79	1.134

Note. Instructors rated students' competencies/skills on a scale of 1 = Very poor, 2 = Poor, 3 = Average, 4 = Good, and 5 = Very good. Overall, instructors rated students strongest in terms of their technical presentations, abilities to conduct literature reviews, ability to analyze and present data, knowledge of their research area, and knowledge of the scientific method (mean ratings range = 3.60–3.80, scale 1 to 5).

ISETCSC Center. Since 2009, they have been run as a joint effort of NSF-OEDG and NOAA-ISETCSC. In 2012, NASA content was added. This was through the National Institute of Aeronautics Center for Reliable Autonomic Small Satellite Systems; teachers were trained on using locally available materials to build atmospheric sensors. More than 300 teachers were provided a week-long (40 hours) summer workshop in Earth and atmospheric sciences at NCAT.

A formal evaluation of the teachers' workshops was conducted in 2010 (Bililign, 2013a). The results show that workshop participants reported an increase in their knowledge of geosciences as well as their ability to incorporate geosciences activities into their lesson plans. Participants also reported an increase in their familiarity with and confidence in explaining career opportunities in the geosciences to students, to some degree. However, following the program, fewer than 40% of participants indicated that they were more than merely "familiar" with careers in the geosciences. No formal evaluation was done after 2010.

Conclusions and recommendations

Two examples of federally funded programs aimed at increasing diversity in the geosciences, one in atmospheric sciences and the second in geophysics, are provided to yield lessons learned and provide recommendations for a successful approach to increase diversity and build human and infrastructure capacity in the geosciences at HBCUs and MSIs.

The NOAA-funded ISETCSC was responsible for developing research and educational capacity in NOAA-relevant sciences and technology at five MSIs (including two HBCUs). One of the successfully accomplished goals was increasing research capacity in NOAA-relevant STEM areas at MSIs and HBCUs (Schimmel & Bililign, 2015).

The main challenges the ISETCSC faced were maintaining a cutting-edge research portfolio without faculty release time, lack of funding for upgrading infrastructure, and lack of buy-in from all internal participating units in investing to sustain the program soon after the federal funding ceased. The interdisciplinary nature of the center was a challenge, because faculty members had little incentive/reward from their colleges and the university (Bililign, 2013b; Morse, Nielsen-Pincus, Force, & Wulfhorst, 2007) for participating in the center in terms of overhead return, credit for supervising graduate students outside their department, and credit for publishing scientific articles in interdisciplinary journals. Heavy teaching loads (three to four classes per semester) were also a factor that significantly suppressed research productivity, overburdened younger faculty, and eroded morale (Gasman, 2013; Gasman & Samayoa, 2017). These challenges are not unique to HBCUs but are true at most universities the size of NCAT. However, the large amount of funding and the overhead returns generated should have allowed for overcoming the challenges.

Due to the size of the NOAA funding support ($2.5 million/year, 2006–2012), it was easier to convince university administrators to facilitate the establishment of the ASME programs and hire the tenure-track faculty needed for these programs. However, efforts to institutionalize the federally funded geoscience programs and the ISETCSC at NCAT by developing an Earth System Science and Engineering Institute were not successful. The lack of commitment by university administrators and administrative personnel changes was one of the reasons. Although about seven core ISETCSC faculty continued to collaborate, obtaining funding to sustain the research at NCAT and maintaining contacts with some of the NOAA and NCAR scientists, the collaboration between partner institutions was not sustained. NCAT and other MSI students who were part of the center were unable to conduct research at NOAA labs once the NOAA funding ceased.

The undergraduate ASME program at NCAT is an independent degree program under the Department of Physics. The program lacks visibility because it is rare to have an atmospheric science program in a physics department. This factor could also be a barrier for recruitment and program growth. The program is considered low enrollment, which could be targeted for elimination if enrollment and retention are not improved. There has been a steady growth in enrollment and improved retention since 2016 because of new NSF funding that provides financial support, year-round research experience, and mentoring to ASME majors (Bililign, 2016). Most URM students have financial problems and often must work off campus to support themselves (NASEM, 2018). This interferes with their school work and affects their performance and ability to survive in the program. The financial support through the NSF funded program not only helped them to focus in their school work but kept them engaged in year-round research, which provides more time and opportunities to interact with faculty and graduate students.

The expected outcome of NSF-OEDG program was recruiting and retaining five to ten students in the NCAT geophysics concentration. This goal failed due to several factors. The fact that the NCAT program did not have a dedicated geophysics faculty member in the subject area was a significant obstacle. Postdoctoral fellows and adjunct faculty taught the geophysics courses. There was no clear institutional commitment to sustain the program beyond the external funding period. In addition, the partnerships with PSU and the AfricaArray program were discontinued when departmental administration changed.

A significant barrier to building capacity in the geosciences was lack of institutional commitment and support to sustain the externally funded programs beyond the funding period. This is related to the insufficient support by top leaders and administrators within HBCUs, because they do not often keep up with the shifting education, research, and outreach paradigms outside traditional academic programs (Mills Campbell, 2017). The lack of commitment to grow geoscience programs is understandable, because HBCUs operate on tight budgets that often are not conducive to long-term visions for new programs (Kenney, 2016), unless there is strong administrative leadership that understands the long-term societal benefits and needs. NCAT administrators were willing to provide strong letters of support and commitment to funding agencies to secure the funding. Maintaining institutional commitments to a program of low enrollment but high benefit to society is a challenge. This is because, first, the benefit to all stakeholders is difficult to describe/assess and, second, stakeholders must be reeducated regarding the benefits. Furthermore, whenever administrations change, the programs are left vulnerable at institutions that have relatively high levels of turnover, which are common at HBCUs (Palmer, Robert Preston, & Assalone, 2019). Thus, federal funding agencies should include more accountability mechanisms to ensure that, before and during the funding period, awardee universities establish and implement policies and procedures that support sustainability and commit to initial promises made, irrespective of changes in administrations.

There are compelling reasons why HBCUs and MSIs need to develop and sustain programs in geosciences, including the following:

1. URMs and the poor are disproportionately impacted by environmental problems such as hurricanes and poor air quality (Baird, 2008; Ross, 2013; Spelt, Biemans, Tobi, Luning, & Mulder, 2009). For example, Hurricanes Sandy, Katrina, Harvey, and Irma had a significant impact on minority communities in both North Carolina and the nation.
2. The geosciences are relevant to the lives of URMs, who constitute the majority of students at MSIs, because this kind of education provides an opportunity for the students for impactful community engagement.
3. Students increasingly want their studies to be associated with a societal good, such as making people’s lives better or preventing damage to the environment (Heron & McNeil, 2016). Also, among students, there is increasing enthusiasm about problems of global importance (Golding, 2009). Addressing concerns of global importance in STEM education therefore facilitates retention of students in STEM majors (NAS, 2005).

One possible approach is that MSIs will need to build on STEM teaching and learning infrastructures that already exist at their institutions to create, enhance, expand, and connect geoscience capacity through an interdisciplinary and culturally relevant community engagement approach (Gilligan et al., 2007; You, 2017). For most MSIs, geosciences-related courses are distributed across several disciplines with different priorities and are usually just a part of a much larger disparate grouping (Malhotra & Vlahovic, 2011; Rossbach & San Juan, 2016; Solís et al., 2014). Developing an inventory of available geosciences-related courses and creating certificate programs as well as minors in the geosciences would help increase enrollment in existing programs. MSIs need to maintain these programs in the face of significant pressure to close low-enrollment programs. Therefore, to enhance enrollment growth, the geosciences, which provide solutions to issues of societal relevance, can be developed as joint interdisciplinary concentrations by the science programs.

Low enrollment in specialized geoscience curricula or other upper-level STEM courses is a challenge most institutions face. Developing geosciences-related general education courses to expose many students to this interdisciplinary field can generate student credit hours (SCHs) to compensate for the expected low enrollment in the major courses. For example, the general education science course "Weather & Climate Studies" at NCAT, created in 2009, has been a popular course across campus, with both traditional and distance sections offered, with enrollment of more than 100 students (Coursicle, 2019). The Energy and Environmental Systems Department has collaborated with the History Department to incorporate GIS and weather/climate history social science components into the course. These courses serve as a potential recruitment vehicle for ASME students as well as providing visibility across campus for ASME programs. These and other success stories help to support the argument for hiring sufficient numbers of geosciences faculty, as these general education courses generate enough SCHs to justify those hires.

The best practices in training URM geoscience students at MSI learned via the ISETCSC and NSF-OEDG projects include the following:

1. Programs that build strong national lab, industry, university partnerships have the twofold strength of providing students with diverse, motivating mentoring experiences while leveraging taxpayers' investment in the national labs.
2. Funding is needed for holistic approaches to geosciences-focused student recruitment, student retention, student mentoring, faculty development, faculty and staff hiring, research facility development, and so on. Approaches that provide funding in a piecemeal manner are less effective and therefore extremely difficult to sustain.
3. Federal program agencies should be given more flexibility, with appropriate justification, to provide phase-out funding to help programs transition to new sources of funding.
4. Difficult challenges—such as increasing the number of URM students who receive quality training in the geosciences—require long-term investment and use of best practices for significant impact, coupled with clear and tangible commitment by MSI leadership to sustain these programs by including them as priorities in institutional strategic planning by recognizing the long-term social benefits.

Although providing adequate capacity-building grants to MSI is critical in increasing diversity in the geosciences, one-time funding has proven not to be sufficient to grow the programs enough to be self-sustaining, as demonstrated by the NOAA-ISETCSC and NSF-OEDG programs. Federal interventions in these kinds of programs should not be allowed to wither and fade before the programs grow enough. The continued success of the current four NOAA-EPP-funded centers is a result of sustained funding for over 12 years.

Furthermore, when institutions apply for and receive grants for new program development and capacity building in the geosciences, they should be required to incorporate research and education in the geosciences into their long-term strategic plans to ensure that geosciences-focused programs initiated by federal grants are sustained beyond their funding cycles.

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ORCID

Solomon Bililign http://orcid.org/0000-0001-5064-7695

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