RET in Engineering and Computer Science Site: Digital Signal Processing in Radio Astronomy (DSPIRA)

1 Overview

The West Virginia University (WVU) Lane Department of Computer Science and Electrical Engineering (LDCSEE), the WVU Center for Gravitational Waves and Cosmology (GWAC), and the National Radio Astronomy Observatory (NRAO) in Green Bank, WV, propose a Research Experience for Teachers program: “Digital Signal Processing in Radio Astronomy” (DSPIRA). This RET program will provide high school teachers with hands-on experience using high quality open source software development tools, in both research engineering and educational settings.

Through a six week summer program, and academic year follow-up, the teachers will gain experience in the engineering method, via involvement in the research, design, development, and prototyping of digital signal processing (DSP) techniques and applications targeted for the next generation of radio telescopes. Teachers will work in small groups to complete one of two research projects, which will extend into the following school year with interested students. In addition, teachers will collaborate to develop projects that engage an entire class of students in DSP activities that address new WV Science standards. Three cohorts, each composed of ten high school teachers, project staff, two graduate students, and numerous undergraduate students, will form a shared learning community, over the three year course of the project.

DSPIRA aims to:

• Prepare teachers to implement DSP projects with their students, exposing them to exciting STEM career opportunities:
  – Bring new hands-on research experience to high school teachers;
  – Integrate computer science squarely into the high school curriculum, via hands-on learning;
  – Develop and share new educational material, including low cost hardware, open source software, tutorials and worked examples, with teachers and students;
  – Introduce DSP as a tool to illustrate how to use mathematical concepts in practical applications;
  – Provide the teachers with a broad set of working applications, implemented in open source software, that they can use to illustrate key DSP concepts in an intuitive, non-mathematical way.

• Inspire high school students to pursue careers in STEM disciplines:
  – Assist the teachers in creating hands-on activities that describe core DSP concepts that their students may encounter in real life;
  – Develop projects that high school students will be inspired to try;
  – Provide a unique opportunity to teachers and students to visit Green Bank and implement their DSP projects on working radio telescopes;
  – Develop students’ STEM identity through interactions with near peers, i.e. graduate students and undergraduate students.

• Broaden the reach of the DSP activities developed through DSPIRA:
  – Ensure the sustainability of the RET program by placing all developed material in online Teaching Repositories, both state-wide, and national;
  – Introduce teachers and students to the goals and concepts of the free and open source software model for wide-spread distribution and adoption of ideas and materials;
  – Provide professional development to other WV teachers through statewide conferences, and other programs.

• Develop the communication / pedagogical skills of project staff, graduate students and undergraduate students, through structured discourse with RET participants.

DSPIRA addresses a confluence of three needs: an industry need for greater public understanding of a widely used technology; science and industry’s need to have cross-curricular problem-solvers; and the K-12 world’s need to integrate engineering principles into their new science standards.

1. Advanced digital signal processing (DSP) techniques have become absolutely ubiquitous in current society. Modern smart phones contain cameras, global positioning system receivers, Wi-Fi anten-
nas, inclinometers and accelerometers. The data processing for all of these devices is performed in firmware in a highly integrated “system on chip” processor. Other examples of such DSP usage include game consoles with advanced graphical processing units (GPUs), video streaming devices, and the Internet of Things. Yet, despite being surrounded by these systems, modern consumers, including high school students and undergraduate engineering majors, have very little insight into the basic principles of how they operate. As society becomes technologically more sophisticated, the general public is comparatively less well informed [1].

2. Apart from consumer devices, advanced DSP techniques are now playing a key role across the spectrum of science and industry. For example modern medical imaging, machine vision, and remote sensing satellites used to monitor climate change all require DSP. It is vital that the next generation of scientists and engineers have in-depth exposure to the core techniques in this area.

3. The West Virginia Department of Education recently adopted the Next Generation Science Standards (WV NxE{1}Gen) which significantly integrates engineering principles into core science requirements for the first time. A highly qualified cadre of teachers well versed in engineering principles is needed in the state to successfully meet these new standards. DSPIRA will target motivated WV high school teachers to participate, by seeking those teachers who have demonstrated interest in engineering education.

The three collaborating institutions in this proposal have substantial shared interests in research, development and education. LDCSEE, which will be the site for this RET proposal, is significantly expanding its radio astronomy engineering program. LDCSEE department faculty are founding partners in the WVU Center for Gravitational Waves and Cosmology, and are close collaborators with the nearby Robert C. Byrd Green Bank Telescope (GBT), a world-class facility operated by NRAO. Both of these organizations have extensive experience in delivering high quality high school and teacher STEM education programs, for example through the Pulsar Search Collaboratory (PSC) [2], a state-wide program which is now being expanded nationally.

In addition, WVU is committed to play a leading role in the development of a knowledge-based economy. As part of this commitment, WVU has identified five “Mountains of Excellence.” Two of these include “Improving STEM education and scientific literacy,” and “Achieving international leadership in radio astronomy.” This DSPIRA RET program will leverage both of these areas to provide an outstanding RET program which spans both science and engineering, and research and education.

The logic model which was used to plan this proposal is shown in Figure 1.

2  Nature of Teacher Activities

The RET teachers selected for this program will work closely with university faculty and students throughout the academic year. But, in order to provide a well-defined research focus, we have defined two specific projects that the teachers will undertake during the summer program. These will be substantially completed during the teachers’ intensive six week summer session, but will be structured in such a way that the teachers will continue to expand on these activities, and will be able to use them in the classroom environment, throughout the academic year.

Below, we describe the project implementation environment – GNU Radio, the overall approach to the summer program, some core introductory concepts which will be common to all the DSP developments, and two specific research projects that teacher teams will engage in.

2.1  Software Defined Radio and the GNU Radio project

Teachers will conduct their research using “GNU Radio” [3] software and hardware – an open-source implementation of Software Defined Radio (SDR) [4]. In this approach, components that in the past have typically been implemented in hardware (e.g. mixers, filters, detectors) are instead implemented by means

of software on a personal computer or in an embedded system. The continuous, exponential increase in general purpose computing power means that sophisticated DSP approaches, which previously were only theoretically possible, can now be implemented in software using general purpose computing hardware.

GNU Radio is a free, high quality SDR development toolkit. Unlike e.g. Matlab, GNU Radio provides a totally open development and execution environment, which implements complete SDR systems using a mixture of Python scripts and C++ executables. A core component of GNU Radio is the GNU Radio Companion (GRC), a graphical tool for creating "signal flow graphs", and generating flow graph source code. An example of a GRC signal flow graph is shown in Figure 2.

Hardware components will be implemented using an “RTL-SDR USB Dongle” (a commercial device packaged with a USB interface, which provides a low noise amplifier, mixer, and I/Q sampler). The ready availability of such extremely cheap (around $25) devices means that complete, advanced DSP systems can be put together out of commodity components, and are affordable for use in K-12 settings.

GNU Radio is becoming progressively more popular in the undergraduate classroom. As noted by Braun [6], a typical (conventional) Matlab exercise would be to write an FFT, remaining close to mathematical theory. By contrast, a typical GNU Radio exercise would be to implement a phase shift key (PSK) modem, which represents “learning by doing.” Thus, we can drastically shorten the students’ learning curve by engaging them in building applications, and explaining theory on an as needed basis. Students take steps forward out of their own motivation, rather than passively based on instructions from a professor. This approach is particularly suitable for students who are capable of understanding the concepts, but do not have the formal, mathematical background, and this will be the approach that we take with our RET participants.

Yearly GNU Radio conferences bring together a vibrant community that share both technical developments, and uses of GNU Radio in the academic and teaching communities. Project staff have cultivated connections with the GNU Radio Community Development and User Experience Workgroup, and we will ensure that our work is well aligned with their goals. As part of their projects, the teachers and students will develop new GNU Radio “blocks,” which will be provided back to the GNU Radio community.

Dr. Tom Rondeau, the maintainer and lead developer for GNU Radio and visiting researcher with the University of Pennsylvania, has endorsed our proposed approach (see supplementary documentation).

2The label “Software Defined Radio” is unfortunate, since it might imply the approach is only valid in the narrow field of radio communications. In fact, it is directly applicable to a wide range of DSP applications.
The teaching material developed as part of this proposal will be made available back to the academic and GNU Radio community as a GNU Radio “Out of Tree” project in the Comprehensive GNU Radio Archive Network (CGRAN).

2.2 Outline of the Summer Program

The cornerstone of the RET experience will be a six week residential summer program, in which the teachers will be exposed to the research environment at WVU, develop competencies with DSP and SDR hardware and software, and complete concrete research projects to take back to their home institutions. DSPIRA will be an experiential learning program. Teachers will be given laptops loaded with GNU Radio on day one, and will immediately begin practical hands-on exercises in developing DSP applications. Initially, these will be simple applications which will graphically demonstrate the concepts under study. As the weeks progress, the applications will become progressively more sophisticated.

2.3 Common Introductory Concepts

Through interactive learning, informal, and some formal presentations, the summer session will begin with a short course on DSP topics, using experiments with the GRC software as a means for teachers to gain practical knowledge of the various concepts. We will cover a set of basic concepts beginning with the definition of a signal as a function (e.g. a sine wave) and explaining what it means for a function to have a frequency representation (in this case, a single frequency component). This will be followed by the topics of Fourier series and Fourier transforms, how to remove or enhance the frequency components of a given signal by means of filtering, and conclude in a demonstration of spatial Fourier transforms and filtering in a two-dimensional plane. We will also introduce a few concepts from classical detection theory such as the power detector, and explain how the performance of a detector depends on a threshold as a design parameter.

http://cgran.org/
While these concepts may sound intimidating in the abstract, we have already had excellent results introducing these ideas to Pocahontas County, WV, high school students performing work experience activities at NRAO. Interactive exploration of these concepts using graphical GNU Radio tools allows visualization and internalization of the various signal/image processing operations, without the need to go in depth into the mathematics behind the concepts.

In addition to various DSP topics, the participants will be given an introduction to some relevant radio astronomy concepts. Lectures will cover the distribution of neutral hydrogen (HI) gas in the Milky Way, as well as an overview of pulsars, and the latest theories of fast radio bursts and other transient phenomena. These topics support and motivate the proposed engineering projects. The participants will also learn about the acquisition of radio astronomy data, and some of the main steps of data processing at the “front end” and “back end” of a radio telescope.

As a practical component of the six week workshop, we will work with the participants on the application of newly introduced signal/image processing operations to radio astronomy data. These will comprise the research projects.

2.4 Project One: Development of an Astronomical Spectrometer for Radio Telescopes

In project one, teachers will develop a fully functional neutral hydrogen (HI) Spectrometer. Hydrogen is the most abundant element in the Universe, and the 21 cm (1.4 GHz) HI transition line is the most important signal in all of astrophysics. The HI line is extremely bright, and can easily be detected with very simple equipment. Observations of galactic HI continue to play a key role in understanding the history and evolution of our galaxy and the Universe \([9,11]\). Using the NRAO 20m and 40ft telescopes, and the equipment they will build, teachers will observe Doppler shifts in the HI line frequency due to the rotation of the Milky Way. The properties of galactic rotation are directly related to the mass of a galaxy via a simple derivation appropriate for high school physics students. They can then compare this mass to the total amount of matter in gas and stars, to illustrate the presence of a “dark matter” component that dominates the dynamics of galaxies. Because the HI line has simple physics and is the best tracer of ordinary matter in the Universe, there will be many opportunities for related projects. NRAO has extensive expertise, and practical teaching material, which will be available for these and similar topics.

As a result of their preparatory work, the teachers will have at their finger-tips all of the concepts necessary to construct this spectrometer. Using GNU Radio hardware and software, the teachers will develop the DSP chain to digitize the receiver output, take the resulting time series, pass it through a low pass filter, an FFT block and a complex-to-magnitude conversion, and create a power spectrum. Successive power spectra can then be accumulated, displayed (e.g. as a waterfall plot), and saved to disk. The process of developing and debugging this flow graph will precisely parallel the steps taken by research engineers in developing similar DSP algorithms and hardware (on a larger scale) for the GBT. Throughout the project, teachers will be encouraged to develop lesson plans, which can incorporate methods and developments learned throughout the course of the project.

2.5 Project Two: Processing Large Datasets to Search for Radio Transients

The main objective of project two is to provide the participants with an enriching hands-on experience with digital signal and image processing tools, and to demonstrate how these tools can be applied to do state-of-the-art science and engineering in radio astronomy. Again, one of the goals is to develop GNU Radio blocks that the participants can take back to their classrooms. The new blocks will allow the illustration of complex signal processing concepts through their visualization, avoiding the involvement of equations that would require a higher level background than the students will be likely to have.

Recent discoveries of a few very bright, short duration “fast radio bursts” (FRBs) with their origin outside of our galaxy \([12,14]\) have led to a new research direction. Due to their very short duration and one time occurrence, the search for such bursts is comparable to seeking a needle in a haystack. To detect single bursts in real time, especially from the next generation of instruments which may observe in hundreds or thousands of directions simultaneously, the development of new tools to rapidly analyze a large amount of data is necessary. The main drawback of the current tools is their inability to process data in real time. In the
past several years a large effort has been undertaken by many research groups across the world to speed up the processing time by the use of hardware (GPUs) and development of new efficient software / algorithms ([15][16]).

The Fourier transform (FT) is a well-established engineering tool used in the analysis of circuits, signals and systems [17]. Spatial or two-dimensional FTs are applied to analyze the frequency content of images and multi-dimensional signals [18]. They display in a different way the information (often hidden from a subject’s eyes) contained in a signal, and also provide the basis for the development of new, efficient algorithms to extract a signal or detect its frequency signature. In application to radio astronomy, it has recently been demonstrated that the spatial FT is able to blindy extract the frequency signature of a giant pulse in a time series containing a pulsar or millisecond pulsar signal [16]. The word “blindly” implies that a single application of the spatial FT to the data also generates an estimate of the dispersion measure, a characteristic of the dispersive environment through which the signal travels.

Using spectrograms (plots of frequencies contained in a radio astronomy signal versus time) of previously detected FRBs such as the Lorimer Burst [12] (Figure 3) we are currently researching a blind and fast (real or near-real time) method to detect the presence of FRBs in radio astronomy data, using a spatial FT.

![Figure 3: A time-frequency plot of the Lorimer Burst (top) and its spatial Fourier transform zoomed on low frequencies (bottom). The axis labels $u$ and $v$ are discrete spatial frequencies. The Lorimer Burst is the brightest of the eleven published FRBs. Most such bursts are not visible in a time-frequency plot. In spite of being bright, the Lorimer Burst was difficult to detect due to its very short duration and one time occurrence. The spatial FT is a tool which allows both the detection of an FRB and a simultaneous estimate of its dispersion measure, in near real time.](image)

We will begin by converting radio astronomy data into spectrograms. With a sliding window applied to the spectrograms, the participants will be looking for a signature of a giant pulse as shown in the top panel in Figure 3. The window with the giant pulse will be transformed using a spatial FT, and the magnitude of the transformed data will be displayed as shown in the bottom panel of Figure 3. For the initial illustration this will be done manually, but it will be automated for pipelining later.

As a research component, we will work on the application of well-known tools and algorithms, as well as developing new tools with the participants. A example list of planned activities for the participants is summarized step-by-step below. These activities are listed in arbitrary order and do not have to be implemented all at once. If participants are successful in implementing one of these items they will be able to select another subproject from the list. The participants will have an instructor, or instructor’s Graduate Research Assistant, continuously available to assist them if necessary, throughout the implementation of the practical components.

1. Use existing signal / image processing tools and develop new algorithms for mitigating noise and Radio Frequency Interference (RFI) in the data. One traditional approach to mitigate RFI is to remove
the horizontal and vertical axes in the \((u,v)\)-plane, that is, the spatial FT of a spectrogram. However, removal of these parts of the \((u,v)\)-plane does not always remove all the interference, and superior algorithms are needed.

2. Develop new automated signature detection algorithms. The current DSP approach involves evaluation of the Hough transform \([19]\) that performs an integration along a line and then searches for the orientation that generates the maximum integrated value. Alternative, more powerful approaches may be possible.

3. Use existing DSP tools and develop and apply new image enhancement algorithms such as noise removal and filtering out the high frequency components of the spectrograms, to further enhance signal to noise ratio.

4. Use GNU Radio to demonstrate the new algorithms.

After completing the practical component of the project, the teachers will package together their new GNU Radio blocks with existing blocks, and may use these to demonstrate the various DSP concepts in the classroom. Instead of going in depth into mathematical concepts at a level students do not possess, the teachers will be able to supply students with the already developed GNU Radio blocks.

2.6 Enrichment Activities at WVU

The Freshman Engineering Program and the Outreach Program Office at the Benjamin M. Statler College of Engineering and Mineral Resources at WVU offer numerous summer programs that will provide the teachers with opportunities to engage in additional engineering activities besides their specific research projects. Some of these programs include summer camps with K-12 students, the Academy of Engineering Success, and regular freshman engineering summer courses. In particular:

- Teachers will have the opportunity to observe students in engineering summer camps, to learn more about the implementation of engineering design activities in their classrooms.
- To help teachers visualize the holistic nature of engineering design while developing skills, practices, and habits of mind related to engineering practices, they may participate in the Academy of Engineering Success. This engages students and teachers in small engineering design challenges.
- Astronomy professors from the WVU Center for Gravitational Waves and Cosmology will present research talks on their science, especially that enabled by DSP techniques.
- Teachers will be exposed to other applications of DSP research at WVU:
  - The ongoing development of the Canadian Hydrogen Intensity Mapping Experiment (CHIME) \([20]\). Co-PI Bandura and graduate students will share their work in CHIME, illustrating advanced applications of the same techniques RET participants are using on their projects.
  - Biometrics. The Lane Department is well known for its research in biometrics. RET participants will tour the NSF Center for Identification Technology Research and interact with data acquisition equipment such as fingerprint sensors, iris scanners, and face cameras.

2.7 Transfer to the Classroom

Teachers will have two avenues with which to transfer their experience back to the classroom. First, they can continue their research projects with their students. At the end of the summer, teachers will be able to take the fully functional hardware (laptop plus dongle) and development environment back to their home institution. Also, a complete implementation of their project work will remain connected to the NRAO 20m telescope. Throughout the academic year, teachers and their students will be able to use the telescope remotely, using the software they have developed. As and when they and their students develop improved versions of their software, teachers will be able to upload these back to Green Bank for actual deployment, again emulating actual practice for the GBT.

Second, the teachers can use the development expertise they have gained to create additional classroom activities in line with their curriculum and the WV NxGen standards. For example, students could investigate how the unique sound of a musical instrument is generated by a specific combination of the fundamental plus harmonics. Or, they might use the built-in microphone in a laptop to capture sound files, and develop a GNU Radio application to uniquely identify individual voices using their “spectral fingerprint.” The six
week summer program will culminate in an opportunity for the teachers to pilot test their classroom activities with 9th grade students attending science camp at the NRAO. The timeline for these activities is given in Table 1.

<table>
<thead>
<tr>
<th>Week / Topic</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Week One</strong></td>
<td><strong>Activities</strong></td>
</tr>
<tr>
<td>Orientation. Signals and Systems short course.</td>
<td>Become familiar with the WVU research environment. Introduce the research projects. Introduction to GNU Radio. Start work on simple DSP experiments.</td>
</tr>
<tr>
<td><strong>Week Two</strong></td>
<td><strong>Activities</strong></td>
</tr>
<tr>
<td>Orientation (continued). Signals and Systems short course.</td>
<td>Introductory DSP experiments and tutorials by WVU Engineering and Astronomy faculty, and NRAO scientists and engineers. Communication discussions between RET participants and staff to improve RET instruction. Begin development of classroom applications.</td>
</tr>
<tr>
<td><strong>Weeks Three and Four</strong></td>
<td><strong>Activities</strong></td>
</tr>
<tr>
<td>Research Project Work.</td>
<td>Teachers break into teams to work on summer research projects, under the guidance of faculty and graduate students. Teachers, graduate students and faculty engage in education discussions to develop best practices for transferring RET experiences to the classroom. Continue to provide feedback to improve the RET experience for future cohorts.</td>
</tr>
<tr>
<td><strong>Week Five</strong></td>
<td><strong>Activities</strong></td>
</tr>
<tr>
<td>Project Integration.</td>
<td>Integrate the DSP applications to target hardware / data (the NRAO 20m telescope, fast radio burst search data obtained with the GBT). Tour the GBT, meet with NRAO engineers, scientists and educators.</td>
</tr>
<tr>
<td><strong>Week Six</strong></td>
<td><strong>Activities</strong></td>
</tr>
<tr>
<td>Classroom Transfer.</td>
<td>Continue to integrate and test DSP applications. Work with high school students in residence in Green Bank, to pilot test activities that will be used in the classroom. Write action plans.</td>
</tr>
</tbody>
</table>

Table 1: The RET Summer Program Timeline

3 The Research Environment

3.1 The WVU Lane Department of Computer Science and Electrical Engineering

The WVU LDCSEE has a burgeoning DSP for Radio Astronomy program. It has close ties with the NRAO in Green Bank, and some LDCSEE faculty (including the PI and Co-PI) are founding members in the WVU Center for Gravitational Waves and Cosmology.

PI Natalia Schmid has been with WVU for more than twelve years. She is engaged in the development of several programs with their roots in DSP. With detection and estimation being her primary research topic, the graduate students supervised by her in the past have developed optimal decision rules and stochastic estimators for a variety of pattern recognition and biometric recognition projects, and for decision making in wireless sensor networks. One of her latest research interests is designing new decision statistics based on probability models used to describe radio astronomy data. Jointly with Richard Prestage (her collaborator from NRAO) and her graduate and undergraduate research assistants, she is currently in the process of developing a new blind approach to detect fast radio bursts and bright millisecond pulsars. This new direction of her research is part of this proposal.

The WVU LDCSEE has recently announced DSP for Radio Astronomy as one of primary programs for the department to expand. Co-PI Kevin Bandura has been hired as a part of this growing program. He has been deeply involved in the digital processing design of the Canadian Hydrogen Intensity Mapping Experiment (CHIME) and is currently developing new systems for future radio surveys. After joining WVU, with his graduate student he continues his work in developing the CHIME correlator system, including new
methods for RFI removal and instrument stabilization. He is expanding this program, and is now developing systems for the new HIREX project in South Africa. The digital backend for HIREX is planned to be a variant on the CHIME system, and a WVU graduate student is working on developing the feed system for the telescope.

Due to their common interest in DSP for radio astronomy, Schmid and Bandura plan to collaborate in developing a new educational program in DSP for Radio Astronomy (new graduate and undergraduate classes) as well as in building a joint research program within LDCSEE. As part of the summer program, RETs will be encouraged to interact with this ongoing research, and will have shared lab space with WVU graduate students and faculty.

3.2 The National Radio Astronomy Observatory

RET participants will be immersed in the research environment of the NRAO during two weeks of their summer experience. The Green Bank site is a high tech village where NRAO scientists, engineers, technicians and machinists collaborate with many university groups across the country, to develop new instrumentation, and to maintain the capabilities of the GBT as the most sensitive fully-steerable telescope in the world.

Preparing the next generation of scientists and engineers, who are capable of performing cross-disciplinary engineering research and development, has always been an integral part of the NAO mission. NRAO has had a summer student internship program since 1959, a continuous Research Experience for Undergraduates (REU) program since 1987, and a program to support first or second year graduate students since 1997. We have also augmented this program with the addition of several teacher participants, funded through RET extensions to the NRAO REU grant.

In addition to the REU / RET program, NRAO also hosts summer activities for teachers and K-12 students, offering K-12 teacher professional development, short courses for undergraduate / community college professors, and one to two week camps for middle and high school youth. These programs have been a strong and valuable part of the NRAO tradition of community service through the education of future scientists and engineers, and high school and community college teachers have been an integral part of them.

3.3 The Project Team

Our senior team has substantial experience and a record of involvement with middle and high school teachers and students, and undergraduate engineering education.

Natalia Schmid (PI) (Professor, LDCSEE, WVU) has research interests in linear signals and systems, statistical signal processing, stochastic systems, estimation and detection, and information theory with applications to biometrics, wireless sensor networks, pattern recognition and most recently to radio astronomy. She regularly teaches these subjects at WVU. She will coordinate all aspects of the project, develop and implement a Signals and Systems short course, and mentor research teams.

Kevin Bandura (co-PI) (Assistant Professor, LDSCEE, WVU) Kevin Bandura is actively involved in the CHIME telescope project. He has experience in K-12 education, co-teaching a hands-on electronics course for the Summer Academy for Math and Science (SAMS) program at Carnegie Mellon. He will assist with the overall organization of the program, provide instruction, and mentor teachers in their research projects.

Marjorie Darrah (External Evaluator) (Associate Professor of Mathematics, WVU) Dr. Darrah’s research interests are neural networks, genetic algorithms and STEM education. She will conduct the external evaluation for the project.

Martin Braun (Industry Partner) (Senior SW Design Engineer and UHD Driver team manager at Ettus Research / National Instruments and Community Manager for the GNU Radio project) Dr. - Ing. Martin Braun has worked in the field of software defined radio for the entirety of his career, both in academia (with a research focus on SDR, digital signal processing and radar) as well as in industry with his current position with Ettus Research, a National Instruments company. He will provide advice to the project to ensure that we appropriately address industry goals.

Alex Mejia (Senior Personnel) (Assistant Professor of Engineering Education, College of Engineering and Mineral Resources, WVU) Dr. Mejia studies engineering literacy, funds of knowledge, engi-
neering discursive practices, and K-12 engineering education. Dr. Mejía has worked on engineering education research, and has developed culturally responsive and standards-based engineering curriculum materials for K-12. He will conduct the internal evaluation of the project, and provide education research statistics.

Richard Prestage (Senior Personnel) (Scientist, NRAO; Adjunct Professor, Department of Physics and Astronomy, WVU) Dr. Prestage has twenty years of experience commissioning large single-dish radio telescopes. His current research interests are telescope performance enhancements, development of advanced pulsar, spectral-line and beamformer instrumentation, and (with PI Schmid) the detection of radio transients. He will collaborate in the development of the Signals and Systems course, present enrichment material on radio telescopes, mentor teacher research teams, and coordinate teacher project work at the NRAO.

Sue Ann Heatherly and Maura McLaughlin (Senior Personnel) Sue Ann Heatherly (Senior Public Education Officer, NRAO) and Maura McLaughlin (Professor, Department of Physics and Astronomy, WVU) are the PIs (together with Duncan Lorimer) of the Pulsar Search Collaboratory [2], a project that engages high school students and teachers in working alongside astronomers and graduate students to conduct astronomical research – discovering and characterizing pulsars. This collaboration has led to a number of joint publications with high school students ([21, 22]). In 2015 the team received NSF award # 1516512 “Collaborative Research: Developing STEM self-efficacy and science identities through authentic astrophysics research in online and face-to-face environments (STEM-ID).” Dr. McLaughlin will be an adviser to the project and will present enrichment lectures to the participants on her pulsar and transient research. Sue Ann Heatherly will collaborate with project staff to develop a top-down hands-on pedagogical approach to the teacher instruction, and will assist teachers in developing classroom projects.

Loren Anderson (Senior Personnel) (Assistant Professor of Physics, Department of Physics and Astronomy, WVU) Anderson’s research focuses on Galactic HII regions, the zones of ionized gas surrounding young massive stars. HII regions are one of the primary mechanisms that inject energy into the Galaxy. They are relatively rare but have a large impact on their surroundings. Dr. Anderson will introduce radio astronomy to the participants, as well as present enrichment lectures on his Galactic HII region research.

Graduate Students In addition to these Senior Personnel, the project will recruit two Graduate Students who will work closely with RET participants during the six-week summer program and who will conduct followup activities in teachers’ classrooms during the academic year.

4 Participant Recruitment and Selection

The DSPIRA program will introduce the concepts of DSP, and novel image processing applications, via their application to radio astronomy data. We are eager to work with highly motivated teachers to ensure that our projects have transferability and relevance to teachers’ classrooms. To that end, we seek teachers who are committed to teaching an engineering curriculum, and will therefore target teachers involved in Project Lead the Way (PLTW) [23]. In West Virginia, twenty-six schools in thirteen counties currently have PLTW programs. Letters of support have so far been obtained from four of these counties (see supplementary documentation). Should we need to widen our recruitment efforts, there are, within a 200 mile radius of WVU, 290 additional schools in adjacent states with PLTW engineering programs.

We will recruit through direct contact with PLTW schools, but we will also open DSPIRA to other excellent teachers in West Virginia and neighboring states, advertising through large state-wide science / mathematics teacher listserves. Application to DSPIRA will be made through a WVU RET website. Teachers who have experience in K-12 engineering education, who are skilled practitioners of project-based teaching and learning and who have a potential to serve students that are typically under-represented in STEM fields, will be selected. Where possible, more than one teacher will be selected from an individual school – teacher pairs will be encouraged to apply together.
## 5 Follow-up Plan

Before teachers complete their summer research experience they will write and submit an action plan for engaging their students in DSP. The RET teachers will contact DSPIRA staff to notify them of a start date for their classroom projects, and will discuss their plans and how they would like to structure interaction with project staff.

We know from past experience with the Pulsar Search Collaboratory that interaction between students and STEM professionals can strongly motivate students to enter a STEM career path. Graduate and even undergraduate students have an especially strong impact because they are nearer in age to the high school students. As DSPIRA projects move from summer research into high school classrooms, WVU graduate students and undergraduates who have taken DSP courses will interact with high school students and their teachers at three stages during project implementation:

1. Within two weeks of project initiation at an RET school, DSPIRA staff, and graduate / undergraduate student teams, will hold a virtual meeting with the high school class to introduce themselves, have the students describe their work, and take questions.
2. Graduate student / undergraduate student teams will travel to the school to assist with the hands-on project work. They may bring demonstration instrumentation with them.
3. DSPIRA staff and graduate student / undergraduate teams will hold a second virtual session to assess progress and give advice.

Students and teachers will be invited to WVU for a capstone event where they exhibit and communicate their work to their peers and DSPIRA staff. At this event, they will tour the WVU engineering departments, and graduate / undergraduate students will share the work they are doing on other projects as part of their post-secondary education.

## 6 Project Evaluation and Reporting

This project incorporates engineering, astronomy, and teaching practices through a summer research experience for teachers. Teachers participating in this project will be required to develop and implement a unit that incorporates astronomy and DSP principles and practices into the curriculum. The success of the program will be evaluated based the objectives of the project: (a) participating teachers will bring new hands-on research experience to their classrooms; (b) participating teachers will develop and share new educational materials with teachers and students; (c) the research team will introduce DSP as a tool to illustrate how to use mathematical concepts for practical applications; (d) sustainability will be ensured by placing all developed materials in an online Teaching Repository; (e) the research team following up with participants and participants’ creating of informal learning experiences for students; and (f) providing a unique opportunity to teachers and students to visit Green Bank and work at the GBT. Evaluation will be based on a mixed methods approach for data collection and analysis [24]. Table 2 shows an overview of the objectives, evaluation questions, and data gathering mechanisms to be considered for the evaluation of the project.

The evaluation plan includes both formative and summative evaluation to determine if the project's goals are met. The **formative evaluation** plan includes evaluation at multiple points to ensure the goals of the project are met and will be conducted by an external evaluator, Dr. Marjorie Darrah, a researcher with expertise in educational evaluation and an internal evaluator, Dr. Alex Mejia, who has expertise in Engineering Education and qualitative data analysis. Adjustments to the plan will be made semi-annually if necessary. The purpose of the formative component of the evaluation is to assure that the project is progressing towards its stated objectives, as well as how and in what ways progress is being made. Periodic reports and dialogue will ensure any needed course adjustments can be made in a timely manner. The **summative evaluation** plan will be completed on the basis of the final goals met during the project. One important idea presented in the summative report will be the impact of this work and the logical next steps as it expands to a larger research and development effort. The summative evaluation will culminate in a final report that will, as described above, identify short and long-term goals and objectives, from participants’ perspectives, as well as identify factors that supported and / or constrained the project’s ability for meeting its goals and for its ability to have potential impact on the field.
<table>
<thead>
<tr>
<th>Project Objective</th>
<th>Evaluation Question</th>
<th>Data Gathering Mechanism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participating teachers will bring new hands-on research experience to their classrooms.</td>
<td>In what ways do the teachers bring new hands-on research experiences to their classrooms? How do the research experiences prepare the participants to include science and engineering in their classroom teaching?</td>
<td>Interviews of Teachers (during school year). Observation in the classroom (during school year). Examination of lesson plans (end of workshop). Science Teaching Self-Efficacy Survey (beginning and end of workshop).</td>
</tr>
<tr>
<td>Participating teachers will develop and share new educational materials (including GNU Radio blocks, etc.) with teachers and students.</td>
<td>To what extent do the participants effectively translate research experiences into innovative curriculum? What ways are the participants’ lessons shared with their peer?</td>
<td>Examination of lesson plans (end of workshop). Send lesson plans to Teach Engineering for Evaluation (ongoing)</td>
</tr>
<tr>
<td>The research team will introduce DSP as a tool to illustrate how to use mathematical concepts in classrooms for practical applications.</td>
<td>How do the research activities (especially DSP) prepare the participants to include science and engineering in their classroom teaching?</td>
<td>Focus groups (middle of workshop). Interviews (during school year).</td>
</tr>
<tr>
<td>Ensure sustainability of the RET project through placing all developed material in an online Teaching Repository.</td>
<td>How many lessons were submitted to the teaching repository? How many lessons were published on the Teach Engineering website?</td>
<td>Examination of the teaching repository (ongoing). Tracking of lessons published on the Teach Engineering website (ongoing).</td>
</tr>
<tr>
<td>Research team follow-up with participants and participants’ creation of informal learning experiences for students.</td>
<td>What follow-up activities took place after the summer workshop where project team member interacted with the participants? What informal educational activities were developed by participants? How effective were these activities?</td>
<td>Interviews with teachers (during school year). Quarterly Activity Survey sent to participants. Quarterly Activity Survey sent to graduate students and researchers.</td>
</tr>
<tr>
<td>Provide a unique opportunity to teachers and students to visit Green Bank and work at the GBT.</td>
<td>How many teachers were given the opportunity to work at the GBT? How did the teachers perceive this opportunity?</td>
<td>Focus Groups (middle of workshop). Surveys about experiences (end of workshop).</td>
</tr>
</tbody>
</table>

Table 2: Project Evaluation Mechanisms

6.1 Data Sources

We will collect multiple types of data over the course of the project. First, participating teachers will be asked to complete pre and post-research experience surveys. A teacher survey will also be administered to participants at the beginning and end of the summer research experience. Several questions of the post-survey will be follow up questions to the pre-survey. Participants will be asked to rate their perception of how the goals of the RET program prepared them to develop standards-compliant curriculum, how effective the program was in translating cutting-edge research into the classroom, their satisfaction of the program, the effectiveness of their mentoring, the professional development opportunities provided, and the new knowledge in science and engineering gained during the program. Additionally, participants will be asked to complete the Self-Efficacy Teaching and Knowledge Instrument for Science Teachers-Revised (SETAKIST-R) [25] at the beginning and end of the summer experience to assess their beliefs in their capacity to attain the specific objectives of the project.

The second type of data to be collected includes responses to a quarterly Activity Survey to be sent to researchers, participants, and graduate students. These surveys will include Likert scale and open-ended questions to determine what activities have taken place in the schools during the quarter (e.g. lessons being delivered, informal education opportunities, visits from research team) to determine areas that can be
improved, and how to provide adequate support to the teacher participants.

As a third method for collection of data, we propose to conduct classroom observations and interviews with the participants. One evaluator and a research team member will visit the classroom as the teacher delivers his / her lesson to determine if the lesson is scientifically accurate, effective, and engaging. An observation protocol will be chosen based on the goals stressed in the workshop as they develop their lessons. The purpose of the follow-up interview will be to collect perspectives related to (a) the experiences of classroom implementation of the participants, (b) the creation of informal learning experiences for students, (c) the use of mathematical concepts in the classroom for practical applications, and (c) the impact of the summer experience [26]. Semi-structured interviews, lasting approximately 30 minutes and based on open-ended questions, will be conducted with the participants and follow-up questions will be elaborated upon the participants’ responses [27]. The interviews will take place during the school year after observation in the classroom is done to involve participants in more reflective interviews [26]. These interviews will be audio and video-recorded and transcribed for subsequent analysis. At least two trained raters, led by Dr. Mejia, will analyze the results and code the data into quantitative units and test rater agreement with a coefficient of inter-rater reliability.

The fourth type of data will be obtained from focus groups. Groups will consist of five participants per group. The cohort of participants will experience similar activities and it would, therefore, be appropriate to interview each participant, which would meet Polkinghorne’s ( [28]) requirement of between five and twenty-five participants with similar experiences. Each participant will meet with their respective focus group in the middle of the summer program for 30 to 45 minutes to discuss significant challenges throughout the summer program, their overall perceptions of engineering, and their perceptions of how the research activities have prepared them to include science and engineering in their classroom teaching. Focus group meetings will also be audio and video-recorded and transcribed for subsequent analysis.

The fifth data collection method will include an examination of lesson plans and submission of such lesson plans to “TeachEngineering” [4] — an NSF funded web-based digital library with standards-based engineering curriculum for K-12 education. Teachers will be encouraged to consult the TeachEngineering site for tips on lesson development.

### 6.2 Data Analysis

The primary quantitative data obtained from the surveys will be analyzed using repeated measures of Analysis of Variance (ANOVA) to determine how effective the research experiences were in preparing participants for the adoption and implementation of engineering practices in the classroom. Because of the small sample size non-normally distributed data is likely, in which case the nonparametric version of ANOVA, the Kruskal-Wallis test will be used instead [29]. Effect sizes will be calculated to verify the study’s findings in the form of standardized mean differences [30]. Statistical correlation analysis and ANOVA [31] will be performed to determine significant factors that are correlated with and / or affect student academic performance. Appropriate post-hoc tests will be used to examine differences between groups.

Transcripts obtained from every audio and video-recording will be analyzed using Constant Comparative Analysis (CCA), which combines category coding with simultaneous comparison of all incidents observed as well as simultaneous comparison across categories [32]. To achieve credible findings [33] theoretical validation [34] and methodological soundness [35], we will utilize several different techniques including gathering information from different sources and peer debriefing for communicative validation [34].

After the lesson is developed by the teachers, evaluators and the research team will examine the lesson plan using a rubric based on the goals of the lesson development and the incorporation of accurate mathematics and science concepts that align with Next Generation Science Standards and appropriate pedagogical approaches. Then feedback from this examination will be given to the teachers for incorporation before the lesson is submitted to the Teach Engineering website for further peer review. The goal is to have at least 80% of the lessons accepted and published on the website.

7 Results from Prior Support

N/A.

8 Dissemination

Our dissemination plan has four objectives:

1. **Transfer of knowledge to the educational research community**: DSPIRA will publish research and evaluation reports and data in the Teach Engineering Digital Library, and present research findings by high school students and their supervisors at the annual conferences of the WV Science Teachers Association and WV Statewide Technology Conferences. The PIs will share all educational and research material developed over the period of the project as well as astronomy data sets obtained with the assembled hardware (lessons and hands on activities) with high-school in state and nationally through the Teach Engineering Digital Library. Teachers will be strongly encouraged to place lesson plans and curricular materials created through the program on the Teach Engineering digital library as well. The WVU RET website will be updated with materials produced from the teacher experiences. It will be built up in particular as a public reference for teachers that have gone through the program to refer to. As a particular example, the curricular materials to build the HI spectrometer will be made publicly available on the site.

2. **Transfer of application to others interested in implementing similar projects**: In its execution, the RET Site is a straightforward project that can be replicated in other science research areas. We will invite computer scientists and electrical engineers, through the IEEE and ACM Societies, to visit our Sites at WVU and NRAO. We will also develop video clips that capture core activities. We will invite “guest” engineers to join our online community, by participating in online events, chats and hangouts, including members of the National Society of Black Engineers[^5] and the Society for the Advancement of Hispanics / Chicanos and Native Americans in Science (SACNAS[^6]).

3. **Community Awareness**: We will disseminate information about the projects, the science and research behind the projects, and the work by the RET participants and their high school students to stake-holders in the communities where the students live. We would like parents, teachers and civic leaders to be aware of the rigorous research their youth are engaged in, and to celebrate their achievement. Consequently, we will:
   - Create and release press releases for each participant teacher and their high school students to their local newspapers (print and web), when teachers and students complete their RET research, when they qualify for a Capstone, or other notable event like detection of an unknown giant transient pulse or FRB.
   - Invite community stakeholders and parents to the Capstone Seminar where students, guided by their teachers, present their work in a scientific meeting setting.
   - Select the two best works of teachers-participants and their students per year to present at the WV Statewide Technology Conference and at an appropriate IEEE conference (ICASSP or ICIP), and blog about it for the benefit of other members, parents, and general public.

4. **Outreach to and interactions with the GNU Radio Community**: This material will be of interest not just to high school students and teachers, but also to a much wider community of DSP developers, amateur radio astronomers and the GNU Radio community as a whole. We will use the GNU Radio web site to share newly developed material with the GNU Radio community. The GNU Radio material will be made available as a GNU Radio “Out of Tree” project available on CGRAN.

[^5]: http://www.nsbe.org/home.aspx
[^6]: http://sacnas.org
9 Broader Impacts of the Proposed Work

Advance discovery and understanding while promoting teaching, training, and learning. Our research and education program engaging high school teachers and through them high school students will draw on the existing well established research and educational collaboration among LDCSEE and Department of Physics and Astronomy at WVU and NRAO in Green Bank, WV.

Participating teachers will spend six weeks in summer at WVU and NRAO and become familiar with DSP, radio astronomy, and principles and practice of radio telescopes via their daily engagement into research, a short introductory course on Signals and Systems, lectures and seminars offered by the participating Senior Personnel, summer educational activities for freshmen engineering students at WVU and educational workshops at NRAO. The six week summer program will conclude with planning how to include the research activities for teachers into their academic curricula so that they can deliver a similar experience to their students. This will trigger interest and curiosity in the next generation of engineers, physicists, mathematicians and radio astronomers and will create a wave of motivated students and early career researchers to enter colleges and universities, and later staff engineering positions in academia and industry of the US.

Broaden participation of underrepresented groups. This RET project will be structured to maximize collaboration time with the aim of producing classroom materials for integration of every-day life concepts, such as investigating unique sounds, into STEM education. All materials will be made available online for wide dissemination. The curriculum materials produced will use innovative teaching methods [36] with an emphasis on application of science to “real world” problems or scenarios [37–40]. Some scholars even suggest that learning science through a Science Studies lens may attract more women to science [41] because it presents science as more inclusive and accepting to underrepresented groups [42]. The combination of education, science, and engineering scholars in our research network will ensure that curriculum materials are grounded in inclusive and multicultural pedagogies that are known to enhance student learning and appeal to a diverse audience [43].

Broaden dissemination to enhance scientific and technological education. The PIs will share all educational and research material developed over the period of the project as well as astronomy data sets obtained with the assembled hardware (lessons and hands-on activities) with high-school teachers, in state and nationally, through the Teach Engineering Digital Library. To broaden the range of available experiences, Computer Science and Engineering faculty and students will initiate DSP and DSP in radio astronomy clubs at participating high schools and later will be involved in their operation. Historically underrepresented groups, including women, will be involved in the project as research assistants.

Benefits to society. Advanced DSP algorithms running in commodity devices (tablets, smart-phones, GPS receivers) are a fundamental part of modern life. The experiences gained by the teachers will give them, and through them their own students, insight into the design, development, and implementation of such devices. The signal processing techniques being developed will be broadly applicable to vision-based navigation, remote sensing, robotics, mechatronics, sensor fusion, brain-computer interaction, computerized tomography and medical imaging, biomedical engineering, radar and sonar imaging, and image and signal processing for security applications. Continuously more powerful distributed computing systems are becoming vital across a wide range of science and industry, and the methods and approaches we will demonstrate are applicable to careers in all of these areas. Astronomy in general has great power to capture the imagination, and is a powerful “hook” to entice students to become involved in STEM subjects.
References


