



MINORITY UNIVERSITY RESEARCH AND  
EDUCATION PROGRAMS (MUREP)  
SCIENCE, TECHNOLOGY, ENGINEERING  
AND MATH (STEM)  
ENGAGEMENT (MSE)

FY 2016 ANNUAL PERFORMANCE REPORT

FUNDING SOURCE:  
OFFICE OF EDUCATION  
MUREP

LINE OF BUSINESS:  
STEM ENGAGEMENT

MANAGING ORGANIZATION:  
KENNEDY SPACE CENTER  
OFFICE OF EDUCATION

ACTIVITY MANAGER:  
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## **ACTIVITY DESCRIPTION**

NASA provides financial assistance (grants and cooperative agreements) to the Nation's Historically Black Colleges and Universities (HBCUs), Hispanic Serving Institutions (HSIs), Asian American and Native American Pacific Islander-Serving Institutions (AANAPISIs), Tribal Colleges and Universities (TCUs), American Indian and Alaskan Native Serving Institutions (AIANSIs), Predominantly Black Institutions (PBIs) and eligible community colleges. The Administration recognizes the valuable role that these institutions play in educating our citizens, as reflected in the Minority-Serving Institutions (MSI) focused Executive Orders signed by the President.

NASA's Minority University Research and Education Activity (MUREP) investments enhance the research, academic, and technology capabilities of MSIs through multi-year awards. Awards assist faculty and students in research and provide authentic STEM engagement related to NASA missions. These competitive awards provide NASA specific knowledge and skills to learners who have been historically underrepresented and underserved in STEM. MUREP investments also assist NASA in meeting the goal of a diverse workforce through student participation in internships, scholarships, and fellowships at NASA Centers and JPL.

MUREP STEM Engagement will support Outcome 1 of NASA's education program: contribute to the development of the STEM workforce in disciplines needed to achieve NASA's strategic goals.

The NASA Swarmathon, funded from NASA MSE, is a challenge to develop cooperative robotics to revolutionize space exploration. This project is overseen by a management team consisting of Dr. Melanie Moses - Associate Professor, University of New Mexico Computer Science (NASA Swarmathon PI), Dr. Josh Hecker – Research, University of New Mexico Computer Science (NASA Swarmathon Technical Lead), Ms. Theresa Martinez – NASA KSC MSP Project Manager (NASA Swarmathon COTR), and Mr. Kurt Leucht – Software Development Team Lead, NASA KSC Swamp Works (NASA Swarmathon Technical Advisor).

Students from Minority Serving Institutions (MSIs) are challenged to develop search algorithms for robotic swarms. Swarmathon participation is designed to (1) improve students' skills in robotics and computer science and (2) further advance technology for future NASA space exploration missions.

## **ACTIVITY GOALS**

Specifically, MSE will seek to:

- Design, develop, and implement a NASA-related STEM challenge targeted for MSI and community college STEM-enrolled student participation;
- Align the challenge design with the NASA mission and with a specific NASA program or project;
- Increase the number of NASA-focused STEM experiences that engage underrepresented groups in active learning to improve retention of information and critical thinking skills;
- Implement proven, innovative practices and programs in STEM teaching, STEM learning, and recruitment and retention of underrepresented/ underserved students in STEM fields;
- Develop and implement processes to capture the impact of activities and strategies implemented through this challenge.

## ACTIVITY BENEFIT TO PERFORMANCE GOALS

### **FY 2016 Performance Goals**

2.4.1: Assure that students participating in NASA higher education projects are representative of the diversity of the Nation.

2.4.5: Continue to provide opportunities for learners to engage in STEM education engagement activities that capitalize on NASA unique assets and content.

## ACTIVITY ACCOMPLISHMENTS

The NASA Swarmathon worked to recruit a broad diversity of MSIs. It undertook a very comprehensive marketing effort that included development of a website, mass emails, mass postcard mailers, publication in a NASA newsletter, a recruitment webinar, partnering with the Penn Center for MSIs, and use of social media. In total 43 different MSIs applied to participate in the inaugural NASA Swarmathon. An application evaluation committee selected 12 teams (representing 14 institutions) for the Physical Competition and 22 teams for the Virtual Competition. After being selected, teams received education and training in the form of webinars, instructional videos, an active Q&A forum, and manuals. In addition, the lead faculty member from each of the 12 Physical Teams received a \$1,000.00 stipend.



*Map of the selected teams - Yellow: Physical teams. Purple: Virtual teams.*

A total of 24 teams (from 26 schools) successfully completed the project by uploading their code to competition organizers. A total of 425 students participated on these 24 teams, which was twice as many students as were anticipated in the Swarmathon proposal. Of the 425 students, 82% of students that reported a race or ethnicity identify themselves as members of an underrepresented group. The competition challenged students to develop algorithms to guide a group of robots to autonomously find and retrieve barcoded tags in an arena. Physical teams participated in two preliminary runs of 30 minutes each, with three Swarmie robots scanning tags, inside a 15 x 15 meter arena. The top four teams advanced to the semi-finals where each team participated in single run of 60 minutes each, with

six Swarmie robots scanning tags inside a 22 x 22 meter arena. This same format was used in a simulated environment for the Virtual Competition.

- Physical Competition Winners
  - \$5,000.00 First Place – Fayetteville State University
  - \$3,000.00 Second Place – Central New Mexico Community College
  - \$1,000.00 Third Place – Southwestern Indian Polytechnic Institute
- Virtual Competition Winners
  - \$3,000.00 First Place – Cabrillo College
  - \$1,000.00 Second Place – Durham Tech Community College
  - \$500.00 Third Place – Texas A&M International University

In addition to the physical and virtual competitions, the Swarmathon also organized a Research Experiences for Undergraduates (REU) program for students. The Swarmathon selected four students from Pasadena City College, Durham Tech, Southwestern College, and Jackson State University. These students were placed at summer research projects at participating schools including the University of Houston, Southwestern Indian Polytechnic Institute, and the University of New Mexico. Students were surveyed and results revealed that as a result of the REU, all of the students became more interested in attending graduate school.

The Swarmathon also selected 26 students from 14 different schools (12 of the schools being Swarmathon teams) to participate in the 2016 Robotics: Science and Systems Conference, which included a full day workshop on the Swarmathon. This annual conference brings together researchers working on algorithmic or mathematical foundations of robotics, robotics applications, and analysis of robotic systems. The Swarmathon utilized NASA funds to provide these students with travel stipends so they could attend.

In order to measure the educational outcomes of the Swarmathon, organizers undertook a carefully crafted evaluation that was developed by Brandeis University and Florida Institute of Technology. The project identified 11 computing and engineering standards, and asked students to self-assess themselves on these standards from a perspective of both before the competition and after the competition. Upon analyzing the evaluation results, it was determined that there were significant gains realized by students. In fact, the average gain for each standard was 0.93 on a 5-point scale.

### **Technical Reports**

Each Physical team was required to submit a five page Technical Report. Teams described the algorithms they applied or developed and the experiments they ran to test robot sensing, localization and swarm foraging performance. They also described techniques to communicate, divide territory for exploration, improve localization, and other methods to mitigate the inherent difficulties of implementing algorithms in hardware.

The winner for the Best Physical Team Technical Report by was California State University-LA. Additionally two virtual teams submitted Technical Reports, and the best Virtual Team Technical Report was awarded to Cabrillo College. Both winning teams received a \$200.00 prize.

All Physical Competition teams were required to do an Outreach Activity and submit a five page Outreach Report. The \$200.00 prize for the best Outreach Report award went to Pasadena City

College. Although Outreach activities were not required for the Virtual Competition teams, two teams chose to do an Outreach Activity and Report.

## **Education / Training**

The NASA Swarmathon seeks to advance students' skills related to both computer programming and robotics. Faculty mentors at each participating school assist and guide students through the process of developing their competitive search algorithms and implementing them on the robotic vehicles. The NASA Swarmathon supplemented this by providing training and educational materials to students and faculty in a variety of formats including:

### **A. Webinars**

The NASA Swarmathon hosted three different training webinars for students and faculty. Content from these webinars included live presentations from Swarmathon team members located at the University of New Mexico and NASA Kennedy Space Center. The webinars spanned 60-90 minutes in length and featured PowerPoint presentations, short instructional videos, and hardware demonstrations. All webinars were recorded and made available for playback later. Copies of all PowerPoints were available for download as well. Webinars hosted included:

Student Orientation - Hardware Overview - January 22, 2016

Technical Questions and Overview of Code Upload - February 26, 2016

Technical Questions and Event Overview - April 1, 2016

### **B. Instructional Videos**

The NASA Swarmathon team produced a comprehensive 35 minute video demonstrating how students could program their robots in a simulated environment. This video was posted to YouTube, the NASA Swarmathon website, and links were sent out to each student via email. Additional short videos concerning robot calibration and other related topics were also produced to educate Swarmathon teams.

### **C. Q&A Forum**

The NASA Swarmathon set up a Q&A Forum so students and faculty could post questions as needed. Swarmathon team members with a technical expertise in Swarm Robotics responded to each question posted, and most responses were provided in 24 hours or less. The forum facilitated a considerable level of communication between students, faculty, and Swarmathon technical staff, thereby allowing Swarmathon teams to gain knowledge and expertise directly from peers, in addition to more traditional teaching methods. Questions were posted to forum topics, for example, Competition Rules, Hardware, and Software (which included Q&A on Robot Operating System (ROS)), the Swarmathon code base, the Gazebo Simulator. While teams were primarily dependent on Swarmathon staff at the start of the competition season, the forum's highly dedicated and persistent user base quickly began sharing tips and tricks that elevated programming proficiency across all teams. This high quality of discourse on the forum ultimately helped the technical staff to refine the Swarmathon code base and user guides, ensuring that present and future competition participants will receive the best instruction available. Statistics for the forum were as follows:

Total registered users - 112

Total topics posted - 127

Total posts under topics - 562

## **D. Hardware and Software**

The Swarmie hardware platform is built on a robust aluminum chassis, which contains four brushed DC motors with quadrature encoders, as well as a powerful 14.8 V, 13.6Ah lithium-ion battery pack. The chassis rests on two pairs of durable rubber tires that provide superior grip and handling on a wide variety of indoor and outdoor surfaces. Additional structural support is provided by laser-cut acrylic plates and 3D-printed, UV-cured resin components. The Swarmie's sensor package includes three ultrasonic rangefinders, a 10-axis IMU, a high-performance GPS board with active antenna, and a lightweight webcam. A common, Atmel-based microcontroller governs all low-level sensing and actuation, in concert with a custom-designed breakout circuit board, which promotes straightforward plug-and-play interoperability. High-level autonomous robot operations, including navigation, sensor fusion, obstacle avoidance, and target detection, are controlled by an on-board mini PC running Linux and ROS, the Robot Operating System. The ROS framework encapsulates these behaviors into application "nodes", facilitating node-to-node communication through a highly-scalable publish/subscribe messaging system.

All low-level and high-level Swarmie software is managed through the highly-scalable Git version control system, which fully supports the style of distributed, non-linear workflow that is essential to the many-user software development environment of the Swarmathon competition.

Git provides a wide range of interaction levels between, and among, Swarmathon teams, which facilitates and simplifies collaboration and learning. All required software repositories are publicly hosted on GitHub.com, where users can report software bugs and suggest new features, in addition to uploading and maintaining their own team's private code base. As teams modify and improve their swarm algorithms, they test these improvements in Gazebo, a highly-accurate, 3D-physics-based robot simulator that replicates the appearance and operation of the Swarmie robots. The native integration of ROS and Gazebo ensures a seamless transfer of control algorithms from simulation to physical robots, which greatly increases the productivity of the teams.

- The Swarmathon-ROS code base, which runs on the Swarmie's mini PC, is available here: <https://github.com/BCLab-UNM/Swarmathon-ROS>
- The Swarmathon-Arduino code base, which is required for the Swarmie's microcontroller, is available here: <https://github.com/BCLab-UNM/Swarmathon-Arduino>
- The Swarmathon-Robot code base, which contains instructions and all required files for building a Swarmie robot, is available here: <https://github.com/BCLab-UNM/Swarmathon-Robot>

## **E. Manuals**

The NASA Swarmathon team authored manuals and made them available at <http://nasaswarmathon.com/robot-guide/> to all participating teams. These manuals included:

- Safety Manual
- Instructional Manual
- Assembly Manual

### **Research Experiences for Undergraduates (REU)**

One of the goals of the Swarmathon is to engage students in computer science research. By participating in the Swarmathon, students are providing important data to the NASA Swamp Works lab, which can be used in research regarding how swarming robots might help future space exploration missions. As a way to further engage students in research, the Swarmathon set up a summer Research Experiences for Undergraduates (REU), modeled after the highly successful REU program operated by the National Science Foundation and coordinated through the Distributed REU program funded by the Computing Research Association – Women (CRA-W).

The Swarmathon management team selected four students from Pasadena City College, Durham Tech Community College, Southwestern College, and Jackson State University. These students were placed in summer research projects at participating schools including the University of Houston, Southwestern Indian Polytechnic Institute, and the University of New Mexico. Students were provided with a stipend, transportation to the institution, and housing for the duration of their 8-week stay. The students were interviewed via telephone about their experience. The survey revealed that as a result of the REU, all of the students became more interested in attending graduate school. In particular, students expressed a desire to attend the institution where they did their research experience with one exception where the institution does not have a graduate program.

### **Robotics: Science and Systems Conference**

Dr. Melanie Moses, the Principle Investigator for the NASA Swarmathon, organized a Swarmathon workshop at the 2016 Robotics: Science and Systems Conference. This is a top-ranked international conference in robotics and artificial intelligence. It took place on June 18, 2016 at the University of Michigan. As a way to further educate students, and strengthen future participating teams, the NASA Swarmathon selected 26 students from 14 different schools (12 of the schools being Swarmathon teams) to participate in the conference. The Swarmathon utilized NASA funds to provide these students with travel stipends so they could attend. All students presented posters in an interactive session with Robotics faculty, and three of the students were speakers during the conference.

The students had the opportunity to attend the Swarmathon Workshop on Saturday, the “Becoming a Robot Guru” Workshop on Sunday, and the complete track of presentations on Monday through Wednesday. The workshop included:

- talks on swarm robotic algorithms and platforms by students and faculty,
- tutorials on the Swarmie physical platform and simulation environment in ROS/Gazebo,
- a panel discussion on success in robotics by faculty and researchers,
- an interactive poster session in which students presented their research,
- and a keynote talk from NASA Kennedy Space Center on the potential of robotics to contribute to In Situ Resource Utilization (ISRU) as part of the NASA Journey to Mars.

The Swarmathon tutorials included active programming exercises, along with the following:

- Introduction to Physical and Virtual Platforms
- Improving Localization: Live Exercise, Intro to Kalman Filters, Alternative Approaches
- Search in the Real World
- Enhancements to the Virtual Platform
- Physical Gripper Extension

A full list of talks is available at <http://nasaswarmathon.com/rssworkshop/> . Participants from the “Becoming a Robot Guru” Workshop (<https://www.cs.unm.edu/amprg/robotGuru16/>) were surveyed by the Center for Evaluating the Research Pipeline. 77% of students selected the top available choice “very much so” when asked if the workshop had increased their interest in computing, and 65% selected the top available choice “very much so” when asked if their interest increased in having a research career in the area of computing.

**Fayetteville State University - Physical Competition Champion**  
**View Competition Run at:**  
<https://youtu.be/HL5EQ1LHSrM>





## **ACTIVITY CONTRIBUTION TO ANNUAL PERFORMANCE INDICATORS (APIs)**

### **FY 2016 Annual Performance Indicators**

ED-16-1: Provide significant, direct student awards in higher education to (1) students across all institutional categories and levels (as defined by the U.S. Department of Education); (2) racially or ethnically underrepresented students, (3) women, and (4) persons with disabilities at percentages that meet or exceed the national percentages for these populations, as determined by the most recent, publicly available data from the U.S. Department of Education's National Center for Education Statistics for a minimum of two of the four categories.

- Students at UNM were provided a direct stipend for Swarmathon administrative and technical support. This includes one post-doc, five graduate/RA students, and five undergraduate students.

ED-16-2: Engage with at least 80,000 educators in NASA-supported professional development, research, and internships that use NASA-unique STEM content. There were a total of 26 faculty that completed the Physical and Virtual Swarmathon Competitions.

- The program specifically targets underserved and underrepresented students by marketing the program to faculty at Historically Black Colleges and Universities (HBCUs), Tribal Colleges and Universities, Hispanic Serving Institutions, and other Minority Serving Institutions.
- Faculty and students are provided technical information by direct contact with NASA Subject Matter Experts via live online sessions, which include opportunities for Q&A.
- These universities have developed capstone courses, student computer clubs, infrastructure, and a knowledge base that will translate into a legacy with NASA for future NASA opportunities.

425 students participated in the Physical and Virtual Swarmathon Competitions. These students contribute to the overall impact of NASA Education with regard to reaching undergraduate students with an authentic STEM experience.

The demographic data of the students competing in the Swarmathon can be found below:

#### **Race (Please note some students identified more than one race)**

- American Indian/Alaskan Native – 23
- Asian – 81
- Black or African American – 58
- Native Hawaiian or Other Pacific Islander – 5
- White (Hispanic) – 86
- White (Non-Hispanic) – 69
- White (No Ethnicity Reported) – 2
- Mixed Race – 26
- Do Not Wish To Report – 75 (of the 75 not reporting race, 44 did report being Hispanic or Latino)

#### **Gender (408 students reported gender)**

- Female – 88
- Male – 320

#### **Ethnicity (381 students reported ethnicity)**

- Hispanic or Latino – 154
- Not Hispanic or Latino – 227

#### **Disability**

- Report Some Type of Disability – 22

## **ACTIVITY IMPROVEMENTS MADE IN THE PAST YEAR**

One of the goals of the NASA Swarmathon was to recruit a sizeable and diverse pool of applicants from the Minority Serving Institutions (MSIs) that exist across the United States and its territories. To support this goal, many marketing efforts were undertaken including building a website that produced 10,638 visitors, emailing 3,500 identified MSI Computer Science faculty members across the US, sending postcards to 1,000 MSI Computer Science faculty members, doing a publication in the NASA Express electronic newsletter that reaches more than 22,000 subscribers, producing and hosting a recruitment webinar, partnering with the Penn Center for Minority Serving Institutions to disseminate information to their 650 faculty members, and using social media (<http://www.nasaswarmathon.com> , <https://www.facebook.com/Swarmathon/>, <https://twitter.com/swarmathon>). In addition, several teams were recruited by personal emails and informational visits by the PI to campuses.

### **External Evaluation**

In order to measure educational gains realized by students through the Swarmathon, the project undertook a carefully crafted evaluation. The evaluation design relied on external evaluators from Brandeis University and Florida Institute of Technology (FL Tech). A survey was created which largely focused on examining student gains in educational standards related to computing and engineering.

Specifically, the Accreditation Board for Engineering and Technology (ABET) accredits college and university programs at the undergraduate and master's level in applied science, computing, engineering and engineering technology. As part of the accreditation process, ABET developed desired student outcomes for each of the programs.

The Swarmathon project identified 11 ABET outcomes from computing and engineering to measure the effectiveness of the project on students' ability to meet educational objectives. Upon analyzing the survey results, FL Tech determined that for each of the 11 ABET standards, there was significant gain in self-perception for students who felt that they met the standard not at all or by a low amount before participating in the Swarmathon, with an average gain of 0.93 (on a 5 point scale). This was particularly evident for standards two (an ability to analyze a problem, and identify and define the computing requirements appropriate to its solution), three (an ability to design, implement, and evaluate a computer-based system, process, component, or program to meet desired needs), four (an ability to design and conduct experiments, as well as to analyze and interpret data), and five (an ability to function on multidisciplinary teams).

In addition, faculty members provided feedback regarding their experience in the Swarmathon.

The following 2 quotes from the surveys exemplify positive aspects:

- "In my knowledge and experience, this project is one of the best projects on engaging Computer Science students in an advanced hands-on project that increase their technical skills and ability to create and work within teams."

- "The learning process... It took us a long time to get up to speed... but once we started on ROS it was amazing. Having the physical bots was awesome. They could see their results in real time (in a way). Working on a PHYSICAL project for them was amazing for them."

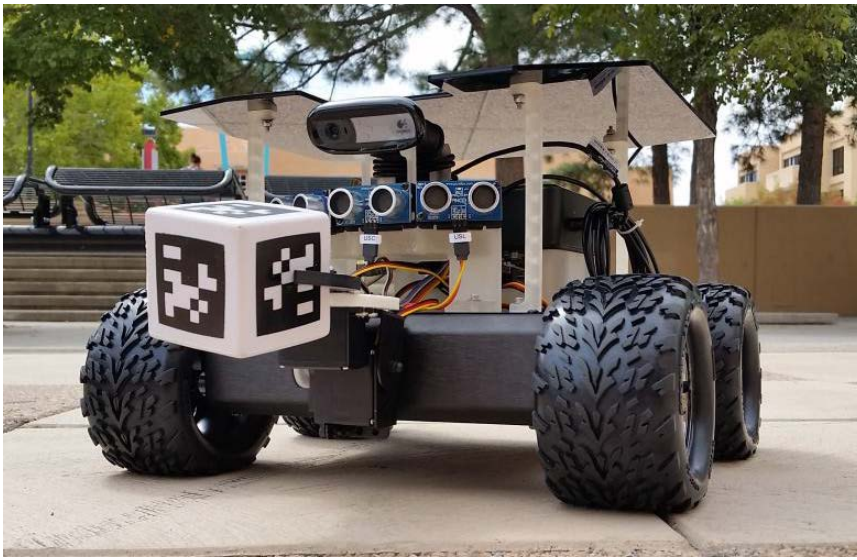
A complete report was submitted to NASA containing an overview of: (1) statistics regarding student participation - including school, MSI type, race, gender, ethnicity, etc., (2) results from the ABET

skills survey questions - including participants and control groups, and (3) feedback garnered from the telephone calls to MSI faculty and students.

**Planned changes for 2017 Competition:**

There were 42 teams selected to participate in the 2017 NASA Swarmathon, of which 20 were chosen for the Physical Competition (two of the teams were comprised of two schools), and 22 for the Virtual Competition. These schools represent at least one participant from the following seven different MSI types: *AANAPISI-Asian American and Native American Pacific Islander Serving Institutions*, *ANSI/NHSI-Alaskan Native Serving Institution/ Native Hawaiian Serving Institution*, *HBCU-Historically Black College University*, *HSI-Hispanic Serving Institution*, *NASNTI-Native American Serving Non-Tribal Institution*, *TCU-Tribal College University*, and *PBI-Predominately Black Institution*.

In addition, the Swarmathon is excited to showcase an improved version of the Swarmie robot that includes a Gripper to grab cubes, instead of roving over flat tags as they did in the 2016 competition.



## **ACTIVITY PARTNERS AND ROLE OF PARTNERS IN ACTIVITY EXECUTION**

- University of New Mexico – grantee, primary responsibility for administration of Swarmathon
- KSC Swamp Works - NASA Swarmathon Technical Advisor
- Secor Strategies – subcontractor, primary logistics responsibility
- Brandeis University – external evaluation
- Florida Institute of Technology – external evaluation
- Colleges that participated in the competition:
  - 24 teams (26 schools) that competed in the 2016 NASA Swarmathon.

### **University - Community College; Competition; MSI Type\***

- Cabrillo College; Virtual; HIS
- California State University, Channel Islands; Virtual; HSI
- California State University, Los Angeles; Physical; HSI
- Central New Mexico Community College; Physical; HSI
- City College of New York; Virtual; HSI
- Claflin University; Physical; HBCU
- Durham Tech Community College; Virtual; HSI /PBI
- Fayetteville State University; Physical; HBCU
- Florida International University; Physical; HSI
- Honolulu Community College; Virtual; ANSI/NHSI
- Jackson State University; Virtual; HBCU
- Morehouse College; Physical; HBCU
- Navajo Technical University; Virtual; TCU
- Pasadena City College; Physical; HSI/AANAPISI
- Polytechnic University of Puerto Rico; Virtual; HSI
- San Jacinto College and University of Houston Clear Lake; Physical; HSI
- Southwestern College; Virtual; HSI
- Southwestern Indian Polytechnic Institute (SIPI); Physical; TCU
- Texas A&M International University; Virtual; HSI
- University of Hawaii Maui College; Virtual; ANSI/NHSI
- University of Houston; Physical; HSI
- University of Puerto Rico at Arecibo; Virtual; HSI
- University of the District of Columbia & Howard University; Physical; HBCUs
- York College of The City University of New York; Physical; PBI

### **\* MSI Types**

- *AANAPISI = Asian American and Native American Pacific Islander-Serving Institutions*
- *ANSI/NHSI = Alaskan Native Serving Institution/Native Hawaiian Serving Institution*
- *HBCU =Historically Black College University*
- *HSI = Hispanic Serving Institution*
- *NASNTI = Native American Serving Non-Tribal Institution*
- *TCU = Tribal College University*
- *PBI = Predominately Black Institution*