Empowering First-Generation and Diverse Undergraduate Researchers in 3D-Printed RF Design for Communications, Defense, and Aerospace

Engineering Research Fellowships and Peer-Learning at Whittier College

Whittier College, Home to Diverse and Talented Students: Whittier College is a 4-year liberal arts institution located in Whittier, California. We provide access to higher education to under-served populations of Southern California, including communities like East Los Angeles. Whittier College is also home to a broad range of students from across the country, and international students. According to our institutional research, fully 70% of our study body are people of color, and 40% are classified as first-generation students. Established in 1887, we have built a proud tradition of elevating these students through higher education to professional success. Recognized for excellence in this area, Whittier College has been designated as a Title V Hispanic Serving Institution (HSI) under the Higher Education Act.

Our institutional research shows the diverse nature of our endeavors in STEM education. We host 15 majors in our 3-2 Engineering Program per year (five-year average), with 50% of those students identifying as first-generation and 77.5% identifying as people of color. Our 3-2 engineering program has physics, chemistry, and mathematics tracks, and students complete the final two years at the University of Southern California. Our Integrated Computer Science program also has tracks in physics, mathematics, and economics, and is one of the fastest growing majors on campus. Starting with just two majors in 2018, the program has grown to 32 majors in 2021, with 33% of the students identifying as first-generation and 76% identifying as people of color. Finally, our Physics program is home to 19 majors per year (five-year average), with 35% of those students identifying as first-generation and 63% identifying as people of color. Research fellowships granted to our STEM students in the areas of engineering and technology will directly contribute to the diversification of STEM disciplines.

Research Goals and Proposed Fellowships: Recent developments in additive manufacturing have unlocked the potential for undergraduate student researchers to develop radio-frequency (RF) antenna designs for radar, aerospace, telecommunications, and physics research. Traditionally, the design and fabrication of RF antennas has been limited by two factors. First, the design and simulation of RF elements is usually accomplished using expensive, proprietary software. Second, the fabrication of complex prototypes is limited by the ability to machine conductive structures with lengths on the order of 1 cm – 10 cm efficiently on a mass scale. Prof. Jordan Hanson in the Dept. of Physics and Astronomy at Whittier College has developed a process by which novel RF designs can be created and fabricated, solving both problems simultaneously.

Using open-source software, computer-assisted design (CAD) visualization tools, and 3D printing, RF antennas for diverse applications can be produced by students at low cost. This creates a strong educational potential for first-generation and diverse undergraduate students in Southern California to develop valuable engineering skills applicable to firms in the region. Through the work of Prof. Hanson, Whittier has collaborated with the Office of Naval Research (ONR, https://www.onr.navy.mil) in the area of RF design. The College is also a participating institution in The IceCube Collaboration (https://icecube.wisc.edu), which will incorporate novel RF designs on a mass scale in Antarctic field research. Our Integrated Computer Science and 3-2 Engineering Programs are home to diverse and first-generation students ready for hands-on learning experiences designed to prepare them for future careers in technological sectors.

Our program will finance year-long research fellowships made available to first-generation and diverse STEM students. We will begin with Python coding boot-camps that introduce students to open-source computational electromagnetism (CEM). CEM is used to predict the performance of RF and microwave systems, given the geometry and initial conditions. Our students have already received funding in this area from The Fletcher-Jones Foundation and ONR. Experienced students will be recruited to help guide first-year participants in a small group setting, building a culture of progress through peer-to-peer learning. This is tried-and-true approach that has worked in our STEM courses, in which students work together on design problems in class. Participants will utilize our in-house high-performance computing resources, which have already been acquired. As the students' coding skills progress, we will begin exploring standard RF antenna designs. Once the students master simple antenna shapes, with well-understood properties, the students will begin to incorporate machine learning techniques into the design phase. We will optimize designs for application-specific needs for IceCube Gen2 and ONR.

Using newly developed conductive 3D printing filament (https://www.multi3dllc.com), student groups will print RF elements to form phased arrays in the [1-10] GHz bandwidth. Using standard microwave test equipment shared with our laboratories by ONR, we will verify the operation of our end products. The students will gain hands-on engineering experience by learning to construct a laboratory setup that radiates RF signals from a transmitting antenna and detects them with a receiving antenna. Learning to operate RF test bench equipment is a valuable skill for an undergraduate resume. Once positive results are confirmed, the students will share their results in two ways: writing results for peer-reviewed publication, and incorporation of their findings into Whittier College STEM curricula. Professor Hanson teaches several courses ideal for research integration into the course curricula. Future Whittier College students will therefore be inspired by our progress, thereby facilitating future recruitment into the program.

<u>Curricular Integration through Peer-Learning:</u> Professor Hanson teaches the following four courses ripe for research integration: Electromagnetic Theory, Digital Signal Processing, Calculus-Based Physics II (Electromagnetism), and Algebra-Based Physics B (Electricity, Magnetism, and Modern Physics). Future Whittier STEM students, who are increasingly first-generation and diverse, will benefit from hands-on demonstrations and activities designed to ground course curricula in a real-word application. Real-world applications are important because they enhance the concepts for students who are being exposed to the underlying mathematics and physics for the first time. Further, studies show that activities centered on peer-to-peer learning produce strong benefits to students in STEM courses relative to only receiving instruction from a professor. For example, consult *Peer Instruction: A User's Manual* by Eric Mazur (Prentice Hall, 1997).

One straightforward curricular integration is for students to present results to our Electromagnetic Theory course, PHYS330. This is a standard upper-division physics course taken by most engineering and physics majors at most colleges in the United States. The educational impact of this course is limited by the fraction of students who can grasp the concepts from vector calculus used to describe electromagnetic fields. Modules based on real RF systems backed by CEM modeling would served to demonstrate electromagnetic theory in practice. CEM modeling provides computational insight into electromagnetic systems too complex to analyze mathematically. Further, encountering these projects through peers will add value to the course.

Another course that will benefit from research integration is Digital Signal Processing (DSP). Recent versions of this course have used audio engineering and electronic music as media for applications of digital signal processing concepts. In DSP, signal waves are broken into components and the components are analyzed individually before being reassembled. For example, a signal component could be the amount of power in the total signal at a single frequency. Radio waves are no different from other waves in this regard, for they can be decomposed into signal components. Waveforms measured with our newly 3D-printed RF antennas could be digitized with existing lab equipment (such as our oscilloscopes) and incorporated into a hands-on analysis activity. Students in DSP would analyze the radio signals and draw connections between the antenna geometry and received signal properties.

In our introductory electromagnetism courses, we are tasked with covering content ranging from basic principles about electric charge, all the way to electromagnetic fields. It can be a daunting challenge for a typical student, who may not be a major in physics or engineering. However, as these courses draw to a close (typically in the Spring semester), we encounter Maxwell's Equations that describe electromagnetic radiation. Rather than cover the theory with what time remains and hope the students retain the material, student researchers who designed our custom RF antennas could present Maxwell's Equations from a conceptual standpoint. A live demonstration with transmitters and receivers would solidify the concept of radiation for the introductory students, and replace what has been a purely theoretical module.

Details of Student Participation

Research Fellowships: We envision 5-10 undergraduate fellows working on the long term fellowship component. These dedicated students will be drawn from our diverse group of undergraduate STEM majors, concentrating on 3-2 Engineering, ICS/Physics, ICS/Math, and Physics. Beginning in Fall 2022, the group would work 10 hours per week building the necessary coding experience to produce designs. In Spring 2023, we envision this same group moving up to the optimization level and printing elementary versions of their designs using the 3D printer. For Summer 2023, each group member will receive a summer stipend to participate in 3D fabrication of the optimized designs.

Research Integration into Course Curricula: The research fellows will conduct the peer-led activities and demonstrations for the introductory and advanced courses. The introductory courses typically involve 30 students per semester, and the advanced courses typically involve 15 students per semester. These numbers only account for the courses taught by Prof. Hanson, and could grow as we develop on-campus partnerships with other instructors in computer science and mathematics.