# Landsharks to Astronauts: Towards a New STEM Culture of Excellence

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## Abstract

Herein, we present the results of a preliminary study of our proposed holistic approach to STEM outreach, education, and research facilitates. The "STEM Culture of Excellence" is based on providing opportunities for high school, undergraduate, and graduate students to interact in a robust research environment with industry and federal professionals through education and training. This work contains preliminary data towards addressing the following research question: *Will holistically incorporating STEM outreach, education, and research significantly improve K-20 outcomes, broaden underrepresented participation, and motivate academic and industrial participation?* Extending upon the previously presented "Heads in the Game" program, the "Landsharks to Astronauts" program included 48 high school, undergraduate, and graduate research scholars - including 19 women and 11 African-Americans, participated in research projects with C Spire and University of Mississippi Medical Center, NASA's Human Research Program, Protxx Inc., and Cadence Design Systems. These projects focused on sensors and devices for effective medical systems, utilization of novel digital health infrastructures, and development of algorithms data mining for medical issues. Undergraduate students simultaneously learned how to develop research projects and mentored the high school scholars, which allowed them to simultaneously be researchers, mentors, and emerging experts in computer engineering areas. We present pre- and post- assessment data from the high school scholar's computer science, biomedical, and nutritional courses. We also present longitudinal data from previous year's participant's successes in applying for colleges, and how the distribution of advisement materials to high schools from low-income school districts impacted the student's college readiness. We have provided college advisement packets to nine school districts in the Mississippi Delta region. We will also demonstrate the potential for success for this approach to STEM outreach for generating intellectual property, conference and journal publications, training students to pursue national scholarships, and industrial and federal grants.


## Background and Motivation

STEM employment opportunities in the U.S. are projected to increase by 3 million by 2026, but there is a projected deficit of 1.5 million qualified STEM graduates [1]. There are several challenges in developing a robust, actionable U.S. STEM educational policy and ecosystem. Educational initiatives over the last 20 years have not produced the required improvements in math, science, or reading literacy to address the qualified STEM workforce deficit. Exam results from the *Programme for International Student Assessment* (PISA) [2] show that American students have remained near median scores for Scientific, Mathematical, and Reading Literacy since 2000, as shown in Fig. 1. During the same timeframe, Germany went from 27th out of 30 countries in reading, 28th in mathematics, and 25th in science - with median scores of 484, 490, and 487 respectively – to significantly improved scores in 2012 with median scores of 514 in mathematics, 508 in reading, and 524 in scientific literacy [3].

The STEM Pipeline is disjointed and has several "leaks" where potential candidates are lost. According to the National Center of Education Statistics, the median family income of parents of STEM majors is $88,037 [4]. The median income in the U.S. is $57,617, which is 34.6% below

that median. Additionally, children from families in the top 1% of income distribution are *ten* times as likely to become inventors as those from below-median income families [5, 6]. By 8th grade, half of students will have given up on STEM as a career [7]. Only 69.7% of high school graduates attend college [8], and more than half of college students who declare in a STEM field will change majors or drop out of school entirely, meaning 11% of HS graduates become qualified STEM professionals, and the deficit would not be met if 100% of STEM students graduated.

Table 1: PISA Results for U.S. Students compared to the International Median since 2000.

| | Science Literacy - US | *Int'l Median* | *Difference* | Math Literacy - US | *Int'l Median* | *Difference* | Reading Literacy - US | *Int'l Median* | *Difference* |
|---|---|---|---|---|---|---|---|---|---|
| 2000 | 499 | *500* | *-1* | 493 | *500* | *-7* | 504 | *500* | *4* |
| 2003 | 500 | *491* | *9* | 477 | *500* | *-23* | 494 | *495* | *-1* |
| 2006 | 489 | *500* | *-11* | 474 | *498* | *-24* | N/A | *493* | *N/A* |
| 2009 | 502 | *501* | *1* | 487 | *496* | *-9* | 500 | *493* | *7* |
| 2012 | 497 | *501* | *-4* | 481 | *494* | *-13* | 498 | *496* | *2* |
| 2015 | 496 | *493* | *3* | 470 | *490* | *-20* | 497 | *493* | *4* |

There are significant socio-economic barriers to growing and diversifying the STEM workforce, and outcomes highly correlate to income, educational access, race, and gender. There are significant barriers to broadening participation among women and underrepresented groups in STEM areas. Between the ages of 11-15, STEM participation among girls begins to significantly decrease, primarily due to cultural pressures, gender stereotypes, and lack of professional role models in those fields [9, 10]. And while underrepresented groups make up 38.8% of the K-12 population, they only make up 9.1% of the STEM workforce. This number needs to *triple* in order to match their representation in the U.S. population, as shown in Fig. 1. Furthermore, women and minorities that do gain STEM employment often leave the field due to feel marginalized or undervalued. Women and minorities are more likely to experience implicit bias, racism and sexism, and harassment in the workplace, particularly during internships [11].

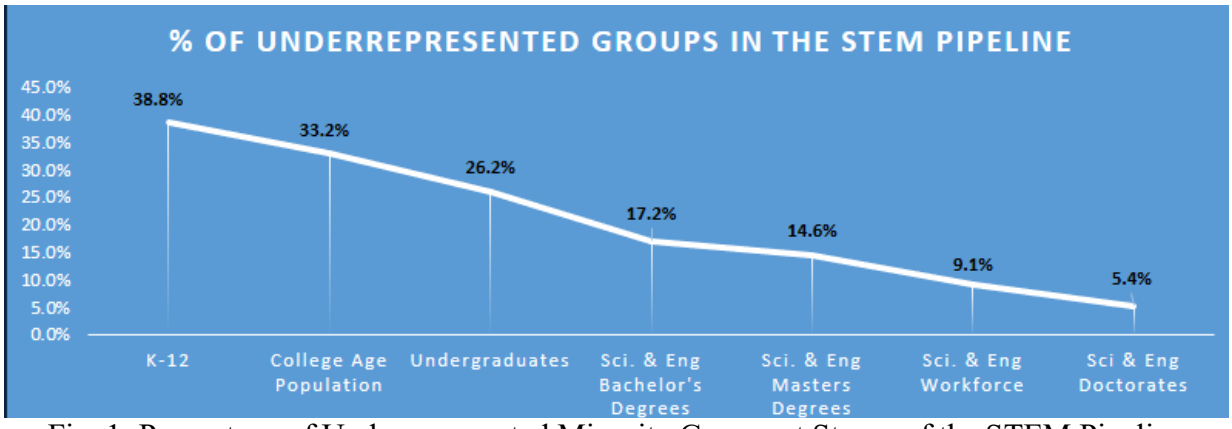

Fig. 1: Percentage of Underrepresented Minority Groups at Stages of the STEM Pipeline

High schools that serve primarily underrepresented student populations often lack the resources to adequately prepare and guide students for STEM careers. Twenty-five percent do not offer Algebra II, 40% do not offer chemistry or physics, and only 33% offer Calculus, and only 6% offer computer science [12, 13]. In areas with high poverty, limited access to resources – such as high-

speed internet – means that guidance counselors often have out-of-date or limited materials to help high school students apply for college. Consider Fig. 2 below of the state of Mississippi in 2016. The figures show areas in Mississippi where (a) there is Fixed Broadband Deployment of 3Mbps/768kbps, (b) percentage of residents below the poverty level, (c) percentage of minority residents, (d) high school graduate rates, and (e) medically served communities. There is a clear correlation between communities with limited resources for technology and healthcare, poverty, low graduation rates, and underrepresented groups. As a result, the groups where the opportunity best exists to address the STEM deficit are the same groups that lack access to entry into the pipeline.

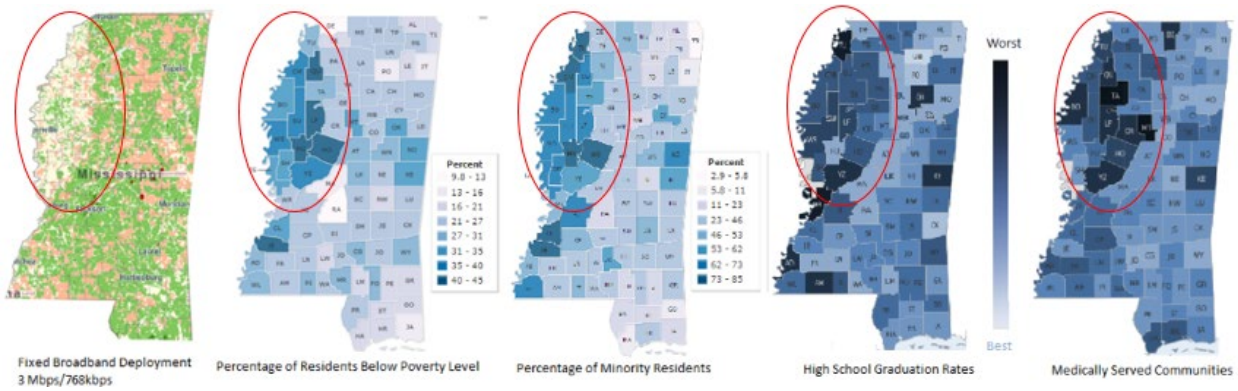


Fig. 2: Correlation of Technology, Medically Underserved, Poverty, Race, and High School Graduation Rate in Mississippi as of 2016.

Consider the case of the Leland High School Class of 2015. Leland High School which serves Leland, MS, represents a student body where 100% of students receive free or reduced student lunch, and 95% are African American. Eighty-seven percent of seniors indicated they intended to go to college. However, 70% did not take the ACT or SAT prior to their senior year and 73% indicated they "did not know how to apply to college" [14]. Only 3% demonstrated proficiency in Math, 15% in reading, and 31% proficiency in English. Despite the fact that 36% of Leland students took AP courses, not a single student earned AP college credit on their exams. U.S. News and World report rates Leland High School's AP College Readiness Index Score as a 9.1 out of 100 [15]. Sixteen teachers teach the entire curriculum for a student body of 254 students.

Furthermore, efforts to make AP Examinations available to students from impoverished areas have resulted in high failure rates on exams. Fifty percent of Mississippi high school graduates were African American in 2015 [16]. From 2009-2016, as shown in Table 2, 1573 African American students took the AP Calculus AB Exam, which constitutes 22.34% of all test takers. However, 89% of students who took the exam received a score of 1 or 2, meaning that the additional access to AP Exams did not translate into improved access to university. This phenomenon is exacerbated when comparing results of AP Exams for courses where significant pre-requisites are required. As shown in Table 3, only 5.42% of students who took the AP Calculus BC Exam were African American, and they only consisted of 2.76% of student who earned a 3 or higher on the exam. The disparity between boys and girls becomes more evident here, where 60.93% of students who earned credit on Calculus BC were boys. These disparities are even more evident when analyzing the AP Computer Science A Exam. As shown in Table 4, 95% of students who earned a 3 or better

on the AP Computer Science Exam were boys, 6% were African American, 6% were Latino, and 68% attended a private school [17].

Table 2: AP Calculus AB Exam Results, Mississippi, 2009-2016.

| | 5 | 4 | 3 | 2 | 1 | T | Percentage | Credit Percentage | Percent Passing |
|---|---|---|---|---|---|---|---|---|---|
| *White* | 742 | 612 | 646 | 527 | 1900 | 4427 | 62.88% | 75.79% | 45.18% |
| *Black* | 42 | 51 | 80 | 91 | 1309 | 1573 | 22.34% | 6.56% | 11.00% |
| *Latino* | 23 | 23 | 21 | 25 | 97 | 189 | 2.68% | 2.54% | 35.45% |
| *Asian* | 152 | 89 | 56 | 53 | 178 | 528 | 7.50% | 11.25% | 56.25% |
| *Other* | 37 | 34 | 31 | 30 | 191 | 323 | 4.59% | 3.87% | 31.58% |
| **Total** | **996** | **809** | **834** | **726** | **3675** | **7040** | | | **37.49%** |
| *Boys* | 604 | 470 | 434 | 354 | 1673 | 3535 | 50.21% | 57.14% | 42.66% |
| *Girls* | 392 | 339 | 400 | 372 | 2002 | 3505 | 49.79% | 42.86% | 32.27% |

Table 3: AP Calculus BC Exam Results, Mississippi, 2009-2016.

| | 5 | 4 | 3 | 2 | 1 | T | Percentage | Credit Percentage | Percent Passing |
|---|---|---|---|---|---|---|---|---|---|
| *White* | 156 | 90 | 83 | 83 | 238 | 650 | 73.45% | 69.85% | 50.62% |
| *Black* | 3 | 5 | 5 | 4 | 31 | 48 | 5.42% | 2.76% | 27.08% |
| *Latino* | 3 | 1 | 2 | 2 | 15 | 23 | 2.60% | 1.27% | 26.09% |
| *Asian* | 66 | 28 | 17 | 6 | 21 | 138 | 15.59% | 23.57% | 80.43% |
| *Other* | 3 | 7 | 2 | 4 | 10 | 26 | 2.94% | 2.55% | 46.15% |
| **Total** | **231** | **131** | **109** | **99** | **315** | **885** | | | 53.22% |
| *Boys* | 146 | 79 | 62 | 52 | 176 | 515 | 58.19% | 60.93% | 55.73% |
| *Girls* | 85 | 52 | 47 | 47 | 139 | 370 | 41.81% | 39.07% | 49.73% |

Table 4: AP Computer Science A Exam Results, Mississippi, 2009-2016.

| | 5 | 4 | 3 | 2 | 1 | T | Percentage | Credit Percentage |
|---|---|---|---|---|---|---|---|---|
| *White* | 12 | 12 | 12 | 3 | 6 | 45 | 67.16% | 76.60% |
| *Black* | 1 | 2 | | | 3 | 6 | 8.96% | 6.38% |
| *Latino* | 1 | 2 | | | 2 | 5 | 7.46% | 6.38% |
| *Asian* | 2 | 2 | | 1 | 2 | 7 | 10.45% | 8.51% |
| *2 or More* | 1 | | | | 3 | 4 | 5.97% | 2.13% |
| **Total** | **17** | **18** | **12** | **4** | **16** | **67** | | |
| *Boys* | 15 | 18 | 12 | 3 | 14 | 62 | 92.54% | 95.74% |
| *Girls* | 2 | | | 1 | 2 | 5 | 7.46% | 4.26% |
| | | | | | | | | |
| *Public* | 6 | 5 | 4 | | 10 | 25 | 37.31% | 31.91% |
| *Private* | 11 | 13 | 8 | 4 | 6 | 42 | 62.69% | 68.09% |

Further motivating a change in STEM outcomes is that a disproportionate segment of Department of Defense (DoD) scientists and engineers eligible to retire during the next few years. Eight-eight percent of U.S. military veterans who return to college after deployment to Iraq or Afghanistan have dropped out of college in their first year back at university [18]. Only 25% of universities have a detailed understanding of the causes of stop-out or dropout among their active duty military and student veteran populations [19]. Therefore, growth of the U.S. STEM workforce is increasingly essential to the nation's ability to prevail during future conflicts, particularly while minimizing casualties, since fulfilling the DOD's humanitarian and other missions depends heavily on advances in the nation's technology base.

**Previous Work**

The precursor for the "Landsharks to Astronauts" program was the "Heads in the Game" program for STEM Outreach, Research and Education [19]. Heads in the Game was an innovative, first of its kind program for Athletics and STEM education. Sixteen scholars, including 6 girls and 9 from high schools representing impoverished areas, learned coding, biomedical engineering, and health and sports performance skills. The objective of the program was to leverage the growing awareness of concussions in athletics with the passion for sports in Mississippi to motivate and inspire youth in STEM fields, and create a culture of awareness of STEM opportunities in the scholar's community. During the 2015 implementation, the program showed significant potential to meet these objectives. Pre- and post-assessment data showed significant improvement in the scholar's confidence in Computer Science and Engineering, Biomedical Engineering, and Health and Sports Performance. Furthermore, they gained confidence, teamwork skills, improved time management, and efficiently learning and self-advocacy skills.

**Landsharks to Astronauts**

In this section, we will describe the *Landsharks to Astronauts* program, as well as subsequent senior projects that emerged during the following year. After implementation of "Heads in the Game", several clear needs emerged. It became clear that training of qualified STEM graduates through high school and undergraduate education needed to be transformed from a pipeline with a significant focus on coursework to a climate where STEM graduates are holistically trained to be researchers, mentors, and emerging experts simultaneously. This environment would address the need to show the high school students that college students who were in the same demographics and encountered the same challenges, observe the success of researchers from graduate, faculty, industry, and federal programs from their demographics. Likewise, the opportunity for mentorship for undergraduate and graduate students would not only enable students with leadership skills, help them understand their previous material by requiring the students to explain their previous work, but also allow them to contribute to and learn the importance of cultivating a sense of belonging where people of all backgrounds are welcomed and encouraged to pursue STEM Careers. By exposing student participants at all levels to this kind of environment, the objective is that they would be imbued with an understanding of their professional responsibilities to society and simultaneously strengthening high school curricula and advising capabilities, which will empower all students in the school district. Furthermore, by seeking out and recruiting industry and federal participation, there would be opportunity for extending the summer projects into pilot studies for future collaborations for Intellectual Property and grant proposals, which would

continuously inform the research teams of the new fundamental and transformative challenges as they arise, and motivate participation from tenure and tenure-track faculty.

The program was renamed *Landsharks to Astronauts* as an appeal to students since "Landsharks" has become a very popular, if unofficial nickname, of the University of Mississippi's sports teams since 2007. Twent- seven undergraduate scholars were recruited to participate in Landsharks to Astronauts, where they joined teams that included researchers and engineers from the Electrical Engineering Deepartment, telecommunications provider C Spire, the University of Mississippi Medical Center (UMMC) Neurological Intensive Care Unit (NeuroICU), the UMMC Center for Telehealth, the Cadence Academic Network, and NASA's Human Research Program. These research teams performed research in sensors and devices for effective medical systems, utilization of novel digital health infrastructures, and development of algorithms data mining for medical issues. The 27 undergraduate research scholars performed literature surveys on their topic, interviewed knowledgeable professionals in their field, and proposed a research/project topic based on their background work.

- NASA Human Research Program => Determine mission critical measurable for Egress upon landing on Mars.
- Protxx, Inc. => Comparison of Low-Power Wireless Protocols for Healthcare Sensors
- Cadence Design Systems => Development of Electronic Design Automation courses
- University of Mississippi Athletics => Electrical Water Dispersal System
- University of Mississippi Medical Center / C Spire => Sleeping Cap for TBI patients

Each team also mentored four *Heads in the Game* high school scholars on how to perform research, as well as how to succeed in college. In total, 48 students participated in the Heads in the Game and Landsharks to Astronauts research programs, including 19 women and 11 African Americans.

The eight-week plan for the *Heads in the Game* and *Landsharks to Astronauts* programs that was conducted in the Summer fo 2016 is outlined below:

**-** Week 1**:** The *Heads in the Game* scholars will attend seminars on electrical and computer engineering, biomedical engineering, introduction to health and sports performance, and fundamental research methods. *Landsharks to Astronauts* undergraduate researchers will select research topics and companies and conduct a literature survey on the research area. The beginning of the program will consist of introductory lectures on sensors, VLSI design principles, concussion research, and integration of sensors in telemedicine and astronaut health. *Landsharks to Astronauts* students will introduce themselves to industry professionals through e-mail and request a meeting time during Week 2.

**-** Week 2**:** The *Landsharks to Astronauts* undergraduate researchers will prepare for a one-hour interview to determine the appropriate requirements and specifications for the remainder of the summer. As part of this aspect of the collaboration, we are requesting the opportunity for program scholars during the first or second week to schedule teleconference meetings and Google Hangouts with appropriate scientists, as well as access to authorized hardware and software necessary for completion of the research project as agreed upon after industry expert interviews. The personnel listed below would act as expert consultants in this role, as well as and other engineers as appropriate for the project:

To demonstrate the interest (and potential) for future implementation, a comprehensive list of the academic, industry and federal professionals who devoted time to interview and mentorship is provided below:

- Protxx Sensor and Concussion Research:
  - Dr. John Ralston, CEO of Impaxx Technologies; Jason Thibado, Lead Engineer of X2 Biosystems; Dr. Scott Grafton, Distinguished Professor and Bedrosian Coyne Presidential Chair in Neuroscience at UC Santa Barbara; Dr. Jennifer Fogarty, Chief Scientist of NASA's Human Research Program; Dr. Jacob Bloomberg, Senior Research Scientist at NASA Johnson Space Center Neuroscience; Dr. Dwight Waddell, Director of the Biomedical Program at UM; Mr. Pat Jernigan, Head Football Trainer, UM Football Team; Dr. Jeffrey Somers, Occupant Protection Discipline Scientist - Wyle Integrated Science and Engineering Group.
- University of Mississippi Medical Center (Sleeping Cap)
  - Dr. Michael Lehman, Chair of Neurobiology and Anatomical Sciences at UMMC; Dr. Chad Washington, Assistant Professor of Neurosurgery at UMMC; Dr. Hana San Luis, Assistant Professor in the Neurological ICU and UMMC; Dr. Robin Rockhold, Professor of Pharmacology at UMMC; Mr. Craig Sparks, Chief Technology Officer at CSpire; Dr. Ivy Kelly, DMTS - Technology Strategist, CSpire; Mr. Jason Ball, RF Design Engineer; Dr. Brandi Nester – UMMC Nurse Manager.
- NASA Heads-Up Display
  - Mr. David Ham – Space Medicine Advanced Projects Engineer; Mr. Nate Newby – Integrated Science and Engineering, nathaniel.newby@nasa.gov; Dr. Sara Zwart – NASA Senior Scientist of Life Sciences, sara.zwart-1@nasa.gov; Ms. Lauren Merkle – NASA Education Lead, Biomedical Research; Dr. Daniel Barta, Manager, Life Support Systems Technology Development at NASA; Mr. David Miranda, Project Lead for NASA IDEAS project; Dr. Andrew Abercromby, Project Manager for the Space Exploration Vehicle project; Dr. Shane McFarland, Spacesuit Engineer at NASA/Wyle Labs; Mr. Bill Parsons, former Director of the Kennedy Space Center and Stennis Space Center; Dr. Mary Wusk, NASA's Game Changing Development Program Manager; Dr. Igor Dubinsky, NASA astronaut applicant; Dr. Nicole Stott, Shuttle and ISS Astronaut; General Charles Duke, Apollo 16 Astronaut.
- Ole Miss Electrical Water Dolly
  - Dr. Melinda Valliant – Associate Professor; Dr. Shannon Singletary – Associate Athletic Director; Mr. Ross Bjork, Athletic Director; Mr. Larandust Coleman – Senior Athletic Trainer; Mr. Ray Lysinger – Assistant Football Athletic Trainer; Mr. Paul Lowe – Mechanical Engineering Shop Supervisor; Mrs. Allyson Best, Director of Technology Management.
- Cadence Design Systems
  - Dr. Patrick Haspel, Head of Global Academic Partnerships, Cadence; David Pursley, Product Manager of High Level Synthesis products; Luke Lang, Engineering Director of Low Power Group; Elias Felton, Engineering Director of the Virtuoso Design Group; Michael Huebner, Professor and Chair, Embedded Systems and Information Technology at Ruhr University at Bochum; Bonnie Willoughby, Director of World Wide Training Services; Cheryl Mendenhall, Director of the Cadence University Program; James Chew,

Group Director of Aerospace and Defense; Steve Carlson, Technology and Market Strategist.

Based on industry feedback, the research teams proposed a project under my supervision to complete for the remainder of the six weeks. Once the proposal is approved, the undergraduates will present their proposal to the *Heads in the Game* scholars. Four high school scholars will join each undergraduate research team. Additionally, *Heads in the Game* scholars will continue their seminars, as well as received training on the Protxx sensorimotor devices.

**-** Weeks 3 and 4**:** The *Landsharks to Astronauts* scholars will continue their research projects under my supervision. They will mentor the *Heads in the Game* scholars in learning and contributing to project development. Each *Heads in the Game* team will also have the opportunity to conduct interviews and ask questions with the industry professionals that may benefit their future. At the end of the 4th week, the *Heads in the Game* scholars will conduct a public presentation of their research topics and accomplishments.

**-** Weeks 5 through 8**:** The *Landsharks to Astronauts* student research teams will continue their proposed research projects. They will also learn advanced subjects such as sensor design, secure and reliable communication protocols, resume and GRE preparation, and NSF Graduate Research Fellowship and NASA Graduate Scientist Research Fellowship preparation. At the end of the 8th week, the *Heads in the Game* scholars will conduct a public presentation of their research topics and accomplishments. Students will also produce summary articles based on their research, and pursue publications.

**Project Results**

Below is a brief description of the results of the projects, where the research teams consisted of high school, undergraduate, and graduate students.

C Spire and University of Mississippi Medical Center: The research team proposed a peripheral device which integrates EEG-monitoring sensors into a cap which monitors and enhances sleep cycles of severe TBI patients, and a secure wireless protocol between the sensor cap and a mobile app to enable ease of use by doctors and nurses. The team has been invited to present the progress of their work at the *Mississippi Rural Health Annual Conference* [20] and the *Louis Stokes Mississippi Alliance for Minority Participation Conference* [21]. This work also served as a pilot for a DoD Psychological Health and Traumatic Brain Injury Research Program (PH/TBIRP) proposal.

NASA's Human Research Program: The research team determined the need to develop a Heads-up Display (HUD) on the helmet of an EVA suit towards an integrated display and environmental awareness system. Methods for leveraging the Protxx sensors that displays real-time biomarker status of the astronauts' vitals, as well as monitoring Spaceflight Associated Neuro-ocular syndrome, were presented in [22]. They also developed a test of an Organic Light Emitting Diodes (OLEDs). The team has been invited to present their research both at the Louis Stokes Alliance for Minority Participation Research Conference [23] and NASA Johnson Space Center's EISD Research Day in December 2016 [24]. This work also served as a pilot for a NASA Human Research Exploration Opportunities proposal (NNJ14ZSA001N).

Cadence Academic Network: The research team coordinated with technical experts at Cadence to learn, improve, and implement Cadence design tools for use in the Computer Engineering courses at the University of Mississippi. Under my supervision, they developed a plan for a course flow with an emphasis on the areas that the Cadence software will improve quality education, than using Cadence's Internet Learning Series (iLS) they learned and complete the relevant courses with the goal of improving upon the course. The team has been invited to present at the 2017 Cadence CDNLive Annual Conference [25]. This paper eventually won the Best Paper Award – Academic track at the Cadence CDNLive in 2017.

UM Athletics Water Dollys: The research team assessed the needto improve upon water dollys used during practice and games. There were several functional and conventional errors with these water dollies, which caused the University of Mississippi football team to lose significant amount of money in replacement parts for these water dollies. Based on feedback from the football athletic trainers, they developed an insulated waterproof wrap, designed and installed a smart charge, and put in a battery charge reader will be put on the outside on the waterproof casing holding the water pump and battery. To improve the current water hose coils, the implemented an elastic hose, and testing demonstrated improved efficiency and service life. The design has a pending patent application in place.

Protxx, Inc. – The research team worked with industry experts to develop improvements to the Head-Trax System. Using highly accurate low-power sensorimotors that quantify and transmit head impact data, design and compared web protocols specialized for low power machine to machine (M2M) communication. By using IoT devices to services in the internet, they were able to facilitate devices that operate on a separate bandwidth (915 Mhz ISM band), which allows for additional security. This work contributed to a journal [26] and an invited conference paper [27], and the research team collaborated with Protxx to win the Silver Spring competition [28], and the Sacramento Kings "Capitalize" start-up contest [29].

**Pre- and Post-Assessment Data**

Pre- and Post-Assessments were collected from both the *Heads in the Game* high school scholars as well as the *Landsharks to Astronauts* college scholars. The study and guidance materials may be found at [30].

Table 5: Heads in the Game – Computer Science and Engineering

| Assessment | Coding Skills | Computer Engineering | Problem Solving | Real-World Awareness |
|---|---|---|---|---|
| Pre-Assessment | 3.1 | 2.7 | 6.75 | 1.4 |
| Post-Assessment | 8.92 | 7.3 | 9.1 | 7.6 |

Table 6: Heads in the Game – Biomedical Engineering

| Assessment | Biology | Biomedical Engineering | Neurology | Real-World Awareness |
|---|---|---|---|---|
| Pre-Assessment | 7.1 | 3.8 | 1.3 | 1.6 |
| Post-Assessment | 9 | 7.4 | 7.4 | 7.4 |

Table 7: Heads in the Game – Health and Sports Performance

| Assessment | Anatomy | Chemistry | Nutrition | Real-World Awareness |
|---|---|---|---|---|
| Pre-Assessment | 5.6 | 6.4 | 4.5 | 4.5 |
| Post-Assessment | 8.8 | 8.8 | 9.2 | 9.3 |

Table 8: Heads in the Game – Applying for and Succeeding at College

| Assessment | Standardized Exam Prep | Admissions Essay Prep | Scholarships and Fellowships | College Success Habits |
|---|---|---|---|---|
| Pre-Assessment | 2.8 | 5.3 | 2.1 | 4.4 |
| Post-Assessment | 7.2 | 7.5 | 7.7 | 7.3 |

Table 9: Research Methods and Public Speaking

| Assessment | HITG Public Speaking | LTA Public Speaking | HITG Research Methods | LTA Research Methods |
|---|---|---|---|---|
| Pre-Assessment | 2.1 | 4.3 | 1.4 | 3.7 |
| Post-Assessment | 7.5 | 8.6 | 7.9 | 8.8 |

Table 10: Landsharks to Astronauts - Future Employment

| Assessment | Resume | Job Application | Professional Communication | Engineering Confidence | Leadership |
|---|---|---|---|---|---|
| Pre-Assessment | 4.1 | 3.3 | 2.7 | 6.6 | 4.8 |
| Post-Assessment | 8.9 | 8.7 | 8.7 | 8.8 | 8.2 |

**Quantitative Benefits and Lessons Learned**

In this section, the results of the pre- and post-assessment data (Tables 5-10) are evaluated in order to the potential benefit of implementing this holisitic approach to research and education. In the summers of 2015-16, the "Heads in the Game" smart and connected health research program involved 48 UG, 32 HS (from 165 applicants), and 6 graduate scholars, of which 19 were girls, 21 were from minority groups, and 4 veterans. Several federal and industry partners, including NASA, C Spire, Cadence, athletics departments, and medical centers provided mentorship through responses to interviews, feedback to weekly memorandums, and computing resources. Industry and federal partners expressed satisfaction about their participation and project outcomes, and provided the same resources to senior design, research project extensions, and grant proposals.

In Tables 5-7, assessment data was presented describing the high school scholars confidence in areas pertaining to Computer Science, Biology, and Health and Sports Performance.

- Because the students were rising juniors or seniors, many of them have taken some form of Biology or Chemistry course, or learned problem-solving skills, so their pre-assessment scores were relatively high compared to their self-assessment of their coding skills, familiarity with computer engineering, nutrition, and neurology.

- The undergraduate researchers felt relatively confident in the engineering skills, but felt unprepared with respect to developing their resume, applying for jobs, professional communications, and public presentation of engineering work.

- The two most significant increases in confidence for this high school students were in Computer Engineering (from 2.7 to 7.3), Biomedical Engineering (from 3.8 to 7.4), and Neurology (from 1.3 to 7.4). The data reflects their confidence in their knowledge, not their knowledge of that material. We did not conduct any final examinations on the material. The increase in confidence can be traced to the interaction between the high school students, undergraduates, graduate students, faculty, and industry professionals working in that area. When the students were working on their project, their knowledge was constantly being strengthened and reinforced by their partners. Therefore, a potential benefit of the proposed holistic approach is significantly increased confidence in material they were consciously uncomfortable with only one month prior. Future work would investigate the long-term benefits of students pursuing careers in both industry and academia in areas they were scared to pursue in their formative high school years.

- Another area of significant improvement was the high school scholar's confidence in nutrition. Mississippi routinely ranks 50$^{th}$ in health, life expectancy, and obesity. Having the opportunity to interact with the Ole Miss Athletics Department and the faculty from the Center for Health and Sports Performance showed the students the benefits of proper nutrition. They spoke with athletes who discussed the importance of proper eating, and graduate students showed the correlation between nutrition and performance in sports and the classroom. Additionally, some students took the lessons to heart, and their classmates saw them change their diet and safely lose some weight during the program.

- One significant benefit for all the scholars was the requirement for the weekly presentation to the rest of the researchers. Industry professionals in particular impressed upon the researchers the need for scientists and engineers who can convey their ideas in a public forum. Several students who were previously remiss to present in front of groups became confident during the final presentation in front of 250 people.

- One benefit to the undergraduates was professional preparation. Students received training and advice on resume development, and the feedback from industry was immediate and positive. We would receive feedback from companies indicating their satisfaction with the resumes and professional communication of scholars applying for their positions. When we would share this information with the scholars, they became more confident that their professional skills were being strengthened. One benefit of this program for universities are additional avenues for Career Centers to collaborate with the departments to develop resumes and cover letters that strongly position graduates for competitive jobs.

- The other primary benefit to the undergraduate researchers was the development of leadership skills. During the program, undergraduates initially found it challenging to convey concepts to the high school students at a level they would understand. Over the course of the three weeks, they learned how to convey technical information to non-experts, and then learned how to empower the high school scholars to independently learn some engineering skills, empowering both the high school students with confidence in the

information and the undergraduate researcher through mentorship opportunities. A benefit to academia and industry is the growth of scientists and engineers capable of mentorship of new employees and teaching new students, which would create a cycle of empowerment of the next generation of the STEM workforce.

Next, we will briefly outline the future success stories of the high school, undergraduate, and graduate scholars who participated in this program. These success stories show the potential for these programs to generate new streams of students and researchers for universities, which can eventually grow and diversify the STEM workforce.

- Two patent applications. Two journal publications
- One Barry Goldwater Recipient, Two Barry Goldwater Honorable Mentions
- One DoD SMART Scholarship Recipient
- One National Science Foundation Graduate Research Fellow
- Eighteen students continued these projects in Senior Capstone.
- Seven Honors Theses at the University of Mississippi.
- Two successful grants with NASA and C Spire
- Three high school scholars became their first AP Computer Science student to earn a 3 or better on the AP Computer Science A Exam.

Continued success with the Mississippi Delta High Schools: According to the Center for High Education Policy Analysis, the recommended student counselor ration is 250:1. However, in the Mississippi Delta, the ratio is 812:1. During the program, we request Heads in the Game scholars develop a packet and give it to their guidance counselor when they get back to their high school. By publically disseminating the materials, our aim is to *improve the skill set and potential for college admittance of **all** students in these economically disadvantaged areas, not just the students admitted to the Heads in the Game program.* Six high schools in the Mississippi Delta (East, JFKHS, J.J. McClain, Shaw, Humphreys, and Palmer) are currently using these materials to provide improved guidance to their students or improve their curriculum.

**Future Work**

The mission of the STEM Culture of Excellence is to provide opportunities for high school (HS) students and teachers, as well as undergraduates (UG) and graduate researchers to interact in a robust research and educational environment in tandem with academic, industry, and federal partners. The proposed approach holistically incorporate STEM outreach, education, and training. Students and teachers from low-income regional high schools, and UG students from institutes with limited research capabilities, will be recruited to develop new research projects with post-secondary and faculty researchers at Notre Dame. HS scholars participate in courses which develop knowledge in relevant STEM areas, and receive mentorship from university admissions, scholarships, and career success personnel. UG scholars are exposed to Research Methods, and

simultaneously perform literature surveys while mentoring the HS scholars on the research topic. Teachers will take masterclasses from graduate and faculty researchers, and work with the UG and HS scholars on research. The research scholars will conduct interviews of experts, and then propose a topic and conduct research based on their feedback. Field Building Conferences will facilitate research presentation, discussion of educational challenges, and exchange of ideas between all participants. Annually implementation of outcomes will create a feedback loop, cultivating continuous growth of research and educational excellence.

There currently exist several transdisciplinary NSF programs, such as REU and RET Sites, S-STEM, STEM+C, STELAR, INCLUDES and ITEST, which integrate STEM teaching, learning, and research for preK-post secondary students in formal and informal settings. The vision of the STEM Culture of Excellence Center is to extend these programs by simultaneously bringing knowledge and innovation to school districts and community colleges, as well as broadening participation, by supporting active research and mentorship opportunities between teachers, HS, UG, and graduate scholars, and provide quantifiable benefit to industry, academic, and federal partners through development of transformative research, grants, and intellectual property. Field Building conferences will facilitate development of a set of measurable and a standardized database for reporting STEM outcomes. HS scholars will provide a copy of their advisement materials to their guidance counselors to improve college application and success materials for their peers.

To determine the effectiveness of the proposed Culture of Excellence, we must address the following research questions through longitudinal studies in order to develop a theory of action which may be replicated nationwide: (1) Does participation in research for HS students alongside UG scholars improve outcomes in science and math literacy, as well as standardized test scores, as opposed to just with faculty researchers? (2) Does simultaneously performing research and mentoring HS scholars improve UG outcomes in academic and research self-efficacy, and leadership? (3) To what extent does participation in the Center for multiple years contribute to retention, graduation, and job employment outcomes? (4) To what extent does participation in a Center with participants from all educational levels cultivate a sense of belonging among women and minorities, and contribute to their retention and success? (5) To what extent does participation in masterclasses and research with HS and UG scholars improve a teacher's capability to translate their experiences and new knowledge gained into their classroom activities, as opposed to just working with faculty researchers? (6) To what extent may the benefits of participation in the Culture of Excellence by industry and federal agencies be quantified in terms of economic benefit and readily-trained employees and researchers?

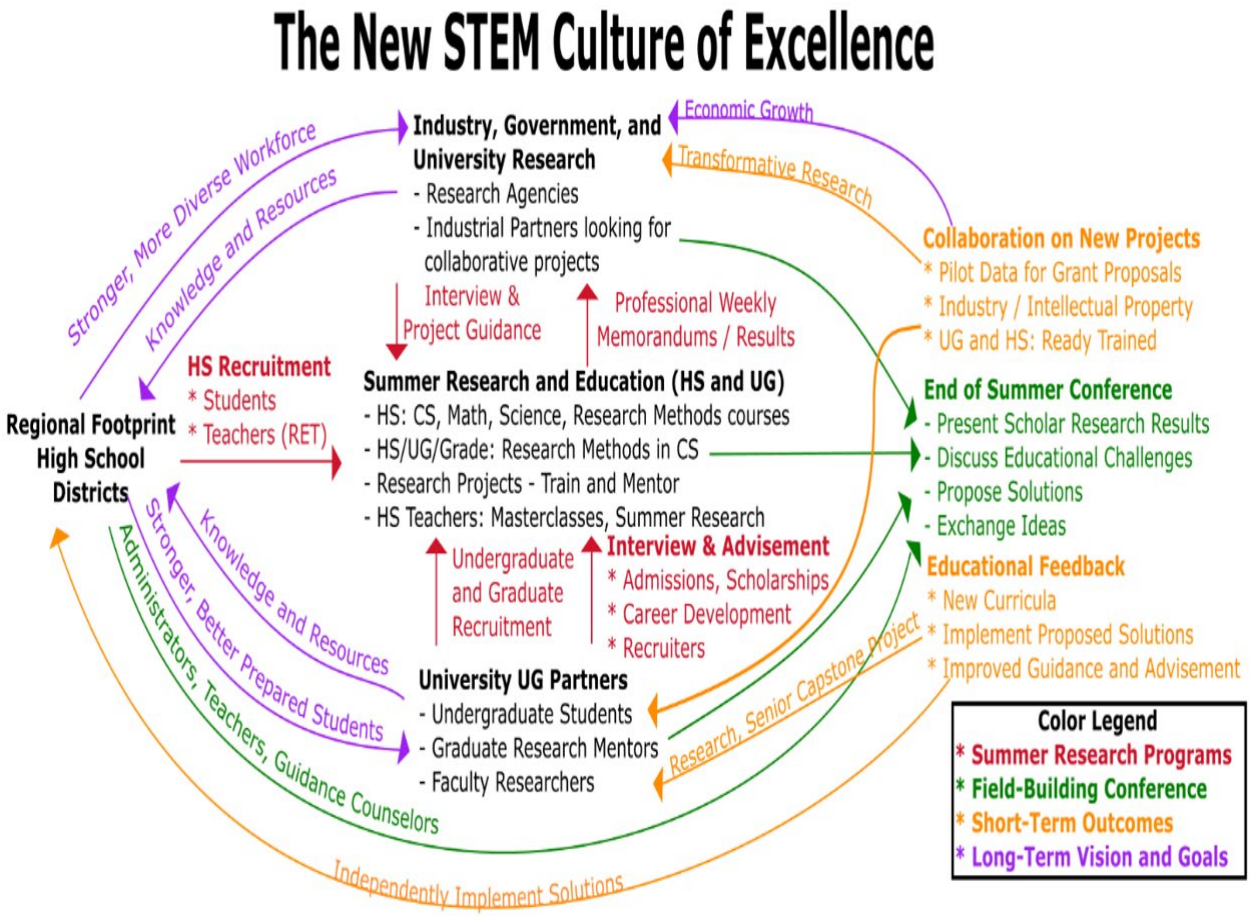


Fig. 3: Long-Term Vision for STEM Cultures of Excellence.

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