NSF-CAREER: Translation of Machine Learning and Additive Manufacturing to Accelerate and Diversify Science and Engineering

Radio-frequency (RF) phased-array systems optimized with machine learning have become powerful tools in science and engineering. Recent progress in phased-array radar development has applications in particle astrophysics [**?**, **?**, **?**, **?**], polar research [**?**, **?**], and 5G mobile communications [**?**]. Phased-arrays are comprised of RF antennas working in tandem to boost received signal sensitivity, and to actively scan transmitted signals without moving parts. There are at least two barriers that impede phased-arrays from enhancing future science and engineering projects on a wide scale. First, the computational electromagnetism (CEM) properties of RF systems are designed with expensive, proprietary software that does not interface with open-source machine learning tools [**?**]. Second, RF systems are manufactured using costly and time-consuming traditional machining techniques. Ongoing scientific and engineering efforts can be enhanced by a solution that allows machine learning optimzation to flourish, reduces design and manufacturing costs, and diversifies participation by reducing financial barriers. Undergraduate education at Whittier College will be enhanced with CEM, machine learning, and 3D printing, as research and educational opportunities will be integrated into the curriculum.

We propose to create an open-source CEM and additive manufacturing ecosystem capable of 3D-printing phased arrays with conductive filament [**?**, **?**, **?**]. We have already demonstrated that open-source CEM tools used in photonics can drive the RF phased-array design process [**?**, **?**, **?**]. This research will support diverse, ongoing efforts ranging from IceCube Gen2 (radio), Center for Remote Sensing and Systems (CReSIS) missions, and Office of Naval Research (ONR) radar projects. One application in particle astrophysics is the Askaryan Radio Array (ARA), in which phased arrays have increased sensitivity to ultra high-energy neutrino (UHE-ν) interactions in the ice sheet beneath the South Pole [**?**]. The arrays are vertically polarized, due to mechanical constraints within the ice. Our research could provide a *horizontally polarized* design that overcomes the mechanical constraints through machine learning, boosting the chances of making the first UHE-ν observations in history [**?**]. This research will *accelerate* and *diversify* research in UHE-ν, climate science, and RF engineering by *translating* successes in CEM and materials research. This work will be integrated into our curriculum and research programming at Whittier College, a Title-V Hispanic Serving Institution (HSI). By providing research and educational opportunities to a diverse undergraduate population, we will help diversify the STEM workforce.

Whittier College has a proud tradition of providing access to higher education to Spanish-speaking and traditionally under-represented students, and we are a the only HSI member of the IceCube Gen2 collaboration. People of color and first-generation students make up 63% and 29% of our student body, respectively. Internal assessment studies indicate that students of color . We have learned from workshops hosted by the Cottrell Scholars Network that emphasizing student dignity and self-efficacy can increase the performance of diverse undergraduates in our courses [**?**, **?**]. Emphasis in these areas makes students feel they *belong* in our courses, despite encountering adversity. In keeping with the theme of *translation*, and in order to emphasize the dignity of our students no matter their background, we seek to create a bilingual (Spanish and English) mobile application (app) that introduces STEM concepts within a welcoming digital environment.

Our app will adapt to individuals using machine learning techniques. There is precedent for such an app in the DuoLingo method for language and mathematics [**?**]. We seek to provide data insights about student learning to instructors through the app, which should lead to more efficient and customized classroom instruction. A prototype application is being built by Whittier College undergraduates. The creation and implementation of this program represents an opportunity for Whittier College students to enhance the learning experience for their peers while gaining valuable coding and machine learning experience. In addition to algorithms presented within the Duolingo method, the educational data mining (EDM) literature provides examples of apps that boost engagement and success in introductory STEM courses [**?**, **?**, **?**, **?**].

Members of our community have shared that translating mathematics and physics exercises into Spanish aids in solving them. Our application will boost their skills and build confidence by offering them engaging, game-like physics training in the language of their choice. Finally, we propose to create a bilingual physics lecture series and recruitment events designed to welcome broader community members into the Whittier College research environment.