Research Experiences for Teachers in Machine Learning

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Abstract— Machine learning and Artificial Intelligence (AI) are national priority areas for research, education and workforce development. This work in progress paper describes a Research Experiences for Teachers program in sensors and machine learning launched in the summer of 2020. Motivated by national AI workforce needs, we designed a program that engaged high school teachers from STEM fields in machine learning research. In 2020, the program focused on AI algorithms for solar energy systems. Because of the COVID-19 conditions, the research experience was virtual and ran with a smaller teacher group than originally planned. The program included development of training content, algorithm and software training, research in solar energy monitoring, development of research reports and lesson plans, research presentations, and assessment. The assessment of the program included surveys, interviews, presentation observations, and follow-up in high school content delivery.

***Index Terms*— machine learning, sensors, RET, STEM, high school teachers, AI, quantum computing**

I. INTRODUCTION

National Science Foundation (NSF) Research Experiences for Teachers (RET) programs span several STEM areas and previous programs reported research, outcomes and assessments in [1-5]. In this RET program, teachers are recruited and trained in machine learning (ML) algorithms [6-10] and software. The ML topic of the RET was motivated by national workforce needs, the many ML applications that energize and intrigue students, and the ML relevance to STEM education and recruitment. The program recruited teachers from STEM fields including Physics, Mathematics, and Computer Systems with the emphasis on attracting teachers from minority-serving high schools. The intellectual focus of the program is on establishing foundations to create a workforce in ML and Internet-of-Things (IoT), starting at the high school level. This work in progress paper provides descriptions of all technical and assessment sessions, lessons learned, and experiences gained on delivery of such a program under COVID-19 restrictions. In addition to examining the diversity of participants and the diversity of students they reach, there are key evaluation goals that will be examined.

These goals for RETs include: (1) increased knowledge in ML and sensors, (2) increased knowledge of how to apply ML into teachers' subject area, (3) increased ability to create lesson plans, (4) RET dissemination of lesson plans, and (5) student interest and engagement. The paper is organized as follows: Section II reviews the program format, Section III describes the research theme, Section IV describes the virtual lab experiences, Section V describes the preparation and recruitment for the program, Section VI provides the organizational structure for the teachers, content of training materials and the use of VC sessions, software notebooks and LMS to provide training, Section VII describes assessments, Section VIII discusses the next steps for the program, and Section IX provides the conclusions.

II. PROGRAM FORMAT

The program began with recruitment and pre-training of participants using a series of video-streamed modules that provided the basics of ML. In parallel, the participants attended daily sessions where they began compiling and developing content to form lesson plans for delivery in their classes. Challenges included: a) designing and delivering theoretical and software implementation content via video conferencing (VC) sessions, b) reviewing live online participant work and providing feedback, c) guiding the participants in establishing documentation and presentations, and d) guiding the participants in developing research results for possible publication. Teachers worked on machine learning solutions for solar energy system faults [25] and forecasting. Machine learning [11,12] was used for detecting and classifying faults [13,14] in solar panels. By embedding teachers in this research, they acquired skills in terms of knowledge on data preprocessing, feature extraction, machine learning and implementation in Python. Participants learned how to profile algorithms in terms of performance and complexity and how to present ML results in terms of confusion matrices [15]. Interactive VC sessions guided participants in the preparation of their own materials for implementation in their high school classrooms.

Meetings included delivery of synchronous content via VC sessions and asynchronous content delivered through

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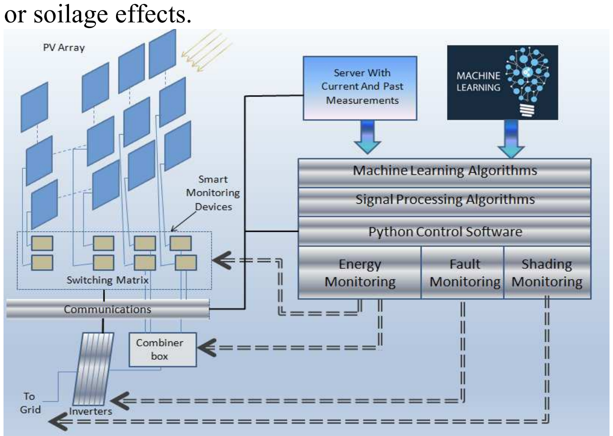
prerecorded modules, Learning Management System (LMS) pages, and Google notebooks. Daily pre-recorded seminars were also delivered to provide background and exposition in multidisciplinary applications of sensors and machine learning. The weekly program consisted of: a) orientation, b) description of RET projects, c) curriculum and lesson plan preparation, d) compliance with national and state standards, e) adaptation of materials and transition of research knowledge to lesson plans, and f) scientific documentation of research in IEEE-style formats and presentation. Participants presented their results weekly to faculty and graduate student advisors and received technical feedback. The graduate advisors interacted with the teachers daily, discussed software implementations, and planned research results for their final reports. To assess the program impact, an external evaluation plan was developed that included both formative and summative assessments. An assessment specialist continuously interviewed participants to evaluate research progress and quality of documentation and lesson plans. At the end of the program, participants gave a final research presentation, provided a lesson plan related to ML, and prepared for implementation of the lesson in their classes. The final presentations were given to a diverse audience that included other teachers, faculty, graduate students, assessment specialists, administrators, and industry representatives.

III. RESEARCH FOCUS

Machine Learning [11-13] was the focus of this program, which was designed such that ML was part of all teacher-developed lesson plans. In the summer of 2020, the project focus was on solar energy. This is an area where our faculty and graduate mentors have knowledge, ongoing projects, publications, patents, and access to data [14,15]. The overall solar array monitoring concept is shown in Fig. 1 where sensors and actuators have been used for obtaining voltage, current, irradiance, and temperature from each solar panel. This data is then analyzed using ML algorithms which cluster measurements with the goal to determine whether the photovoltaic array is underperforming which will indicate the presence of an electrical fault, damaged module, and shading or soilage effects.



Fig, 1. Solar Panel Monitoring Concept using Machine Learning. RET participants learned how to use ML algorithms to detect faults in solar power plants.

The ML task was to detect faults and classify faults into one of several categories. Through this task the RET participants gained knowledge and skills on ML algorithms, the development of ML software, and the energy monitoring application. In parallel, the participants developed lesson plans for taking this knowledge to their classes.

The RET participants began their training with several hands-on sessions with ML software. Training started with descriptions of K-means clustering and then continued with descriptions of Support Vector Machines (SVM), Neural Networks (NN) and a brief exposition to Positive Unlabeled learning. The teachers initially used J-DSP [16,17], an object-oriented program that works on a browser, for the very initial introduction to machine learning. Two projects were designed for the teachers. The projects included research on ML tools for solar energy systems and are briefly described below.

RET Project 1: Solar Array Fault Detection using Machine Learning. This project explored ML methods (Fig. 2) for fault detection. Objectives included: a) survey of ML techniques, b) study of solar array faults, and c) identify faults in photovoltaic systems using national databases of voltage, current, irradiance and other parameters. A dataset with 21,000 labeled features was used.

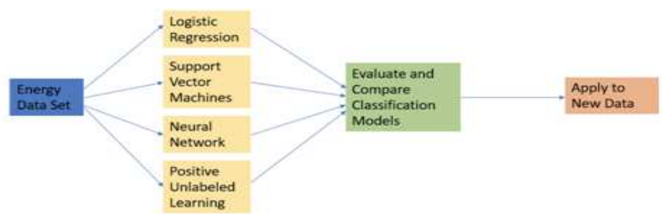


Fig. 2. ML Algorithms for Fault Detection Experiments.

Data was classified using logistic regression, SVM and NN classifiers. Confusion matrices [13] were used to assess fault detection [24]. A sample result for logistic regression [26] is shown in Fig. 3.

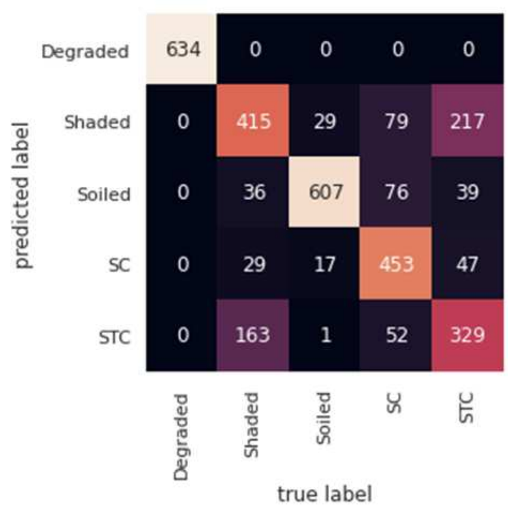


Fig. 3. Confusion Matrix for PV fault detection using logistic regression.

The experience from using ML and assessing properties was used by the teachers to design a lesson plan which was implemented in the Fall of 2020.

RET Project 2: A Hybrid Regression Algorithm for Solar Power Forecasting. The objective is to compare ML algorithms for the task of energy forecasting. Computations for solar power forecasting were performed using linear regression, logistic regression, and multivariate regression. Synthetic and real data obtained from rooftop installations was used to assess the algorithms which were implemented in Python. Comparative results were presented in the final presentation given by the teacher. The experience from energy forecast using ML was embedded in a lesson plan by the teacher, which was implemented in the Fall of 2020.

IV. INTERACTIVE ML RET SESSIONS

To perform the actual hands-on lab programming portion of the RET, we used a series of custom interactive Python programming tutorials using the free online Python programming environment Google Colab. Colab notebooks provide both a free, zero-setup programming platform for learning and an interactive teaching tool that enabled the participants to focus on fundamental ML concepts without concentrating on syntax and other details. Google Colab hosts online Jupyter Notebooks which include both documentation and code.

For each ML topic, a brief lecture was presented and a Colab notebook on the topic was explored with a graduate mentor. That notebook and additional resources were made available using a GitHub account. Participants were encouraged to modify the notebook and change the code sections to better understand each concept. After ML training, participants began working on their research. The research problems examined by RET participants in 2020 focused on applying and evaluating machine learning tools for solar energy monitoring, forecasting and fault detection. Participants implemented ML algorithms for solar energy systems in Python. Specifics on tools, schedules and training components are also discussed in Section VI.

V. PREPARATION AND RECRUITMENT

To guide the design of the RET program, we surveyed several other teacher training programs [1-5, 18-21] and leveraged relations with on campus synergistic teacher experiences endeavors [22]. The teacher experience programs covered in [18-21] covered motivation, assessments, sensor technology and lessons learned. Interdisciplinary projects were defined that would be appropriate for high school and community college instructors teaching STEM subjects. Emphasis was placed on recruiting from minority serving high schools and community colleges. Recruitment efforts were amplified by leveraging established educational partners of the Engineering Research Center for Bio-mediated and Bio-inspired Geotechnics (CBBG) that serve students from groups traditionally underrepresented in engineering. Also, this RET held some joint technical sessions with two other workforce programs with technical overlap in ML, namely, REU [23] and IRES [24] projects.

We received 15 applications from high school and community college faculty for the 2020 RET program, which operated under COVID-19 restrictions. Because of the uncertainty, the program accepted only two applicants: one male and one female, both self-identified as African American. The applicants each come from Title 1 high schools with high minority enrollment (85% at Bioscience High School in S. Phoenix and 62% at Sahuarita High School in S. Tucson). Math was a common subject taught by both teachers, in addition to physics and engineering for one and AP computer science for the other. The teachers also reported some coursework in AI and programming. The entire five weeks of the program were virtual, including lab components.

VI. ORGANIZATIONAL STRUCTURE

Although the COVID-19 pandemic prevented in person interaction during this first year of the program, the nature of the research projects assigned to the teachers made it easy to accommodate for virtual learning. Before the start of the program, a course was established in the university's LMS to house all materials, such as training modules, resources, templates, and assignments. An initial two-day 'boot camp' training was provided, where teachers completed hands-on training on signal processing (SP) and machine learning. Other seminars included: a) lab safety, b) intro to sensors, c) SP and data filters, d) hands on ML computing, e) curriculum development, f) crosscutting topics on social aspects of AI deployment, and g) research poster and report preparation. An overview of the virtual RET program is shown in Table 1.

Table 1. RET in ML Schedule Overview.

Week	Topics
1	Orientation, safety, intro to research
2	Python for ML, research abstract writing
3	Python ML for solar data, ML seminar
4	Curriculum development, research posters
5	Lesson presentation, Python for ML & energy

Each of the RET participants developed an instructional lesson plan based on concepts from their research experience and aligned with state and national standards. The teachers were provided an Instructional Lesson Plan Template to write the instructional unit. The template included components required for submission to TeachEngineering.org and alignment with K-12 State Standards, Next Generation Science Standards (NGSS), and International Technology and Engineering Educators Association (ITEEA) Standards. After implementation into the classroom, the lesson plans were posted on our RET web site.

VII. ASSESSMENT

A mixed methods approach was utilized to assess the program using both formative and summative assessment protocol. Formative assessment included survey questions asking participants to provide recommendations for improvement during the program. Summative assessment included surveys, observations of teacher presentations, and interviews. Retrospective pre-test items were used to assess the extent to which the RET participants felt prepared to deliver engineering content to their students. Specifically, they were asked to rate their preparedness "prior" to their participation and "presently" at the end of the summer program. As shown in Fig. 4, both RET participants felt "mostly" or "completely" prepared to accomplish all tasks.

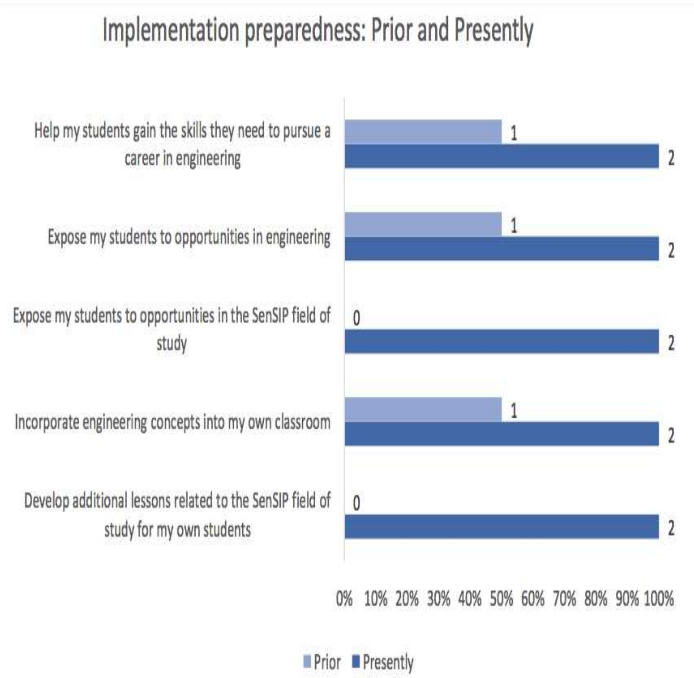


Fig. 4. Evaluation of ability of RET participants to deliver materials before and after the 2020 program.

Surveys and interview data confirmed that the educational programming for the RET participants was implemented as intended, despite the abrupt transition to a virtual learning environment. Results from the summative evaluation demonstrated that, overall, the RET program positively impacted knowledge and skills, as directly reported by RETs and they have already begun sharing the knowledge and skills they've learned with other teacher colleagues and administrators in their schools.

Additional details, statistics and qualitative assessments were provided in the CREST evaluation report [27].

VIII. RET WORK IN PROGRESS

The RET project continues in 2021 and activities will expand to include several ML applications that go beyond energy. Unless pandemic conditions improve drastically, we anticipate that the program will be virtual in the summer of 2021. The program will recruit seven high school teachers and two community college instructors as RET participants. The five-week program will start beginning of June 2021. Research projects that will be available for teachers include: a) COVID-19 detection via audio samples and ML [29-30], b) Pruned neural networks for power optimization, c) breathing sensors and metabolism estimates, d) machine learning for audio recognition, e) COVID-19 hotspot detection, f) Sensors and ML for activity detection, and g) Quantum computing and ML [31-33]. The program will be run in parallel with an REU program and synergies will be leveraged. We anticipate teams of teachers and students addressing research problems. Bootcamp training in sensors and ML will include usage of Google notebooks and other tools. In addition, the program will include opportunities for RET participants to present their research to faculty, industry engineers, and the public. Cross-cutting training sessions in ethics, policy and standards will be offered. In addition, all participants will again develop lesson plans based on assigned research project.

The evaluation team will work with project faculty to ensure that program components are implemented. Evaluation will extend into 2022 when teachers will implement lesson plans in their classes. Regular feedback loops throughout the delivery of activities will monitor implementation, address challenges, and modify program components as needed to meet the grant requirements.

IX. CONCLUSION

This work in progress paper discusses the first year of an RET program in ML. Projects, training and assessment have been presented for the summer 2020 experience, which occurred during the pandemic. Evaluations were presented for the program that engaged two teachers. Key outcomes and findings from 2020 included: a) ML training modules with software were carried in HS classes, b) both teachers learned ML basics and were able to transition their research into lesson plans, c) lessons were implemented and delivered to HS students and evaluations are detailed in [27]. In addition, both teachers produced research results which they presented in seminar and workshop meetings to industry, faculty and students. These presentations were also assessed by the evaluator. Finally, the technical collaboration with REU and IRES programs with similar ML research focus enriched the RET experience with relevant seminars and important research results. Work in progress will implement and assess the RET program for summer 2021, which will engage nine instructors. The program in 2021 will expand to several application areas beyond energy, including sensors and ML for health diagnostics, quantum machine learning, neural networks and imaging for bycatch systems, sensors and ML for COVID-19 detection, and surveillance applications. These projects will run in parallel with our summer REU and IRES projects. The program in 2021 is planned to be mostly virtual and results and assessments from 2021 will be presented at the conference. Details including reports and presentations on our RET program can be found on a dedicated web site [28].

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