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Cover

Federal Agency and Organization Element to Which Report is Submitted:	4900
Federal Grant or Other Identifying Number Assigned by Agency:	1516269
Project Title:	Collaborative Research: Developing STEM self-efficacy and science identities through authentic astrophysics research in online and face-to-face environments (STEM-ID)
PD/PI Name:	Sue A Heatherly, Principal Investigator
Recipient Organization:	Associated Universities, Inc.
Project/Grant Period:	10/01/2015 - 09/30/2021
Reporting Period:	10/01/2020 - 09/30/2021
Submitting Official (if other than PD\PI):	Sue A Heatherly Principal Investigator
Submission Date:	01/28/2022
Signature of Submitting Official (signature shall be submitted in accordance with agency specific instructions)	Sue A Heatherly

Accomplishments

* What are the major goals of the project?

STEM-ID is an Innovations in Development Project called "Collaborative Research: Developing STEM self-efficacy and science identities through authentic astrophysics research in online and face-to-face environments". West Virginia University, the National Radio Astronomy Observatory in Green Bank, WV, and ten partner institutions around the country are working together on the STEM-ID project- with an ambitious goal to build a nationwide research community of

practice called the Pulsar Search Collaboratory (PSC). The PSC engages high-school students, their teachers, undergraduate students, and college faculty in a shared effort to discover new pulsars, and characterize known pulsars through analysis of radio astronomy data collected with the Green Bank Telescope (GBT).

STEM-ID project goals:

1. Increase the number of high school students, particularly from underserved groups, who intend to major in STEM fields, and their preparation for STEM career paths. High school students will:
 - a. develop competencies in the conduct of science
 - b. develop science identity
 - c. seek appropriate challenging activities that advance STEM career goals
 - d. persist in the PSC and in formal STEM activities through high school and into college
2. Deepen high school educators' self-efficacy and confidence in conducting scientific research and in their science teaching. Educators will:
 - a. develop confidence in their abilities to conduct research alongside scientists
 - b. develop competency in implementing research projects with their students
3. Improve undergraduate students' persistence in STEM majors through the development of competencies in 21st century skills. Undergraduate students will:
 - a. develop communication skills, and leadership through mentoring of high school students
 - b. develop creativity and collaboration skills through their contributions to the online collaborative environment
4. Enable educational research to determine:
 - a. the factors that contribute to or detract from students' STEM identity, persistence and career intentions
 - b. the relationship between STEM identity and persistence in STEM in high school through sophomore year of college
 - c. how perception of the research apprenticeship experience differs among youth of different gender and ethnicities
 - d. the effect of program components and events on patterns of participation in the PSC

STEM-ID builds on a successful ITEST project that provided professional development to teachers, the establishment of teacher-led school-based PSC clubs, ongoing interaction with pulsar scientists, and an annual Captone Seminar that brought all active student and teacher members together at West Virginia University for a scientific meeting and career exploration activities. In addition to preserving the core elements of the original project, in order to realize the goals of the STEM-ID project partners have several concrete objectives to accomplish. They are to develop:

- an online environment for learning and sharing
- an online professional development workshop

- an active and committed geographically distributed system of partner (Hub) institutions
- capacity of near-peer undergraduate students to mentor high school students
- advanced research opportunities for participants who gain basic proficiencies and wish to progress in the community of practice
- an ongoing, iterative educational research informing programmatic modification

*** What was accomplished under these goals and objectives (you must provide information for at least one of the 4 categories below)?**

Major Activities:

Over this reporting period, the STEM-ID project hosted two online six-week Pulsar Search Collaboratory (PSC) online training workshops for 147 PSC members. Participants included new PSC high school students, veteran members, teachers and undergraduate students. The workshops employ a flipped structure. Participants watch recorded training videos, and complete homework, and then join a pulsar astronomer for a live Zoom session to discuss. The goal of the workshop is to prepare students and teachers to be proficient data analysts before giving them access to pulsar data. However, about half of the participants are veterans, and attend the live sessions primarily for enrichment and camaraderie.

PSC students continue to be prolific analysts, and contribute to the search for new pulsars. Since the beginning of the STEM-ID project in 2015, PSC students have analyzed over **one million** pulsar discovery plots.

Travel and social distance restrictions brought about by COVID-19 resulted in a cancellation of our annual PSC Camp at Green Bank Observatory. However, as circumstances improved, we were able to host a Capstone event at WVU in August 2021. Thirteen high-school students, 4 non-WVU undergraduates, 3 high-school teachers, and four WVU undergraduates participated.

In addition, West Virginia University hosted a special topics course that enabled high-school students to earn college credit. Four students completed the course in 2021. The students went through the training during the workshop, including the homework in the training videos. They wrote a research paper about a topic in the field of neutron stars which they could choose on their own. The topics chosen by the students were covering magnetars, anomalous X-ray pulsars, and radio pulsars (ordinary and recycled). They learned how to structure such a research paper and how to write it. In addition, they were required to make a poster of their research during this course which they presented during the in-person or virtual Capstone seminars. All students worked with data taken with the 20-meter radio telescope (either archival data or data that they took during the course). The syllabus is included as a supplemental document.

Also, we piloted a new program where we offered participants the opportunity to be involved in research projects. Three projects were offered and roughly 40 PSC members participated. Each of the three research teams was led by a postdoc, graduate student, or faculty researcher, and each team had a mix of high-school students, high-school teachers, and undergraduate students. Over summer 2021, we engaged 5 undergraduate students and 1 high school student to develop Jupyter notebooks to analyze 20-m telescope data taken for these projects. These

notebooks are currently being used (tested) by student research teams- the notebooks and projects are a permanent opportunity in a sustained PSC.

An additional high-school PSC member investigated the sonification of pulsar search data, as a preliminary step in making the PSC accessible to students with blindness and visual impairment.

We hosted a small group of Community-Technical College faculty at the Green Bank Observatory to introduce them to PSC research activities and to assess interest in expanding PSC research experiences to students enrolled in CTCs. This convening has resulted in continued collaboration. It is our goal to submit a IUSE proposal that would develop research partnerships between four-year and two year schools to engage CTC students in authentic research as part of their early college experience.

Finally, we have nearly completed the new PSC website and database, hosted at pulsars.nanograv.org. It provides a better interface for grading plots and hosts course materials and communication and collaboration tools. This website will be used by the broader pulsar community for inspecting search output from many surveys. We will transition to this new interface in February 2022, when we begin our next online workshop.

Specific Objectives:

A major goal of the Pulsar Search Collaboratory is to build stepping stones along a STEM success pathway for students. The first step is analyzing pulsar search plots. Anyone, including the youngest high school students gain entry into our scientific community by mastering the nuances of inspecting these plots. However, additional projects are needed for students further along their STEM career path. As mentioned above, we have initiated advanced projects for PSC students who have successfully completed the pulsar search project.

Educational research shows that engaging students in authentic research early in their college careers impacts STEM student success, and so in summer, 2021 the Green Bank Observatory supported six rising college freshmen and two undergraduate mentors to participate in a face-to-face two-week internship at the Green Bank Observatory in the summer of 2021. Students worked with GBO scientists and educators to develop methods for radio-frequency interference mitigation. There was also a good amount of opportunity for informal interactions and community building. Undergraduate mentors led some of these sessions, providing valuable professional development for them.

The research goal of the internship was to engage students in a shared research project to investigate a novel technique for identifying radio frequency interference in GBT data. This work is critical to ensure the success of future wide-band searches for new pulsars. A second but no less important goal is to help students understand how to be successful in college.

Mentor-led professional development sessions designed to help prepare students for college life and STEM success included:

- **DIY Time Management Calendar:** Mentors assisted interns in completing time management calendars. They used their course schedules and an online generated activity template
- **Campus Resources:** mentors led interns on web scavenger hunt to locate and investigate campus resources.
- **Resume Building:** Green Bank REU students had previously shared advice, their application process and application materials with our interns; interns worked with mentors to build or improve existing resumes, and start on a cover letter.
- How to apply for a summer REU

Research: The student research project stems from an effort to design and build an innovative receiver that will dramatically improve the Green Bank Telescope for pulsar research. A key problem to be solved in order to make this new technology work is real-time removal of Radio Frequency Interference (RFI).

Research Interns directly contributed to the development of this new cutting-edge receiver, by characterizing novel cyclostationary RFI plots to be used for future machine learning algorithms.

Additionally, as outlined in our No Cost Extension request, we piloted an instrumentation project with our interns. They were tasked to build and operate a horn antenna-Software Defined Radio system, as a pilot test for potential broader implementation of an instrumentation component to the PSC. This “side” project was a highlight of the internship. Participants called out aspects such as building something tangible in a team, using raspberry pis, engaging in Gnu radio block programming and interacting with engineers as valuable aspects of the internship.

Significant Results:

Online Workshop Assessment: At the conclusion of the Spring 2021 online workshop we conducted a survey to assess participants' perceptions of the workshop components, level of support and supplemental materials, The survey served not only as an assessment of the workshop but provided valuable input toward building a better online interface. Thirty participants responded to the survey (41% response rate). Of those responding, 10% were K-12 Teachers, 43% were High school/middle school students, 23% were Undergraduate students, 7% were Grad students and 17% were UG Professors. Respondents represented 15 states. The majority of respondents were new to the PSC which makes sense as they would be most likely to be present at the last workshop session.

Most respondents (80%) agreed or strongly agreed that the course prepared them to certify to access discovery plots at the conclusion of the workshop. With the exception of the PSC search manuals and the Forum, most resources on the website were found to be very useful to the workshop participants. The forum, an add-on to the website, had become somewhat deprecated, and new participants could not access it without a manual approval step. We were well into the workshop when we recognized the problem. In response to this issue, many respondents

suggested the use of SLACK or Discord as alternatives. When asked about the most beneficial thing they learned from the workshop, those who responded indicated that learning to analyze data, score plots, and recognize pulsars was the most beneficial. Greater than 80% of respondents indicated that the workshop changed their perceptions of several areas: “Understanding what everyday research work is like”, “Confidence in my ability to contribute to science”, and “Comfort in discussing scientific concepts with others”. The workshop may have had a positive effect on respondents’ STEM identity development. Greater than 80% of respondents agreed or strongly agreed that being a STEM person was an important part of their identity. However this question was asked only at the conclusion of the workshop, so it is difficult to know the impact of the workshop on this attribute. Survey respondents offered many suggestions for resources, changes to the website and forum, which are being incorporated into the new integrated website at pulsars.nanograv.org. A full summary of the workshop survey can be found in the supplemental documents.

Summer Intern Assessment: A pre/post survey was administered to summer intern participants, and of the six interns, five completed the survey. With such a small sample, it is impossible to gauge the significance of the results. That said, the survey assess pre/post gains in five subscales of STEM career, STEM efficacy, school belonging, STEM identity, and STEM plans (on a 5-point scale of Strongly Disagree to Strongly Agree), as well as the four subscales of knowledge about research, attitudes and behaviors about research, personal skills, and research skills (on a 5-point scale of None to A Great Deal). At pretest, subscale scores ranged from a high of 4.70 (STEM plans) to a low of 3.43 (STEM career). At posttest, six subscales showed an increase from pretest scores, with research skills showing the most increase (0.23) and personal skills showing the least increase (0.04). Three subscales decreased, ranging from 0.12 to 0.40. The highest score at the posttest was **STEM efficacy** (4.47) and the lowest was **STEM career** (3.55).

The posttest survey also included a set of 16 items about the internship components rated on a 5-point scale (Strongly Disagree to Strongly Agree). ALL respondents strongly agreed with the following statements: This experience helped to improve my research skills.

- This experience helped me to increase my knowledge of research within a STEM field.
- This experience helped me to increase my general scientific knowledge.
- The things I learned during this experience will help me stay in my STEM major when my coursework is challenging.
- This experience will help me succeed in college.

The lowest mean score (4.0) was associated with the statement: I am more likely to pursue a STEM degree as a result of this experience.

Seven items about the usefulness of the internship components were rated on a 5-point scale (Not at all Useful to Very Useful), and three items

about the usefulness of their research project were rated on the same usefulness scale. Perceived as most useful to our interns were meeting/conversing with faculty members, the research oversight/training provided by faculty members, team-building activities, and the community building mentoring provided by undergraduate mentors. A full report can be found in the supplemental documents.

Key outcomes or
Other achievements:

*** What opportunities for training and professional development has the project provided?**

The PSC has evolved from a highschool student focused project to include undergraduate students and professors. In addition to the training activities offered by the PSC workshops, faculty(N=18) took part in a PSC workshop as part of the Winter 2021 AAPT meeting. Undergraduate students are often tapped to be mentors and leaders within the PSC as they gain expertise. During this reporting period, undergraduate students took leadership on the development of Juoyter notebooks for advanced PSC projects an

*** Have the results been disseminated to communities of interest? If so, please provide details.**

Over this reporting period, PSC members conducted a teacher workshop at the Winter 2021 meeting (virtual) of the American Association of Physics Teachers. **Eighteen** undergraduate physics teachers attended. We will contribute to an AAPT meeting next summer July 9-13, 2022 in Grand Rapids MI. with a special session, Pulsars and Radio Astronomy.

PSC activities are communicated to the NANOGrav membership at regular meetings and conferences.

Over the course of this award, two peer-reviewed publications discussed the structure and educational impact of the PSC and three papers discussed PSC pulsar discoveries and follow-up observations. These papers included 37 high-school student authors. In addition, two graduate student theses were published based on PSC research.

Supporting Files

Filename	Description	Uploaded By	Uploaded On
Workshop Survey.pdf	Workshop Survey Results The workshop survey was administered to participants at the conclusion of the Spring PSC workshop. It is designed to assess the impact of the workshop, and to gain recommendations for future improvements.	Sue Heatherly	01/28/2022
Summer 2021 Intern Survey.pdf	The intern survey is administered to student participants before and after their participation in the 2-week experience to assess changes in their STEM efficacy, identity, and education and career plans; sense of school belonging; and knowledge of, attitudes about, and skills to conduct research.	Sue Heatherly	01/28/2022

Filename	Description	Uploaded By	Uploaded On
PSC_syllabus_Spring_2022.pdf	PSC students can earn physics course credit through West Virginia University while in high school by completing the requirements in this syllabus.	Sue Heatherly	01/28/2022

Products

Books

Book Chapters

Inventions

Journals or Juried Conference Papers

Licenses

Other Conference Presentations / Papers

Other Products

Software or Netware.

Three Jupyter notebooks have been developed to aid students in accessing raw data, and conducting high level analysis of that data to conduct original research investigating magnetars, giant pulses and pulsar scintillation.

Other Publications

Patent Applications

Technologies or Techniques

Thesis/Dissertations

Websites or Other Internet Sites

Pulsa Science Collaboratory

<https://pulsars.nanograv.org>

The Pulsar Science Collaboratory website is the culmination of an extensive effort to bring the communication and research components of our program together by:

formalizing training courses

integrating training materials with the research including access to pulsar survey data under one "roof".

building advanced projects to investigate magnetars, giant pulses and pulsar scintillation. These projects require that students master the data analysis techniques of professional astronomers.

housing access to Jupyter notebooks to assist students in conducting advanced projects.

providing discussion forums, news and announcements across the community.

Participants/Organizations

What individuals have worked on the project?

Name	Most Senior Project Role	Nearest Person Month Worked
Heatherly, Sue	PD/PI	2

Full details of individuals who have worked on the project:**Sue A Heatherly****Email:** sheather@nrao.edu**Most Senior Project Role:** PD/PI**Nearest Person Month Worked:** 2

Contribution to the Project: Organize and facilitate online workshops Organize and host internships and camps
Contribute to evaluation and reporting.

Funding Support: National Science Foundation**Change in active other support:** No**International Collaboration:** No**International Travel:** No**What other organizations have been involved as partners?**

Name	Type of Partner Organization	Location
California Institute of Technology	Academic Institution	Pasadena, CA
Cornell University	Academic Institution	Ithaca, NY
Texas Tech University	Academic Institution	Lubbock, TX
University of Vermont	Academic Institution	Burlington, VT
University of Wisconsin	Academic Institution	Milwaukee, WI
Vanderbilt University	Academic Institution	Nashville, TN
West Virginia University	Academic Institution	Morgantown, WV
West Virginia Wesleyan College	Academic Institution	Buckhannon, Wv
El Paso Community College	Academic Institution	El Paso, TX
Howard University	Academic Institution	Washington, DC
Montana State University	Academic Institution	Bozeman, MT
Morehead State University	Academic Institution	morehead, KY
Penn State Abington	Academic Institution	Abington, PA

Name	Type of Partner Organization	Location
Penn State University	Academic Institution	State College, PA
Shepherd University	Academic Institution	Shepherdstown, WV
SmartStart	Other Nonprofits	Irvine CA

Full details of organizations that have been involved as partners:

California Institute of Technology

Organization Type: Academic Institution

Organization Location: Pasadena, CA

Partner's Contribution to the Project:

Collaborative Research

More Detail on Partner and Contribution: Faculty and undergraduate mentors are working to create a PSC hub.

Cornell University

Organization Type: Academic Institution

Organization Location: Ithaca, NY

Partner's Contribution to the Project:

Collaborative Research

More Detail on Partner and Contribution: Faculty and undergraduate mentors are working to create a PSC hub.

El Paso Community College

Organization Type: Academic Institution

Organization Location: El Paso, TX

Partner's Contribution to the Project:

Collaborative Research

More Detail on Partner and Contribution: Faculty and undergraduate student mentors are working to establish a PSC hub

Howard University

Organization Type: Academic Institution

Organization Location: Washington, DC

Partner's Contribution to the Project:

Collaborative Research

More Detail on Partner and Contribution: Faculty and undergraduate student mentors are working to establish a PSC hub

Montana State University**Organization Type:** Academic Institution**Organization Location:** Bozeman, MT**Partner's Contribution to the Project:**

Collaborative Research

More Detail on Partner and Contribution: Faculty and undergraduate student mentors are working to establish a PSC hub

Morehead State University**Organization Type:** Academic Institution**Organization Location:** morehead, KY**Partner's Contribution to the Project:**

Collaborative Research

More Detail on Partner and Contribution: Faculty and undergraduate student mentors are working to establish a PSC hub

Penn State Abington**Organization Type:** Academic Institution**Organization Location:** Abington, PA**Partner's Contribution to the Project:**

Collaborative Research

More Detail on Partner and Contribution: Faculty and undergraduate student mentors are working to establish a PSC hub

Penn State University**Organization Type:** Academic Institution**Organization Location:** State College, PA**Partner's Contribution to the Project:**

Collaborative Research

More Detail on Partner and Contribution: Faculty and undergraduate student mentors are working to establish a PSC hub

Shepherd University

Organization Type: Academic Institution

Organization Location: Shepherdstown, WV

Partner's Contribution to the Project:

Collaborative Research

More Detail on Partner and Contribution: Faculty and undergraduate student mentors are working to establish a PSC hub

SmartStart

Organization Type: Other Nonprofits

Organization Location: Irvine CA

Partner's Contribution to the Project:

Collaborative Research

More Detail on Partner and Contribution: SmartStart conducts the external evaluation for the project

Texas Tech University

Organization Type: Academic Institution

Organization Location: Lubbock, TX

Partner's Contribution to the Project:

Collaborative Research

More Detail on Partner and Contribution: Faculty and undergraduate student mentors are working to establish a PSC hub

University of Vermont

Organization Type: Academic Institution

Organization Location: Burlington, VT

Partner's Contribution to the Project:

Collaborative Research

More Detail on Partner and Contribution: Faculty and undergraduate student mentors are working to establish a PSC hub

University of Wisconsin

Organization Type: Academic Institution

Organization Location: Milwaukee, WI

Partner's Contribution to the Project:

Collaborative Research

More Detail on Partner and Contribution: Dr. Joe Swiggum leads a PSC hub at UW Milwaukee

Vanderbilt University

Organization Type: Academic Institution

Organization Location: Nashville, TN

Partner's Contribution to the Project:

Collaborative Research

More Detail on Partner and Contribution: Faculty and undergraduate student mentors are working to establish a PSC hub

West Virginia University

Organization Type: Academic Institution

Organization Location: Morgantown, WV

Partner's Contribution to the Project:

Collaborative Research

More Detail on Partner and Contribution: WVU faculty are PIs, Co-PIs on this project and also the lead organization for the educational research,

West Virginia Wesleyan College

Organization Type: Academic Institution

Organization Location: Buckhannon, Wv

Partner's Contribution to the Project:

Collaborative Research

More Detail on Partner and Contribution: Faculty and undergraduate student mentors are working to establish a PSC hub

Were other collaborators or contacts involved? If so, please provide details.

Nothing to report

Impacts

What is the impact on the development of the principal discipline(s) of the project?

The impacts include:

- High-school teachers showed statistically significant increases in their confidence in conducting research, competency in teaching science and teaching the research process. They also planned to implement PSC research in their classrooms through incorporating PSC research activities and incorporating research knowledge into curriculum discussions
- High-school students showed increases in science identities, and PSC high school student respondents had higher levels of science identity, self-efficacy, and STEM intentions compared to non-PSC respondents.
- Undergraduate mentors showed statistically significant increases in STEM self-efficacy, research knowledge, research skills, research confidence, leadership skills, communication skills, and collaboration skills.

- Graduate student, postdoc, and faculty mentors showed increases in their belief that high school students can contribute to the research process and enhance research. They also showed increases in their enjoyment in working with high school students and high school teachers.
- In addition to this, the astrophysics research done by the students has informed development of pulsar search filtering algorithms and provided insights into pulsar emission mechanisms and populations. In addition, we've provided a model for involving students from a broad range of backgrounds and institutions in authentic astrophysics research. Finally, the database we build this year will be used by astronomers throughout the world as a pulsar searching engine.

What is the impact on other disciplines?

Our model could be used to grow similar programs in other scientific disciplines.

What is the impact on the development of human resources?

Our model could be used to develop similar research programs in lower-resourced environments. Over this reporting period we collaborated with faculty from four community-technical colleges, and one predominantly undergraduate institution to co-develop a proposal for the IUUSE program that would build research opportunities for students who begin their post-secondary STEM journeys at community colleges.

We conducted a successful internship for first generation college students during this reporting period. The internship served as a bridge to college as the participants were rising freshmen. Pre-post survey results indicate that the internship had an impact on students' STEM identity and self efficacy and knowledge of the research enterprise. The internship structure and activities could be a valuable model for others seeking to host similar virtual experiences.

Undergraduate mentors received training in leading projects and mentoring. All students receive experience in in-person and online science communication.

Participants at the AAS meeting received valuable presentation and networking experience.

What was the impact on teaching and educational experiences?

We documented the structure of the PSC and the learning gains in two peer-reviewed publications. These could be used by other researchers hoping to design similar experiential STEM programs.

We also documented the activities of a virtual internship experience, including lessons learned and pre/post results. We were skeptical going into this experiment that it would have the desired interactivity and impact, but it worked. We gained valuable experience that is being put to use- we have made changes to the structure of our academic year online training workshops, and our teaching in general to make virtual learning more participatory and engaging.

What is the impact on physical resources that form infrastructure?

Nothing to report.

What is the impact on institutional resources that form infrastructure?

Nothing to report.

What is the impact on information resources that form infrastructure?

The website and database that we have developed this year will ensure the sustainability of the project past this grant period.

What is the impact on technology transfer?

Nothing to report.

What is the impact on society beyond science and technology?

Students in the PSC take the excitement of their work back to their home schools and towns and this demonstrates the importance of NSF-funded facilities and scientific research to a broad audience.

What percentage of the award's budget was spent in a foreign country?

Nothing to report.

Changes/Problems**Changes in approach and reason for change**

Nothing to report.

Actual or Anticipated problems or delays and actions or plans to resolve them

Nothing to report.

Changes that have a significant impact on expenditures

Nothing to report.

Significant changes in use or care of human subjects

Nothing to report.

Significant changes in use or care of vertebrate animals

Nothing to report.

Significant changes in use or care of biohazards

Nothing to report.

Change in primary performance site location

Nothing to report.

Special Requirements

Responses to any special reporting requirements specified in the award terms and conditions, as well as any award specific reporting requirements.