Holistic Review of Multi-Site Combined REU/RET Program and the Long-Term Effects of Hybrid Mode of Instruction

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Abstract

To increase the participation and graduation rates of post-secondary students from underrepresented and minority groups in the field of engineering, the Smart City Research Experience for Undergraduates (REU) and Research Experience for Teachers (RET) (SCR^2) Mega-Site program was introduced in 2018. The SCR^2 initiative, which has been successfully run for the past four years with funding from the National Science Foundation (NSF), involves a partnership of 14 Historically Black Colleges and Universities (HBCUs) and one Institution serving Hispanic students (HSI). The leading university for this program is Morgan State University in Baltimore, Maryland. Underperforming REU students are encouraged to participate in research opportunities through the SCR^2 program, which has been shown to increase student retention and graduation rates. Participants in RET are chosen from the area's high schools and community colleges that feed into the consortium institutions. RET participants' involvement in practical engineering research projects enables them to inspire their students to choose engineering as a career. With an emphasis on smart and connected cities, the SCR^2 program provides summer research experiences (eight weeks for students and six weeks for teachers). This paper presents our learnings and insights of the program for the past four years with evaluation findings. There have been 116 students and 44 teachers who have successfully participated. The research program was conducted on campus in 2019, but due to COVID-19, the program was conducted online in 2020. In 2021 and 2022, the program was redesigned to be hybrid, and six host sites participated. Despite the changes in the program, students' prowess was enhanced by their teamwork and engagement in the projects. The post-program survey raised concerns about females' participation in the program for four years. Even though the number of female participants decreased from 2019 to 2022, the participating females reported they were confident, satisfied, and gained knowledge by the end of the program. The assessment results, however, make it clear that additional focus is required on women's experiences in the program to increase their sense of belonging in the engineering sector. The SCR^2 program's transition from an on-site to a hybrid serves as an example of how innovation in engineering education may address the problems and give insights into the tools and technologies needed for efficient cross-site communication, faculty advisor/mentor involvement, participant engagement, and making the most of the strong network connecting the participating schools.

Introduction

Initially established in 1987, the REU program expands access to research opportunities for students from minority groups and non-research-focused tertiary institutions [1]. The National Science Foundation (NSF) launched the Research Experience for Undergraduates (REU) program to support this. This program has been proven to support undergraduates to pursue

This material is based upon work supported by the National Science Foundation under Grant No. 1849454.

graduate study in science, technology, engineering, or mathematics (STEM) [2-4]. This research program has also improved students' ability to work through the uncertainty in research problems, sharpening their leadership skills, gaining a more profound knowledge of STEM, and presenting technical work to the audience [5-7]. Undergraduate research can increase the retention of undergraduates in STEM if the students are exposed to research earlier. [8]

Teachers with a good understanding of science and technology can help students at the K-12 level participate in the research, leading them to achieve higher education and preparing them for higher education. To help teachers to keep up with the changes in their fields, NSF has introduced Research Experience for Teachers (RET), which has positive outcomes [9]. The high school teachers who participated in the RET program have gained a deeper understanding of technical research and incorporated their knowledge into teaching activities [10].

The Mega-Site Smart City Research Experience for Students (REU) and Research Experience for Teachers (RET) (SCR^2) program combine the participation of 14 Historically Black Colleges (HBCUs) and a Hispanic Service Institute (HSI) to provide research opportunities in the field of the smart city. This program is for underserved university students and local high school teachers serving in the same communities where these institutions are located. The combination of REU and RET programs has leveraged the technical expertise and institutional resources of undergraduate students and high school teachers. [11]

The SCR^2 program has offered research and mentoring for REU/RET from 2019 to 2022. In 2019, three universities offered the program on-campus to work on 16 research projects for 28 undergraduates and 15 teachers. However, due to COVID-19, the program was offered virtually in 2020 by three universities to 32 undergraduates and 12 teachers who worked on 12 research projects. The program was offered as a hybrid in 2021 across six universities, which offered 18 research projects to 37 undergraduates and 27 teachers. While the program was still hybrid in 2022, five universities participated and offered 11 research projects to 26 undergraduates and 7 teachers. The program has been successful on-campus, virtual, and hybrid. During the hybrid program, few research projects were offered on campus, and others were offered remotely so students and teachers could participate in the program and continue to provide research opportunities to underrepresented minority students.

SCR^2 Program Background

Research Motivation:

The 15 HBCU/HSI institutions, which include Morgan State, Howard, Hampton, Norfolk State, Maryland Eastern Shore, University of DC, North Carolina A&T, Tennessee State, Florida A&M, University of Texas at El Paso, Alabama A&M, Jackson State, Southern, Prairie View, and Tuskegee Institute, have joined forces to coordinate the SCR^2 Mega-Site program. This program is built on the research strength of the host sites like Renewable Energy, Internet of Things Security, Human-Computer Interaction, Smart Grid, Energy Storage, and Advanced Materials. These specific research areas align with the program's main research theme, "Smart and Connected Cities," in a positive way (SCC).

The SCR^2 program started with three host sites in 2019 and 2020 while hosting six locations in

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2021. In the last year, the program had five host sites. The programs recruited almost 30 URM students and 15 teachers during the first, second, and last years and hosted 47 URM students and 23 teachers in 2021.

Methods:

The lead institution, Morgan State University, works with the principal investigators of the active sites to recruit and assign REU/RET participants based on their preferences, evaluation metrics, and recruitment targets. It is vital to ensure students experience life outside their primary institution. Before the hiring, the active sites create project concepts, which are completed by December. Prospective participants are given pre-projects to work on at the beginning of the year, and graduate mentors and faculty advisers at the location conduct training and research activities before the start of the summer program.

REU participants select one of the three active host institutions during the hiring process based on the research activities offered, faculty engagement, and the site's location. Participants in the 6-week RET program, drawn from nearby high schools, do not remain on campus. Participants work on their research for 32 hours per week during the summer, with team-building exercises and the creation of lesson plans (for RET participants) and weekly reports (for REU participants) taking place on Fridays. Participants in RET and REU collaborate on research projects and offer input based on their unique perspectives and experiences. To provide a closer connection between engineering research principles and practical application, the curriculum depends on immersive instruction.

The REU/RET teams create a video "elevator pitch" on their experience and present their work in a virtual research symposium at the end of the summer. The top 9 participants in the program are given stipends to continue their research at their home university during the academic year. For RET participants to bring the proper hardware and components back to their classrooms to support their engineering activities, host institutions cooperate with them to make the necessary purchases. Research projects focused on smart cities use inexpensive parts and equipment that are open to everyone.

Changes Made from 2019 to 2022

Program Recruitment:

The selection process for 2019 was simple as the program was on-campus, making it easy for the students to rank the university and the projects they wanted to work on. Due to the pandemic in 2020, the program was offered remotely, and students, teachers, projects, and the equipment needed for each project were all considered [11]. The recruitment took place before the pandemic, participants could participate in the program remotely, and they all agreed to the adjustments in participation. Although the RET recruiting goal was dropped (9/15), the REU recruitment goal was surpassed (32/30) [11]. Due to the hybrid nature of the program, there needed to be more modifications to recruitment for summer 2021 and 2022. The option of working in person or remotely was given to the chosen candidates. Due to their proximity to the campus of the selected university and the fact that few participants wanted to be on campus, the adjusted curriculum allowed these participants to complete both remote and in-person

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assignments. The stipend amount remained the same whether participants participated remotely or in person.

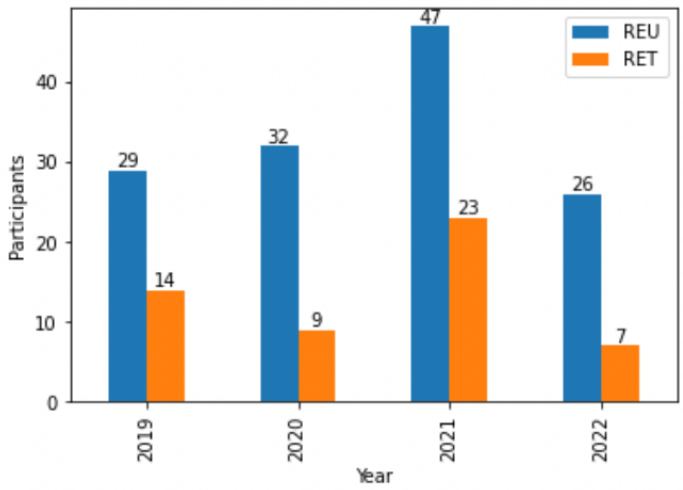

Figure 1. Overview of the number of participants from 2019 - 2022

Projects and Supplies:

The students who participated in the summer 2019 program were on campus working in groups, and the projects were intended to be completed in person. In 2020, when the pandemic hit, it was necessary to restructure the program from in-person to entirely remote. As the projects were already finalized, the projects had to be redefined or combined with other projects so students could participate. Several projects deviated from their planned outcomes because mentors could not share data from their labs with students due to decreased accessibility to campuses. A few projects required equipment ordered through Amazon and delivered to the participant's homes. Some participants experienced late or damaged delivery of their supplies, forcing them to make purchases for which they were later reimbursed. [12] Designing tasks that could be completed remotely and required fewer resources, if not none, was a top objective for Summer 2021 and 2022. Several in-person and hybrid projects were available for participants who desired to be on campus. Some group members worked on the hybrid projects on campus, while others did so from home. Some mentors gathered the data from the testbed in labs and gave it to the students. The remote project materials arrived on time since they had been ordered earlier. To ensure that students stayed caught up on their projects if equipment delivery was delayed, mentors delivered extra equipment they possessed to the participants. Most participants were unaffected by the remote, in-person, or hybrid tasks; they felt at ease working from home and carried on with the projects throughout the fall semester.

Mentoring and Community Building:

Graduate students are generally in charge of daily mentorship and guidance in the SCR^2 program. In 2019, participants collaborated in person with graduate students in their respective labs. However, the mentorship process had to be reevaluated because of the switch to a remote-only program. As would be the case for the in-person program, establishing daily interaction was

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crucial to ensuring that participants remained interested in the research. As a result, mentors were required to set up daily meeting schedules that were recorded and posted for all program participants to see, along with the video conference link. This allowed occasional participation from other group members, program coordinators, and academic advisers in research meetings. Mentors set daily study goals, assessed the previous day's progress, and discussed technical difficulties and potential solutions and suggestions from other group members during these meetings. Screen sharing was used to determine prior work and offer advice. To foster a greater sense of community and engagement, it was mandated that everyone turn on their cameras during this meeting. Mentors frequently held multiple more meetings during 24 hours as needed in addition to the mandated one.

It was recommended to enable all meetings to veer off-topic and discuss anything else that naturally came up. This frequently made it possible for remote participants to get to know one another without using fabricated team-building exercises. However, the daily (and weekly) goals established by the mentors and advisers functioned as a checkpoint to ensure the required research work was still being done. These objectives assist the team in creating their weekly research summaries, distributed to the entire program at the Friday sessions. Following the research summaries on Friday, participants participated in a remote collaborative lunch session, during which they ate their food while speaking on a video conference about various themes. A weekly PowerPoint deck introduced a discussion theme before the Friday session. Participants had to assemble aesthetically appealing presentations that offered their take on the subject. Each participant was invited to give these slides during the Friday lunch sessions with the knowledge that the talk may easily switch to any other subject as the discussions progressed. For example, one conversation topic would be "a movie that impacted my perspective on life," another might be "what are you passionate about." A third might be "how the epidemic has changed a fundamental idea I have had." The mentoring sessions and group lunches' technical and social contacts produced a support system that improved the participant's research and professional growth experiences.

Research Symposium:

The research symposium was intended to be a significant remote engagement because the program involved numerous institutions [11]. Each host site's attendees gathered in a conference room where they shared a video link with conference rooms from other host sites. The symposium was open to anybody who wanted to attend. The groups were instructed to pre-record their presentations and deliver them during the symposium, followed by a live question-and-answer session, to avoid technical difficulties [11]. The website for the program then hosted these videos.

Participants used the elevator pitches in 2020, 2021, and 2022 to create a portfolio of research activities that could be easily shared on social media and provide symposium attendees with an overview of research presentations before the actual presentation. Because of the elevator pitches, the audience could post queries and comments before the event. When the research videos were shown, the Q&A session was altered to a discussion session where the teams may more casually go through aspects of the research that weren't included in the formal presentation and respond to any questions that had been pre-posted [11].

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Project Summaries
2019 Projects:

IoT Device Security Assessment using Side Channel Analysis (Morgan State University)
This study entails looking into IoT device flaws that allow information to leak through side channels like power traces found during cryptographic processes. The IoT testbeds are made up of various devices, each with a distinctive physical design. Physical vulnerabilities in several commercial IoT devices will be evaluated using side-channel analysis (SCA) attacks and differential power analysis (DPA). After identifying the vulnerabilities, the participant will develop a suitable countermeasure to defend against the SCA attack.

Smart Streetlights with Sound and Motion Detection (Morgan State University)
Participants create intelligent streetlights equipped with motion and sound sensors. In the event of a crime, the streetlights' primary function is to gather and transmit data to the application server about gunshots and continuous motion. Participants create other sensor devices by employing microcontrollers like Arduinos and Raspberry Pis and communicate with a server using a communication module (Zigbee or Wi-Fi) to report any gunshot details like the time and location.

Assessment of the Capabilities of Current Battery Technologies (Prairie View A&M University)
The technology to store extra energy during the lean seasons has presented hurdles as improvements are made in sustainable energy supply systems, such as photovoltaic and wind power generation, for example, stand-alone systems cannot be economically and appropriately sized for deep cycle batteries of the lead-acid and alkaline types that have primarily been used as energy storage devices for solar power designs. A prototype will be built outside the lab, where data will be gathered and analyzed after the initial familiarization with the work in the sustainable energy lab.

Wind Data Measurement (Prairie View A&M University)
Photovoltaic is slowly losing ground to wind power generation in the field of sustainable energy systems. The National Renewable Energy Laboratory (NREL) offers wind and wind turbine data to locate wind turbines. However, data for other areas could be more precise due to the lack of wind in certain regions. This project will install a tiny wind generator to measure the wind energy density around Prairie View University.

Wireless Network System for Grid with Node & End Station Development for Remote Sensing (Prairie View A&M University)
IoT applications with Wi-Fi capabilities will be created for microgrid systems. Sustainable energy is used to power these systems as well. The system's ability to communicate with remote end-stations to exchange various data files is made possible by wireless capabilities. In the initial phase, these systems will be coded so that data files can be transmitted based on the timetable to consume electricity prudently.

Renewable Energy Source – Solar Cell (Prairie View A&M University)
The availability of non-renewable energy sources, such as crude oil, natural gas, coal, etc., is dwindling fast. As a result, renewable energy sources like solar, hydroelectric, geothermal, wind,

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and tidal energy are becoming increasingly significant. Numerous breakthroughs are being made to transform these renewable energy sources into forms that may be used. The Current-Voltage (I-V) and Power-Voltage (P-V) curves from the solar array simulator will be generated and plotted during the simulation of solar cells in the MATLAB environment.

Silicon Nanowires- Fabrication and Optical Characterization (Norfolk State University)
The creation of effective solar cells and intelligent lighting is the aim of this research. Using metal-aided chemical etching (MACE), silicon nanowires (SiNWs) will be created, and their effectiveness in lowering the surface reflectance of silicon wafers will be examined. Optical and scanning electron microscopy measurements will be used to evaluate the samples.

Wearable Sensors for Monitoring of Chronic Heart Diseases (Norfolk State University)
This project aims to design a network of piezoelectric thin film sensors that can precisely detect and measure pulse rate for ongoing monitoring of chronic cardiac conditions. Polyvinylidene fluoride (PVDF) thin films will create a wearable sensor grid that can be securely wrapped around a person's wrist. Then, MATLAB programs will be used to process the raw signals further to obtain precise readings of the average heart rate, heart rate variability, and other essential metrics.

Developing Technology for Functional Neural Imaging of Brain Activity using Electrical Impedance Tomography (Norfolk State University)
Non-invasive large-scale imaging technologies have permitted considerable gains in activity localization but have limited temporal and spatial precision. EEG-based methods need to be sufficiently precise. Due to the inherent three-dimensionality of functional MRI, recorded calls may be accurately attributed to their respective origins within the brain. Diffuse Optical Tomography (DOT), typically restricted to scalp optrodes with infrared light, can only produce images of action related to blood oxygenation.

2020 Projects:

Traffic Video Analytics (Morgan State University)
The methodologies for vision-based traffic analytics, such as traffic object localization, identification/classification, and traffic object counting from vision data, are practiced by participants (videos). The knowledge provides a framework for automatically extracting pertinent metadata to create, enforce, and advance traffic laws.

Infrastructure to Vehicle Communication via Traffic Lights (Morgan State University)
Participants create a receiver and transmitter for visible light communication (VLC). The receiver is meant to be inside a car, while the transmitter is integrated into a mock traffic light. This configuration makes infrastructure-to-vehicle communication possible, enabling information sharing with approaching vehicles, such as how long it will be before a traffic signal changes.

Deploying Edge App using Intel OpenVino Toolkit (Morgan State University)
Applications are deployed at the edge using the Intel OpenVino tools by participants. Participants use computer vision technologies (like OpenCV), FFmpeg, and Flask to process and

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extract information from these files. MQTT (MQ Telemetry Transport), a lightweight publish/subscribe architecture created for resource-constrained devices and low-bandwidth settings, feeds data derived from photos and videos to a node server. Inference engines are deployed at the edge.

Medical IOT Testbed (Morgan State University)
To assess the risks involved with said devices when used in a home environment and to ensure security and privacy when it comes to consumers' personal information, data, and other connected devices, the goal of this research is to create a testbed made up of medical Internet of Things (IoT) technologies.

Private Certificate Authority (CA) for IoT (Morgan State University)
For IoT devices, participants set up a private certificate authority (CA). This project is expanded to include Amazon Web Services AWS IoT, enabling remote CA-governed IoT devices to be deployed. Participants in the project can utilize Step-CA to effortlessly automate safe certificate administration, leverage TLS, and access anything that is operating anywhere from anywhere.

Implementation of Distributed Control Algorithms for Multi-Vehicle Systems (Florida A&M University)
Participants gain knowledge of the foundational ideas of control systems and how to apply control algorithms to target devices. Participants learn experimental techniques for coding and managing a network of unmanned ground vehicles. Participants are introduced to string stability in cooperative adaptive cruise control of a platoon of several vehicles. The participants work with QUANSER QBots and are exposed to simulation and programming.

Energy Storage Devices: Characterization and Measurements (Florida A&M University)
Participants gain knowledge of the current Li-based batteries, capacitors, supercapacitors, and other electrochemical energy storage technologies utilized in grid applications and electric vehicle and vehicle applications. The initiative improves knowledge of the critical ideas in sustainable energy systems and the significance of storage systems more generally.

Fabrication and Characterization of Dye-Sensitized Solar Cells (Florida A&M University)
These nanotechnology ideas are covered in this project: 1) The creation of thin films; and 2) the movement of electrons within nanocrystals. Participants discover the fundamentals of dye-sensitive solar cells (DSSCs). Then, participants can construct a solar cell utilizing straightforward device fabrication methods.

Implementation of Computer Vision Algorithms for Autonomous Vehicular Platforms (Florida A&M University)
This project uses a DIY artificial intelligence (AIY) kit to cover the theoretical underpinnings of artificial intelligence. It introduces participants to the actual implementation of AI algorithms used in computer vision and machine learning applications.

Simulation of microwave transmission lines and microwave filters (Alabama A&M University)
The participants role-play two well-known microwave transmission lines and two microwave filters. AppCAD and Sonnet Lite are the first two simulation programs that trainees use. First,

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the two transmission lines' architecture and the two pieces of software functionality are taught to them. Next, they simulate both transmission lines using AppCAD. Finally, using Sonnet Lite, they model the microstrip based on insertion loss and reflection coefficient.

Simulation of linear circuits and analog circuits (Alabama A&M University)
Participants simulate a variety of basic linear circuits and typical analog circuits using the NI Multisim program.

Simulation of Advanced Circuits (Alabama A&M University)
Participants model several highly significant advanced circuits using NI Multisim software. The single-stage BJT common emitter amplifier, single-stage BJT common collector amplifier, differential and multistage amplifiers, operational amplifiers, digital-to-analog converters, analog-to-digital converters, and biCMOS current sources are some of these circuits.

2021 Projects:

Distance detection between objects using Computer Vision (Morgan State University)
Participants will gain experience in computer vision and machine learning techniques for vision-based object detection to detect and estimate the distance of other people within the vicinity of the subject. A framework for social distancing compliance and personal safety will be created using these libraries. Extracting pertinent metadata can reduce the spread of Covid-19 and improve personal security by automatically detecting and describing a person's surroundings.

IoT Application Using Arm Pelion Platform (Morgan State University)
This project aims to provide students with practical experience in creating an IoT platform that supports device management, connection, and data management. Individuals tend to construct a network of interconnected devices with an understanding of how the IoT platform performs under the wood.

Smart Crosswalk Light Implementation (Morgan State University)
Participants will obtain knowledge of computer vision and machine learning methods for vision-based traffic analytics, including localization of traffic objects (pedestrians, cars, etc.), identification and categorization of traffic objects, and counting traffic objects from vision data (videos). The objective is to implement an automatic bright crossing light based on the number of automobiles and pedestrians.

Smart Wheelchair (Morgan State University)
Participants will create a self-contained platform that can substitute for an autonomous wheelchair. This platform will use QR codes along a black-and-white line along the floor to provide localization. An attached camera and a Raspberry Pi will be used for sensing. Moreover, front-facing ultrasonic centers help in obstacle avoidance.

Hangar Application for COVID Resource Determination (North Carolina A&T State University)
Participants will receive knowledge on designing and customizing a program that helps kids develop tools for coping with the stress brought on by COVID-19. In addition, students will

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contribute to augmenting and improving a mobile application created for Android and iOS devices. Students will also help choose resources to be used in the application.

Machine Learning Applications Implemented on Limited Resource Microcontrollers (North Carolina A&T State University)
The participant will research machine learning (ML) applications that can be successfully implemented using modern microcontrollers (like Arduino) and their newly acquired knowledge of embedded systems, wearable computing, and deep learning on low-power microcontrollers (TinyML) to use as they research wearable computing applications.

Smart Supply Chain Management (North Carolina A&T State University)
Participants will get expertise in supply chain management and decentralized application development. A radio-frequency identification (RFID) chip connected to the item makes it uniquely identifiable. These chips can be scanned by an Internet of Things (IoT) device, which can then securely store this data on the blockchain.

Smart Power Distribution Network Simulation Testbed (North Carolina A&T State University)
The student will create computer software that mimics an intelligent electricity distribution grid with several residences, each fitted with an innovative HVAC system that modifies consumption in response to the price signal. With GridLAB-D, an open-source grid modeling program created by the Pacific Northwest National Laboratory (PNNL), and TMY, a weather simulation database created by the National Renewable Energy Laboratory, specifically, the student will learn how to design and implement a power distribution network (NREL).

Smartphone-based Self-Diagnosis of Parkinson's Disease (Norfolk State University)
Parkinson's disease is a neurological ailment that causes stiffness, trembling, and problems with balance, coordination, and walking. The primary objective of this project is to create a smartphone-based, simple-to-use self-diagnostic tool to identify Parkinson's disease in its early stages.

Thin-film PZT Materials for Energy Generation: Testing, Simulation and Equivalent Circuit (Prairie View A&M University)
Participants in the project's initial phase will gain knowledge about the environmental problems caused by carbon dioxide emissions and various mitigation measures. We'll use a thin-film PZT as the energy-producing component (EGM). They will use the energy collecting system's test platform (EHS). The attendees will also learn to measure and test things using an EGM.

Smart Grid IP Security (Prairie View A&M University)
The IP for the intelligent grid lab will be regularly changed by participants using an Arduino microcontroller to thwart hacker attacks on the system. This work intends to create a new IP for each grid using Arduino and WiFi. With machine learning inference, the project will run on the device. To safeguard a SCADA system, participants will create a variety of sensor units utilizing Arduino microcontrollers by assuming two power-generating systems connected by a tie-line.

Remote Operation and Control of the Smart Grid System Using Arduino Microcontroller (Prairie View A&M University)

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Participants will use an Arduino microcontroller to operate the smart grid system remotely. This effort aims to change how the grid typically works by utilizing a microcontroller like an Arduino to wirelessly control devices and sensors on the grid. To run a SCADA system, the Arduino microcontroller will create numerous sensing components, including sound and distance sensors. A tie-line will connect three separate renewable energy sources to a smart grid through the PLC software for SCADA design.

2022 Projects:

Flood Detection using Computer Vision (Morgan State University)
Participants will utilize security cameras to show when an area has experienced flooding. The main goal is to use the 2018 Ellicott City Flood Video to indicate when a flood occurred. The movie is a montage of various surveillance footage documenting the evolution of the 2018 flood in Ellicott City. A video segment will be cut out to show when flooding occurred, and the frames will be taken, examined, and morphed.

Social Media Analysis (Morgan State University)
Participants will use a social network dataset to determine when their accounts were created, how many connections and friends they have, how many likes they have received for uploaded photos, and how many comments they have made on other people's posts. NLP will then be used to identify any mean remarks that others have made on their profile. The profile information, friends, amount of likes and comments, comments left on their profile as well as comments left on other profiles will all be included in the dataset.

Internet of Medical Things (Morgan State University)
With applications ranging from patient vital sign monitoring and reporting to illness prediction and prevention, the Internet of Medical Things (IoMT) is a fast-expanding network of intelligent medical technology and applications. To address concerns about security and privacy, device authentication, and data integrity, we are investigating the various cyber-related risks aimed at IoMT devices and systems throughout this work.

Smart Home Monitoring System for Reduced Power Usage (Prairie View A&M University)
Homes waste much energy because fans and lights are frequently left on even when no one is home. This initiative aims to alert homeowners when they depart from their residences and if any equipment, such as lights, fans, air conditioners, microwaves, or televisions, is inadvertently left on. In this project, the participants will create an intelligent IoT-based system to alert users when they leave their homes and if any appliances are inadvertently left on. A smartphone app will be used to turn off the electrical loads. In this project, a particle photon will be used.

Smart Home Warning System for Safe Environment (Prairie View A&M University)
It is crucial to safeguard family members who may be left alone for an extended period. Moreover, a system that can monitor the room's humidity and temperature and detect gas leaks is desirable. This project aims to give participants a place to construct an IoT system to identify gas leaks, high humidity levels, or other potential fire hazards in a home. Using a suitable smartphone application, the participants will create an Arduino-based monitoring system to detect gas leaks and regulate a home's temperature and humidity.

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Metal-coated SiNWs for Enhanced Biosensing Applications (Norfolk State University)
This project aims to create metal-coated SiNWs for applications that will improve biosensing. By utilizing these resources, students will construct metal-coated SiNWs via chemical etching and thermal evaporation and then use fluorescent die molecules to quantify the Raman signal amplification on the surface of the SiNWs. Also, we'll investigate how variations in conductivity relate to molecule concentration. This project must be done in person.

A Mobile Flow Free Game for Learning Circuits (North Carolina A&T State University)
Participants will gain expertise in developing a mobile game that demonstrates circuit layout principles. The ideas behind Flow Free are the foundation of the game. In addition, students will create a cross-platform mobile application for iOS and Android devices from an online version.

Insights from 2019 to 2022 Summer Program:

Every SCR[2] program evaluation is the responsibility of the SageFox Consulting Group. Pre-surveys, post-surveys, follow-up surveys for REUs and RETs, and post-program surveys for mentors were used in the assessment. These surveys were created in consultation with Audrey Rorrer, author of the CISE REU Evaluation Toolkit survey instruments [13,14]. The questionnaires include subscales that assess research abilities, leadership potential, self-efficacy, sense of one's identity as a scientist, plans to attend graduate school, plans to pursue engineering, mentorship connections, attitudes toward research, etc. The conclusions drawn from the SageFox assessment report are presented in this section and available on the program website [15].

REU Highlights

The data collected during the four years of the program shows that the program has been successful during the pandemic and beyond. The results from the survey suggest that there has been an increase in STEM knowledge, confidence, and high intention to pursue engineering as a degree. Even though the program has been successful and met its goals, the data results show that the experience for women is different from that of men. The highlights of the four years are below:

- Most REU students had yet to conduct research before participating in the program.
- The students enrolled in the REU acquire specialized knowledge, acquire skills, advance their professional growth, and build networks. Most students were primarily engaged in the subject, which made this REU desirable for achieving these objectives.
- The participation of students was more in 2021 compared to the other three years. But with each preceding year, the percentage of women participation decreased from a high of 48% in 2019 to a low of 24% in 2021.
- There was a slight increase in women's participation from 24% in 2021 to 27% in 2022.
- All the participants reported continuing research with the mentors after the program.
- Women showed a positive change in their sense of belonging to the STEM community, which is promising as they also reported placing more importance on their identities as scientists.
- In 2022, women reported being more satisfied with the program, which was different in the last three years.

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- Women tended to experience fewer gains in confidence and experienced decreases in a few areas. Concerningly, categories in which women lost faith tended to be areas of high growth for men. However, this drop in confidence did not correlate with a lack of knowledge gained, as women's reports of knowledge gained were more similar to men's.

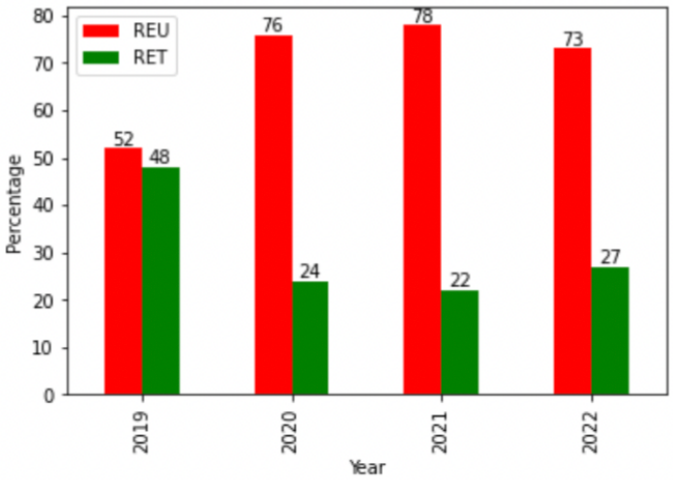

Figure 4. Percentage of men and women in the SCR² program

Participation

In the four years of the program, more students participated, with the percentage of men increasing and the rate of women decreasing. The highest number of students participated in 2021and most of the participants were majoring in Electrical Engineering. After the program, students were comfortable working remotely and had a better sense of time, space, and technology.

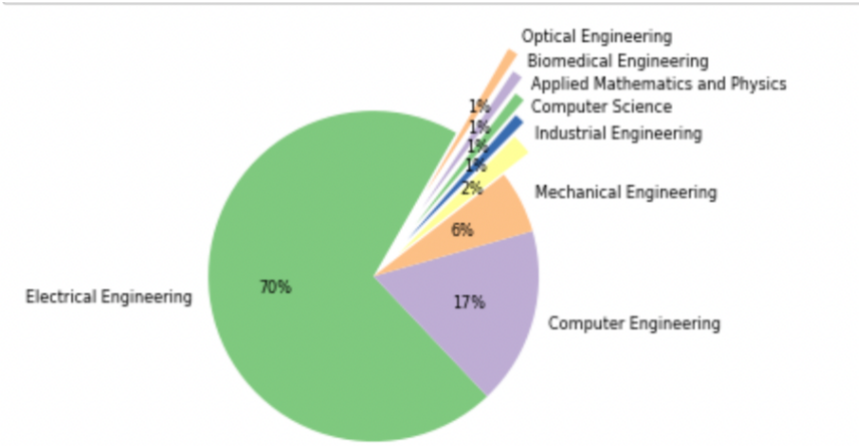

Figure 5. Overview of students majoring in different engineering departments

Confidence

The survey results show that participants' confidence level has increased. Students reported being

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confident in participating in research, formulating a research hypothesis, finding a solution to a problem, interpreting data analyses, and communicating the project results. However, the results also suggest that women gained less confidence after the program. Concerningly, categories in which women lost confidence tended to be areas of high growth for men.

Knowledge

Students participating in the REU program gained more knowledge and skills, particularly regarding career and graduate school prospects. The drop in confidence of women did not correlate with a lack of knowledge gained, as women's reports of knowledge gained were more similar to men's.

"Defending an argument when questions are posed" and "explaining my idea to individuals outside my field" were the knowledge areas where respondents gained the most insight. The advantages for women were especially noticeable when it came to "identifying acceptable research methodologies and designs" and when they were becoming aware of their career options, such as graduate school and research careers. The knowledge of the theory and principles guiding a research endeavor and the nature of a researcher's job also improved for women. On the other hand, males improved the most in their understanding of the graduate school, how to present research and research ethics.

Mentorship

The participants praised the graduate mentors for their mentorship and ability to help the participants on daily bases. The survey results suggest that most participants were satisfied with them and look forward to working with them after the program. This program has helped the students to connect with graduate mentors and gain more knowledge in the STEM field.

Continued Research

Most students are interested in continuing the research work after the program ends. This resulted in students working with the faculty in their respective universities. A few students continued working on the same project to get results, gain more knowledge, and publish papers with their mentors.

Program Satisfaction

Notwithstanding the difficulties, participants express a high degree of program satisfaction overall. The survey results show that the participants were interested in the program and returned the following year. Regarding the faculty advisor, women were generally happier than men. The excitement for pursuing engineering jobs and learning new skills was cited as the program's most rewarding aspect. Problems with the software and other research-related issues, sure to happen in any research context, were more frustrating than the remote job itself.

RET Highlights

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The RET program has helped the school teachers participate in research which has enhanced their knowledge in their fields and helped them keep up with the technological changes. Overall more African American teachers participated over four years. The teachers who participated in the surveys reported that the program had increased their confidence in research and incorporated STEM in their classrooms. In addition, the program has provided flexibility to the teachers as they start their research two weeks after the students (REUs), which required the teachers to work more at developing their teams.

Confidence

Most of the effects were seen in the teachers' confidence in producing research articles for publication, understanding research literature, and understanding the ethical issues surrounding research. Teachers' confidence levels barely changed between 2019 and 2020 but increased in 2021 and 2022.

Classroom Impact

As the program moved from in-person to online to hybrid, the teacher's feedback suggested that they have gained more ways to engage the students in the class remotely and helped them to have a better structure during classes. In addition, they acknowledged acquiring new technical abilities, integrating science and math into real-world applications, accepting project-based learning, and having a higher capacity for compassion for kids with difficulty with the subject matter. The most fulfilling experience, according to one instructor, was "the moment I realized how to apply what I am learning in my teaching environment. That has motivated me to work on a project that would bring the scientific department at our school together. According to another statement, I was excited to learn something novel and valuable that I could impart to kids during the academic year. Another teacher said I'd keep persuading underrepresented students to enroll in engineering courses at HBCUs.

Teaching STEM

The participating teachers have mentioned feeling more confident implementing STEM research in their classrooms and helping students explore the field further. The teachers also feel satisfied with their learning and are willing to adjust their teachings to accommodate more classroom challenges.

Professional Impact

Few participating teachers plan to enroll in graduate programs or future RET programs to further their education.

Program Satisfaction

The RETs survey data suggest that the teachers were satisfied with the projects, research methods, faculty advisors, mentors, and how the program was conducted. However, only some teachers also provided feedback on how the program can be further improved. The teachers were

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also interested in expanding this program to high schools so the students could participate over the summer or school year.

Mentor Highlights

The number of participating mentors increased yearly, but half completed the post-survey. Over the years, the mentors were satisfied with how the program was conducted and was always available during the transition period from in-person to remote. Most mentors reported a good experience with the mentees and planned to continue their relationship. However, only some mentors were satisfied with the knowledge and technical skills of the participants when they joined the program. Mentors mentioned that programming knowledge would be the most beneficial when describing valuable abilities and any training required to aid mentees in succeeding.

Key findings from 2019 to 2022

One of the primary concerns of the program was female participation. In 2019, 48% of females decreased from 24% in 2020 to 22% in 2021. In 2022, this percentage increased to 27%. The female participants' feedback shows they wanted more from the program in 2020 and 2021, which changed in 2022. Most females reported gaining more confidence in reformulating research hypotheses, finding solutions to a problem, interpreting data analysis, and communicating the research results. However, few females also reported participating in research after the program and pursuing graduate school in engineering. From the survey data, in 2022, the female participants identified themselves as scientists and had a strong sense of belonging to the community of scientists.

The cohort yielded a notable result – the remote and hybrid learning experience was highly positive for both students and teachers. A student shared that the opportunity to connect with peers in their field from different locations was remarkable. They also expressed relief in knowing their research struggles were not unique. The ease of working with coding and sharing codes on screen using IDE (Integrated Development Environment) was also highlighted.

A few other remarks from all the participants were:

- Teachers should start the program with undergraduates to not fall behind in research.
- There should be a coding boot camp before the program start.
- Mentors should give the task to students before the program so the participants can be prepared before starting the research.
- Teachers should get more help from mentors and faculty to keep up with the research.

Conclusion

The Smart City Research Experience for Undergraduates and Teachers (SCR^2) is a one-of-a-kind combined REU/RET mega-site involving 14 HBCUs and 1 HSI that offers high-quality opportunities in the field of smart city research to a significant number of underserved undergraduates and the neighborhood high school teachers who serve the same communities from which these institutions recruit for their STEM programs. The Corona Virus (COVID-19) pandemic, which struck the United States during recruitment, posed a challenge to the 2020 program. As a result, the program team changed its format to a remote one and provided the

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coaching and technology support required to make it successful. In 2021 and 2022, the program was conducted hybrid, which was very successful in participation, participant happiness, experiencing STEM research, gaining knowledge and confidence, and identifying oneself as a scientist. The positive results of the cohort after four years are: 1) despite the move to a remote offering, the student cohort was more significant than in 2019 and continues to be a diverse group in terms of demographics and majors; 2) setting up programming boot camps for teachers and students from non-STEM backgrounds; 3) students reported gains in confidence, knowledge, and belongingness in STEM between the pre-and post- surveys; 4) students, teachers, and mentors were all satisfied with the mentor relationship; 5) students report that they increased their desire to obtain an advanced degree. In 2022, more females participated and had positive outcomes. The females identified themselves as scientists and were interested in pursuing STEM degrees.

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This material is based upon work supported by the National Science Foundation under Grant No. 1849454.

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