Professional Evaluation and Growth Plan

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Chapter 1

Introduction

1.1 Beginning

Friends,

I have compiled a report on my progress as a liberal arts educator in the Department of Physics and Astronomy for the period of 2019 through 2021. The following is a reflection on the development of my educational and scholarly practices, and the service I have performed for the College as a mentor, advisor, and committee member. I strive to perfect my teaching abilities, and I am pleased to report that my students are learning and growing. In our last communication, after my supplemental PEGP from 2019, you concurred that my practices are serving the students well, and that meant a great deal to me. One note that stood out was a request to enrich my teaching philosphy by reflecting on how it serves the liberal arts. The given example was about the utility of physics to non-STEM students. I have put a lot of thought into this enrichment, I have progress to share with you.

I have included in my teaching philosphy (Sec. 2.1) my vision for the intersection of broader liberal arts education with physics, mathematics, computer science, and engineering, as I teach all of these. Further, I have created and taught new liberal arts courses in the *Connections 2* and *Culture 3* categories, as well as a College Writing Seminar on scientific and technical writing. I used these courses to show my students how physics, mathematics, and engineering intersect with the history of our ancestors and how we all use scientific modes of thought to thrive. In my College Writing Seminar, we sharpened the skills of conciseness, precision and clarity, and organization in writing. Though these skills apply to physics, they are useful in all writing in which abstract or difficult ideas are communicated.

At a PEGP workshop, a colleague emphasized weaving a narrative about who we are. I have shared my academic origins, and my vision for multi-disciplinary teaching and scholarship at Whittier College (Sec. 1.1.1). I have also written about my family and working during the pandemic (Sec. 1.1.2). I hope these sections provide you with helpful insight about our family and how we hope to serve Whittier College. We thank the FPC in advance for what is sure to be a difficult year of service. We also express our gratitude for allowing us to postpone the PEGP for one year. This helped my family avoid a difficult situation. My spouse is considered an essential worker, and was called back after a shortened maternity leave. I have been working as a full-time professor and a full-time parent *by myself* each day since that happened. Thankfully, my *suegra* (mother-in-law) has stepped in to help after we got vaccinated. I look forward to seeing you this Fall, and from our family to yours, we hope you are well.

Sincerely, Prof. Jordan C. Hanson

1.1.1 Academic Origins

We all share a common theme as professors, in that we encounter ideas that inspire us in college and graduate school. When I was an undergraduate at Yale University, my family was nudging me towards engineering. My curiousity, however, kept returning me to physics courses. In my heart, I knew that I wanted to offer fresh discoveries about the Universe to people, and I fell in love with enlightening others. I learned that the laws of physics morph and merge into one another as the energy of matter increases to relativistic scales where particles move near the speed of light. I also learned that deep from within the Universe originates a mysterious flux of sub-atomic particles ten thousand times more energetic than any human has ever created: *the cosmic rays*. The physics that explains their origin has remained unknown for a over a century, and it could reveal new fundamental laws of Nature. I applied for graduate school in the hopes of one day becoming a professor of physics.

The University of California at Irvine (UCI) is a pioneering institution in the field of cosmic-ray research. In particular, my colleagues at UCI began focusing on the study of cosmic ray *neutrinos*, also known as ultra-high energy neutrinos (UHE-ν), beginning with the Radio Ice Cherenkov Experiment (RICE) [1] and Antartic Impulsive Transient Antenna (ANITA) [2] collaborations. Neutrinos do not have electric charge, while cosmic rays do. Thus, neutrinos propagate in straight lines through the Universe, while any electromagnetic field would bend the trajectory of cosmic rays. Thus, UHE-ν could reveal the locations of the cosmic ray accelerators, thereby teaching us about fundamental physics unexplored on Earth [3] [4]. UHE-ν observations would, for example, provide insight into quantum mechanics at record-breaking energies [5].

Detection of UHE-ν has been a goal of the physics community for three decades. When UHE-ν have energies above a certain threshold, they create cascades of particles in matter that radiate in the radio-frequency (RF) bandwidth, a process known as the Askaryan effect [6] [7] [8] [9] [10]. The IceCube Collaboration published the observations of extra-solar neutrinos using optical techniques at record-breaking energies [11], and later showed that the flux is strikingly close to theoretical predictions [12] [13]. IceCube analyses have not found UHE-ν events, however, with energy greater than 10^{15} electron-volts [14]. It is above this energy that the UHE-ν could one day reveal the source of cosmic rays and new physics. The authors of [14] conclude that Askaryan-class detectors are the logical next step. My colleagues have decided to upgrade IceCube to include RF detectors in a project known as IceCube Generation 2, or IceCube Gen2 (`https://icecube.wisc.edu/`).

Askaryan-class detectors improve UHE-ν prospects because Askaryan radiation is in the RF bandwidth [15]. UHE-ν must strike some material in the Earth's crust that produces an observable radio pulse. It turns out that radio waves travel ≈ 1 km in *Antarctic ice* [16] [17] [18]. Thus, we can create stations comprised of RF antenna channels, supporting electronics, and solar panels [19], separated by 1 km to cover enormous volumes of ice. This is important because the expected UHE-ν flux is low. When a potential signal arrives, stations are triggered to read out the RF channel data [20]. The overall dataset is then comprised of RF waveforms representing signals from all the stations. The data will be used to reconstruct UHE-ν interactions [21] [22]. This type of detector is called an *in-situ* array. As a graduate student at UCI, I led two Antarctic expeditions to create a prototype *in-situ* array: the Antarctic Ross Ice Shelf Antenna Neutrino Array (ARIANNA).

We would leave Los Angeles International airport, and land in Auckland, New Zealand. After collecting our gear, we transferred to the local airline to fly to Christchurch, on the southern island of New Zealand. Usually there would be a week of down time in a bed and breakfast, while we waited for the weather in the Southern Ocean to clear. We would equip our cold weather gear, tinker with our equipment, and read. At the right moment, we filed on to an Army C-17 cargo plane that had both wheels and skiis for landing gear. After a five-hour flight, we would land on the frozen ocean near Ross Island, not far from the berth of the original Antarctic explorers. A truck brought us in to McMurdo Station, the home of the United States Antarctic Program (USAP). There we would receive safety training and logistics to prepare for our expedition into the field. A helicopter would transport us to ARIANNA. Our gear, which arrived by boat in New Zealand, and then by plane to McMurdo, followed us in a separate helicopter.

We began by measuring the ice shelf thickness and radio transparency in Moore's Bay, Ross Ice Shelf, Antactica [23]. We deployed prototype ARIANNA stations in two separate missions. I designed systems that managed station power consumption and recorded environmental data [19] [24]. We demonstrated with computer simulations that a 30 x 30 array would reach target UHE-ν sensitivity. Further, the sensitivity doubled in Moore's Bay through *reflected* events, in which signals reflect from the ocean beneath the ice shelf. We completed the seven-station prototype array, and published upper limits on the UHE-ν flux [25]. We also observed cosmic rays [26] (though we cannot determine their original direction), and completed a second UHE-ν search [27]. UHE-ν

interact more rarely in dense matter, and thus the visible flux is lower than that of cosmic rays. With much larger number of stations in IceCube Gen2, we hope to capture the precious UHE-ν signals.

As a post-doctoral fellow at the University of Kansas, I published the first complete analysis of the ice in Moore's Bay [16]. This research was an intersection of glaciology and physics, for we need to understand our detector and our detector is an ice shelf. I also published the first complete calibration of the ARIANNA RF chain [28]. Using the results, we showed simulations of our detector accurately modeled Askaryan signal strength. We created UHE-ν signal *template waveforms* that account for both the theoretical Askaryan signal and the aforementioned calibration. These templates now serve as the primary UHE-ν search criterion when cross-correlated with data collected in Antarctica [25] [27]. As a CCAPP Fellow at The Ohio State University[1], I improved upon the templates by developing a new analytic theory of Askaryan pulses [15].

Once I joined Whittier College, I turned my attention to the complex path taken by Askaryan pulses through Antarctic ice. The path is curved because the speed depends on the ice density, which changes with depth. An undergraduate student and I worked out solutions for the ray-path of the signals through ice given the density profile [29]. These calculations became a central component of our current software that we use to predict detector sensitivity to UHE-ν [30] [31]. Meanwhile, another student and I designed firmware upgrades to auto-calibrate the RF channel thresholds and presented the results at SCCUR, twice [32] [33]. These tools facilitate expansion and automation of our detector. The pandemic has prevented deployment of these upgrades in ARIANNA, but they will be incorporated in IceCube Gen2. For both projects, I included undergraduate students. The first was a young lady who went on to become a physics researcher for the LIGO project (gravity waves). The second was a student of color and Whittier native who majored in ICS/Math, and who is applying to graduate schools for engineering and machine learning.

I recently returned to the theory of Askaryan radiation, and have begun to study computational electromagnetism (CEM). For the first time, I have created an analytic time-domain model of Askaryan radiation [34]. We are happy to report that the work will be published in Physical Review D, and that it will be incorporated into IceCube Gen2 software. This achievement was made possible by a collaboration with a wonderful undergraduate student who has become a good friend over the past two years amid the pandemic. I describe the importance of this result in Sec. 3. Regarding CEM, I have won two Summer Faculty Research Fellowships with the Office of Naval Research (ONR), in which we apply CEM to radar design. This is an example of the liberal arts mindset in action: I was able to identify a connection between two seemingly unconnected fields, and form a mutually beneficial partnership.

Using CEM, my student and I have created a 3D printed radar design [35]. Knowing that Whittier College cannot afford to subscribe to every IEEE engineering journal, I selected an open-access journal named Electronics Journal so that our students have access to the research. I view choices like these as part of our mission to foster equity and inclusion. Our paper won Top 10 Most Notable Papers in the Electronics Journal for 2020-21 (see Sec. 3). Recently, my colleagues at the naval laboratory fabricated the 3D printed design, and they have provided powerful lab equipment to Whittier College for testing it. It is worth mentioning that this equipment is prohibitively expensive, and thus our partnership with my naval colleagues is opening new doors scientifically. If we succeed, this research has applications to UHE-ν physics (by creating new and better antennas), 5G communication, and radar applications. I describe in Sec. 3 my vision for a partnership with the Navy, and how this will benefit our students.

Finally, I would like to share with you my recent venture into the Whittier Scholars Program (WSP). A student heard of my scholarship regarding Antarctica, and sat down in my office one afternoon. He showed me photographs of glaciers he had taken while visiting family in Norway, and said that he'd like to perform a comparative photographic analysis with historical photos of glaciers all over the world, in order to assess the loss of ice due to global warming. We lept into a partnership that sent him to Norway, Iceland, Alaska, and the National Outdoor Leadership School (NOLS). He began by taking one of my new *Connections 2* courses about the history and current status of science in Antarctica. The research was at the intersection of glaciology, physics, climate science, and environmental social justice.

The work came together as my student gained experience living in the field. I did everything in my power to add him to one of my Antarctic expeditions. Alas, that particular mission was cancelled due to budget cuts and the pandemic. We had hoped to include photos of the glaciers near ARIANNA. These are the same glaciers passed by

[1] Center for Cosmology and Astro-Particle Physics

Robert Falcon Scott and Roald Amundsen as they raced for the discovery of the South Pole. I have been there twice and taken photos, but there were no similar photos to which we could compare. I helpd my student gain admission to the WSP, and our final project gave a holistic view of the environmental, agricultural, and cultural impact of glaciers around the world. My student, who graduated this Spring, told me that he is beginning a book with colleagues he met in Iceland, and that this book will feature our work. I enjoyed the project so much I have decided to help support WSP by serving on the WSP Advisory Board. My offer was accepted and I will begin this semester. Thus, I have come full circle regarding the FPC invitation to serve in the liberal arts. I will share more on this in Sec. 5.

1.1.2 My Family, East Los Angeles, and COVID-19

When I first came to Whittier, I lived down the street on Bright Avenue. I had met a wonderful young woman and we fell in love. In the summer of 2019 we married, and I moved to East Los Angeles to live with her family. My wife's family is quite extraordinary. Her family is originally from Jalisco, Mexico. The family immigrated to Los Angeles, and dealt with gangs and poverty where they originally lived. My wife and all six of her siblings worked hard in school and went to college. We strongly value higher education in our family. My wife and I share our Catholic faith, and we care about our children's education.

Even before I met my spouse, I knew that becoming fluent in Spanish would be helpful living in Whittier. I already spoke a little, and in my first year joining the Whittier community I decided to formalize my Spanish skill by taking Spanish 120. Prof. Doreen O'Conner-Gómez was kind enough to let me audit her course that Fall. She remarked that this was the first time she had seen a STEM professor audit a language course. It turned out to be wonderfully necessary in my family, because our older generation usually does not speak English at home. Our family as a whole is highly diverse, with Mexican, Romanian, American, and Filipino roots. Given the dark and divisive trends that have arisen within our broader culture, and as a Christian and someone who considers himself a loving person, I felt a genuine desire to share this with you.

In my first years as part of the Whittier community, I recognized the same diversity in the families of my students. Many of our students speak Spanish at home with their parents, but English at school. There have been times when I have helped the mother or guardian of a student navigate campus by speaking Spanish, and it has made them more comfortable. As part of a statistics course I taught for the Whittier Summer Session II (2020), I was gathering data from the Whittier College Factbook. It reveals two important numbers about our students. About seventy percent of our students are students of color, and about forty percent are first-generation. My spouse and every single one of her siblings are all first-generation students. Back when we were teaching in person, sometimes colleagues would explain to me over lunch about "the first-generation experience," assuming that the white male physicist was new to the concept. I would always smile inwardly, since my entire family has shared this experience with me.

Given these experiences, I am keenly aware of the importance of our curricular theme of *belonging.* Despite the challenges brought upon Whittier by the pandemic, I have put effort into making that theme a reality. I socialize on Zoom with my first-year advisees and research students in order to make them all feel that they belong. I ensure that I account for equity and inclusion in each decision I make. One stark example was when a student in my section of INTD100 connected to class via Zoom *while at work in CostCo.* I learned to arrange my schedule to account for students' jobs, knowing that many were supporting themselves and loved ones. Being inflexible would have made class accessible only for the wealthy students. Regarding belonging, I am often reminded of a basic fact: *even though my heritage is different from my family and my community, they have accepted me as one of their own.* In the Gospels, we find the Golden Rule to treat others as we would like to be treated. I am called therefore to ensure the students feel that they belong.

Inspiration for New Courses

Inspired by my family, and the theme of belonging, I have created two new courses that serve our current liberal arts curriculum. One is entitled *A History of Science in Latin America,* which was assigned a *Culture 3* and *Connections 2* designation. I could tell there was a hunger for this course. Our students needed to see that *all* of our ancestors performed science. One aspect of that course was the ideas of *central* and *peripheral* scientific communities. Taking STEM courses alone might lead a student to believe that European and American cities have been central to scientific progress, and that Latin American communities have been *peripheral.* Peripheral, in this sense, refers to a community that merely adopts discoveries from the central ones and rarely produces progress. By honestly covering the colonial period in Latin America, we found examples in which Latin American communities were *central* and their European counterparts were *peripheral.* A more accurate description of scientific progress for Latin America and Europe would be a full two-way exchange of knowledge (Sec. 2). I invited colleagues from the Wardman Library to introduce my students to digital storytelling. The students used this skill to create final projects that wove together their cultural heritage, history, mathematics, and scientific discovery.

The second liberal arts course I have created was inspired by the theme of belonging, and my research. It is called *Safe Return Doubtful: History and Current Status of Modern Science in Antarctica.* At first glance, the connection between themes like inclusion and belonging and Antarctica is not obvious. This course is a metaphor for self-exploration. We address three main areas, interwoven throughout the semester. First, we address the history of the race to discover the South Pole in the early 20th century. Second, we cover current scientific endeavors in Antarctica. Third, we perform weekly journal activities that invite the students to look inside themselves and to discover their potential for exploration. The connection to inclusion and belonging emerges as we learn that the winner of the race for the South Pole was a person who took indigenous science seriously. This was the same captain who completed the Northwest Passage, before trying the South Pole. I share the rest of the story in Sec. 2. Thus the course connects inclusion and belonging to survival and exploration. The students learn through history, science, and self-reflection that their survival in new areas of life will be enhanced if they are willing to learn from those different from themselves.

Keeping a Sense of Humor under Quarantine

My fellow tenure-track colleagues and I sometimes discuss if it's appropriate to add a "COVID-19 Impact Statement" to our PEGP. At first I thought, no, just stick to the formal stuff. Keep it short. But I also thought it would be a laugh. So here goes. For those with a sense of humor, this next section is for you.

For those without a sense of humor, I have to ask, like, how are you still here? After we duct-taped together a way to teach our students online in spring 2020, we watched the world lose its freaking mind that summer[2]. Then, the module system, for *a year.* But hooray! The vaccines arrived. Funny thing about vaccines, though, is that you have to go *get them.* Ugh, who has time, right? Seriously, a few people in my family flatly refuse. Here's a fun exercise: try teaching a science course on Zoom and hearing your phone buzzing from an argument about how *the scientists are wrong* in Spanish. Focus, focus ... *just get the blasted shot already* ... "Ok students, let's talk about ... friction! Am I right?" Ay yay yay.

Teaching students remotely was like watching those YouTube channels where people crash into stuff. What I mean is, students would log in to class while driving. Had to make a rule against that. Everyone survived, but ... wow. I thought one of my students was driving on the wrong side of the road while Zooming, but it's ok, he was in India. Another rule I had to make for class: wear clothes. I don't wanna see that. This is a family establishment. After 2.1 seconds of research, I found the Zoom button to have the camera off by default.

My spouse always says that she has the worst luck. I always reassure her: "Have faith honey. We'll be alright." After years of searching, we find each other, marry, and then BAM. Pandemic. Whoops. Our daughter was born right in the exact middle (like, literally within the error of the mean) of the first wave of COVID-19. Whyyyy. The nurses weren't going to let me in the hospital. For the birth of my child. What. Actually they weren't really that keen on letting my wife in either. *Just hang out in the parking garage*, they told my wife, *who was in labor.* After the required amount of suffering took place, they let us come inside to give birth.

Sometimes I had to fight for my students. We made sure to purchase enough bandwidth from Spectrum, but sometimes it still felt choppy. After running some checks, I realized I needed to call Spectrum. They told me, "What do you expect? It's slow all over the city." I got all idealistic: "This is about access to education! For first-generation students no less!" They finally sent a techician, who came to our door holding small metal piece. "Did you know there was a 3 dB attenuator in your coaxial line?" I half-choked on my coffee. I knew that the ONLY JOB of this component is to cut signal power by a factor of two. Whyyyyy. So we removed the Education Blocking Device, and the signal was greatly improved.

Working from home during summer 2020 did make it easier to care for our daughter. We were quarantined, but I managed to convince the ONR that we could perform the research project remotely. My spouse is a dentist, and

[2]After watching *I Am Not Your Negro*, directed by Raoul Peck, and reading *Notes of a Native Son* by James Baldwin, maybe it's more apt to say that we should have lost our minds sooner. I ended up making a chapter of Notes of A Native Son the summer reading assignment for my College Writing Seminar.

the state provided maternity leave. For added spice, they took it away, though, after 12 weeks. Right at the beginning of Fall semester. No vaccines were available yet, so I had to just teach and parent alone. The upside is that I got to spend more time with the baby. My spouse bravely went back to work to help pay her student loans. She treats patients who are supposed to test negative for COVID-19, but the positives sneak past the guard. So basically The Hunger Games for dentists, who tend to be around a lot of, you know, mouths and throats.

Here's another fun exercise: try teaching college-level physics with a six-month-old pooping in your lap. Keep composure. Another one: the baby is napping in her seat, and all is quiet and ready for class. My chihuahua looks at me like he wants to bark at the dogs outside. *Don't you do it, Lobo! I swear...* Does it anyways. So I trained him not to bark, but my neighbors responded by buying a rooster. They. Bought. A. Rooster. In the city. Not chickens! Chickens I would understand for the eggs. We love eggs. Fun fact about cities: they sell alarm clocks. Quirky thing about roosters: they don't have a snooze. This particular rooster was peculiar though, because it would crow twice. Once at dawn, and once whenver my baby was napping during class. Bad rooster.

Despite its quirks, the people of East Los Angeles take great pride in maintaining the community. Except on 4th of July. Then we blow it to smithereeens. As far as I can tell, the goal is to trigger as many car alarms as you can. On our block the record is twelve. I mean, why spend your money on "real" fireworks when you can just fill a rice-cooker with black powder? It's easy. Nothing wakes you up from grading math homework from summer session like shrapnel.

Joking aside, my students were wonderfully understanding when I had to teach with the baby on my lap. The same is true for my colleagues in committee meetings. I like to think she brightened people's day a little. A colleague from another institution who gave birth recently lamented to me that it has been *so hard* lately, for she and her husband (both physicists working from home) hadn't had child care in *six whole weeks!* I died a little inside. It had been almost nine months for me flying solo. Once we all got vaccinated, my *suegra* (mother-in-law) who lives next door, started to come each day to help. Que santa, no? (What a saint, no?). My family has supported us, and we are so grateful.

I hope you are all safe and sound. It turns out that some people in my extended family in the Midwest were not so lucky. My cousin's husband, who was a well-loved football coach and mentor to many junior college students, already needed a lung transplant before COVID-19 arrived. He finally got the lung transplant a few years ago and recovered. And then someone gave him the virus, and he's gone now, along with his father. We pray for them each night now. If any of you have lost loved ones, we will pray for them as well. I've had students miss class to go to funerals. Even though we have all suffered, I still believe it's important to keep a smile on. We are still here, and Whittier College needs us. Soon the students will return, and Whittier College will grow and thrive.

Chapter 2

Teaching

In this chapter, I reflect upon my teaching experiences, and analyze the results of course evaluations. I submitted a supplementary PEGP on teaching in Fall 2019. In that report, I included all courses I taught up to January Term, 2019. For this report, I continue from January 2019 through the present. I am excited to share with you many positive student outcomes from a diverse set of courses. In Sec. 2.1, I have followed the FPC recommendation to reflect upon the role of physics courses within the broader liberal arts curriculum. Given the goals of Whittier College, and persistent divisions within our broader culture, I felt called to reflect in Sec. 2.2 on specific ways I put the values of equity and inclusion into practice in my courses.

In my report submitted in Fall 2019, I discussed a variety of physics teaching modules based in Physics Education Research (PER) and traditional styles. In Sec. 2.3, I review and categorize these methods and highlight which ones I use. I also discuss laboratory activities and online modules in Sec. 2.3. In Secs. 2.4 and 2.5, I describe my introductory physics and math courses, and the corresponding evaluations. In Secs. 2.6 and 2.7, I reflect in the same way for advanced courses. Sections 2.8 and 2.9 follow the same pattern, but for my *CON2* and *CUL3* courses. Sections 2.10 and 2.11 contain descriptions and analysis for INTD100, my section of college writing seminar. Finally, in Sec. 2.12 I give my outlook on future teaching.

2.1 Teaching Philosophy: Growth, Order, and Shared Meaning

The past eighteen months have tested us at Whittier College. To ensure the safety of the community, we had to alter the nature of interactions with students. The pandemic has affected all of us in different ways. Some of us caught the virus or cared for loved ones that did, and others have had to work harder than they ever thought possible. I reflected on these experiences in Sec. 1.1.2. However, after reflecting on my experiences *regarding just the teaching*, I realized something startling. My students and I experienced *greater success* in the period from January 2019 through Spring 2021, compared to Fall 2017 through Fall 2018. I have several explanations for why this is the case.

The first set of reasons have to do with the work that FPC asked of me in the past, and I am grateful for the professional candor. There were three basic ideas to implement. First, the pace of my content needed to be adjusted, in order to maximize overall student success. Second, I needed to increase the number of step-by-step example problems, in order to give struggling students a starting point. Third, I needed to include more traditional lecture content in my integrated lecture/laboratory formatted classes. Traditional content is a term used in physics education research (PER) to refer to the classical teaching style in which a new equation is first introduced or derived on the board, then solved in examples and displayed in graphical form. Traditional teaching (TT) modules are compared and contrasted with PER modules. I impemented these ideas, and the course evaluations showed major increases in every category. I provided clear, graphical evidence, and the results were undeniable.

My second group of thoughts about why my courses went more smoothly during the pandemic have to do with the way physics is taught in our department. There are three reasons my department was well-positioned to make the online transition. First, introductory courses are taught using PER modules in our department. We use PER teaching styles that work well in an online or in-person setting. For example, if we build a lesson around a physics simulation integrated within our textbook, the students are running the simulation in the same way at home as they would in person. Second, introductory courses in our department are taught in an integrated lecture/laboratory format. For laboratory activities, we selected a service called Pivot Interactives. The Pivot Interactives website provided video versions of the same laboratory activities we would have done in class. Students still collected data, and still analyzed results. For most of our advanced courses, these same strategies worked, as long as we created asynchronous videos of TT modules[1]. The exceptions were advanced laboratory courses. I will share what I did in that situation in Sec. 2.6.

The third reason our department was well-positioned has to do with open educational resources (OER). Using OER fosters equity and inclusion, flexibility, and is a strategy that should adopted whenever practical. In all of my introductory courses, and some of my advanced courses, the textbook is free and open-access on any platform. When I was a college student, physics texts cost $100 and had to be purchased in person to obtain the right version. I served as faculty speaker at two OER workshops at Wardman Library, where we learned that $\approx 20\%$ of students struggle to buy textbooks[2]. Further, we use online homework administration software in our department. Thus, the students have access to all content via Moodle, the open-access book, and online homework at all times regardless of their financial status. I learned to use free appointment-booking software that automatically synced with my schedule. The goal was to stay as flexible as possible for students who had to work or care for younger siblings. The students responded positively. But teaching physics goes far beyond issues of problem solving, access, or the pandemic. In the next section, I reflect on the deeper place physics holds within the liberal arts worldview.

Physics within the Liberal Arts: Order and Shared Meaning

Philosophical reflection confuses many physicists. It's not *objective* ... not *testable* ... is what we hear. When we must engage in philosophy, even the philosophy of teaching, physicists turn to an old friend: plagiarism[3]. Although I have been reflecting this past year on *order and shared meaning*, the words of my colleague Prof. John Beacom, from the Center for Cosmology and Astro-Particle Physics (CCAPP), already encapsulate how I view the place of physics within higher education.

Lost in Space, by John Beacom, TEDx @ The Ohio State University: `https://youtu.be/d6eMdixkoRI`

When properly locating physics within the liberal arts world, it is customary to begin by stating that the oldest questions humanity has asked are questions of physics. How old is the Universe? How large is it? Of what is it made? However, I do not think this custom serves the moment. From my home in East Los Angeles and knowing the community where I was born, the sense of division, tribalism, and the increase in anti-scientific rhetoric lead me to respond in a different way. Physics has long had a place within the liberal arts worldview because it provides as least two foundational ideas: *order and shared meaning.*

Physicists use the word *order* in several ways, but the sense in which I use it here is illustrated by a simple experiment. Take out your keys. Raise them a short distance above your desk or lap and drop them. How long does it take them to fall? Is it the same time duration if you repeat it? Though you are now doing a physics experiment, the point is not to understand gravity. The point is you are having a personal encounter with physics through experimentation. Your experience is via your observations, which are meaningful to you. Imagine the entire Whittier College faculty was together again in the Shannon Center for the Arts. We are going to do the experiment together, but with two rules: we hold the keys at the height of the chair in front of us, and we let go when someone gives the signal on stage. Without these two rules, we here a cacophony of keys. When agreeing to follow them, we here a uniform burst of sound as the keys drop simultaneously to the floor.

Following simple procedure creates *order* from our individual experiences. The Whittier College faculty is a diverse group of people with different family backgrounds, ethnicities, first languages, and more. Yet the simple experiment allows us to reveal together a piece of order within the Universe. Gravity does not know who is doing the dropping, and the time duration does not depend on the mass or shape of the keys. We accept that we should all get equal answers. As John says in the TEDx talk in the link above: *As soon as you admit there's one law of physics, there could be many.* The Universe is not total chaos, it is ordered. The order carries deep meaning: we can explain the past, control the present, and predict the future together. Our common experience is identical. After more experimentation, we find the results are identical no matter where we are in the Shannon Center Auditorium. It is a *universal experience.*

[1] This was my experience in teaching PHYS330: Electromagnetic Theory, for example.

[2] This study was done on students at another school before the pandemic. According to Wardman Library research, students in focus groups at Whittier College say the same thing qualitatively.

[3] Relax, the jokes are just to keep you awake. Thanks for doing all this reading.

Notice another facet of physics: order gives rise to *shared meaning.* When we learn about gravity by dropping our keys at our desk, and later find out others have the same experience, we develop a shared understanding of the world that bridges whatever divisions we choose to create amongst ourselves. Physics simply *is*, apart from us. Moreover, physics appears to be consistent everywhere and over time. The consistency means that joining the cross-cultural traditions of scientists extending back to the Enlightenment and beyond allows us to build on the shared meaning of our ancestors. Attending even one national meeting of the American Physical Society (APS) shows us that physics is a discipline that attracts people of all faiths, races, cultures, and ethnicities.

In our last communication, FPC asked me to answer a basic question: *Are there things your physics courses offer a major in business, history, or music that other disciplines cannot?* The answers are order and shared meaning. Take the example of a business major, who understands how microeconomics might drive customer behavior in a sector dominated by small businesses dealing with scarce resources. Given simple precepts, microeconomics should predict optimal production and prices. But how is that possible, given that human beings can be irrational? Is there anything *forcing* people to behave predictably? The answer is the forces of physics. Human beings live within an *ordered* Universe that forces us to act if we wish to thrive. Order arises within the economy in the same way that it does in the Universe: many interacting systems all obeying the same rules. Consider the cost of production. What upper limits are there on the production efficiency of a product? These limits are controlled by physics in that it takes finite time and energy to build a product. Thus, a natural order arises.

Are there things my physics courses offer a music major? Yes: shared meaning. Imagine a student of music trying to understand melodic styles cross-culturally, and she finds that music from one side of a continent sounds different from the other side. Do the laws of physics confer shared meaning? Yes, in the sense that *any music is sound, and all humans detect sound in the same way.* If a melody contains more than one note, sound waves of different frequencies combine to form *harmonies.* Though one group of humans might perceive one set of frequencies as harmony, different from that of another, all groups of humans (and animals, for that matter) perceive *the existence of harmony* via the laws of physics. Shared meaning arises because the laws of physics dictate that harmonies are possible, albeit in near infinite variety. I heard a whale researcher remark in a documentary that "singing is older than humans," meaning we should not be surprised that animals sing. If singing is made of sound waves, then I would add that singing is older than *animals.*

Are there things my courses offer a history major? Yes: both order and shared meaning. The example I share here is taken directly from one of my courses, INTD255. The course is entitled *Safe Return Doubtful: History and Current Status of Modern Science in Antarctica.* It turns out the leader who created the expedition that led the first humans to the South Pole in 1911 was also the man who led the first complete expedition through The Northwest Passage above Canada: Roald Amundsen. Amundsen was a Norwegian ship captain reknowned for his tenacity and curiosity. The Northwest Passage required more than one year, because the seas between the tracts of land in Northern Canada freeze. The ship had to be anchored as the seas began to freeze. Once the ship was frozen, the sailors had the winter to explore the area before the Spring thaw.

During that time, they encountered the *Netsilik* tribe, who greeted them like old friends despite the fact that they had never seen white men before. The Norwegians realized the Netsilik were partners in survival against the harsh northern climate. Amundsen paid attention to how the Netsilik used physics: by melting snow and pouring the hot water onto the bottom of the runners of their dogsleds, they lowered the coefficient of friction between the runners and the snow. The laws of physics (order) are the same for the Netsilik and the Norwegians, so the Netsilik sleds took less work to pull. By understanding this physics together, the Norwegians and Netsilik developed shared meaning. Amundsen later used this trick to upgrade his sleds in Antarctica, and his dogs pulled the sleds faster. His group won the "race" to the South Pole, beating their English competitors by several weeks. This example of shared meaning, order, the laws of physics, and history is one of many I share with my students.

Concluding Remarks about Teaching Philosophy

If physics provides a sense of order and shared meaning to liberal arts students, *teaching physics* is about the growth of the students towards mastering and applying the order, and identifying and applying the shared meaning. Success is measured by the varying degree to which the student can retain, understand, and apply the concepts. The goal of the professor is to formulate the order of physics into specific equations, testing them through experimentation, and to cause the students to master the equations through problem-solving. The student usually encounters confusion, then the ability to solve specific examples. Finally, the professor leads the students to shared meaning by showing them how the concepts apply *in general* to other disciplines.

Teaching physics begins by defining the specific "system" under study, with measurable properties like displacement, velocity, acceleration, mass, and charge. *Classical physics* is a description of the motions, forces and energies that govern all systems. With the addition of temperature and heat, *thermodynamics* may be added to classical physics. Students who do not major in physics usually encounter just classical physics. Physics *majors* progress to *modern physics*, which adds the subjects of relativity and quantum mechanics to the toolkit. We often distinguish between *physics majors* and *non-majors*, who encounter different types of material. The bulk of PER is done in the context of serving non-majors, and thus the named modules (PI, TT, JITT, and PhET) are usually applied to introductory courses.

Quality physics instruction involves using the modules to impart basic concepts to the students and grow their successes from the building blocks. The instructor must be able to build the system of classical physics in students' minds, and then be able to lead students to more advanced applications. At each phase, the instructor must be able to guide laboratory experimentation, while at the same time demonstrating how physics formulas are used to solve problems. Upon examining my teaching, I have found the correct "solution" for our classical and introductory physics courses to be keeping the pace of the modules under control, including more concrete examples, and increasing the proportion of traditional lecture content. I will discuss how the module system affected this plan in Secs. 2.4 and 2.6.

In my advanced courses, a similar approach has led to good results. I have taught an advanced theoretical physics course, a cross-listed physics and computer science course with equal emphasis on lecture and laboratory activities, and an engineering course involving the mathematics of signals. I employ the same active learning modules in these courses as I do in introductory courses, but scale back the PER modules and increase the TT ones. The pandemic restricted my ability to provide laboratory activities in advanced courses, but I responded by utilizing a mixture of technology and teamwork with the students. I note that in my cross-listed computer science and physics course, the students' successes and enthusiasm greatly improved relative to the first time we offered it. In our final January term, I will once more offer my course on signals, and students are already asking how to register for it.

Finally, the students appear to have learned and grown successfully in my *CON2*, *CUL3*, and College Writing Seminar courses. Although teaching College Writing Seminar was a stretch for me, the students practiced and improved their technical writing. I was happy to serve the INTD100 program, and will periodically return to it. The history of science in Antarctica course (*CON2*) was about exploration, self-exploration, and shared-meaning. It is also connected to my field of research which makes it easier for me to use the content to enlighten the students. The history of science in Latin America course (*CUL3* and *CON2*) was about the history of the discovery of order within the Universe across cultures, and how our ancestors discovered that order with science. The students also encountered shared meaning by studying people from mesoamerican cultures *doing science and math in their own way.* Humans from all regions and times in history feel the call to do mathematics and science.

2.2 Addressing Equity and Inclusion

Whittier College prides itself on doing right by our diverse student body. In Sec. 2.1, I shared my reflections on the place physics holds within the liberal arts perspective. What I did not share in that section was that STEM courses are not known for being diverse, nor for fostering equity and inclusion[4]. What might come as a surprise is that many STEM professors work diligently to foster equity and inclusion in their classes, often unnoticed. In Sec. 2.2.1, I reflect on student utilization of open educational resources (OER). In Sec. 2.2.2, I reflect on my experience with flexibility for students with a wide range of issues during the pandemic. Finally, in Sec. 2.2.3, I reflect upon our experience with the Artemis program under the Center for Engagement with Communities (CEC).

2.2.1 Open Educational Resources (OER)

I have given several lectures before and during the pandemic at OER workshops organized by Sonia Chaidez and Azeem Khan[5]. Wardman staff conducted focus groups, and the results were similar to those of other institutions. About 1 in 5 students have difficulty buying books. Further, some students cannot justify spending precious extra dollars on books when the professor only covers half the content within them. To address this problem, my

[4]This is particularly pronounced for the topic of gender, although explaining that nuanced situation is outside my level of expertise and beyond the scope of this report.

[5]I have included my slides for those lectures in the supplemental material.

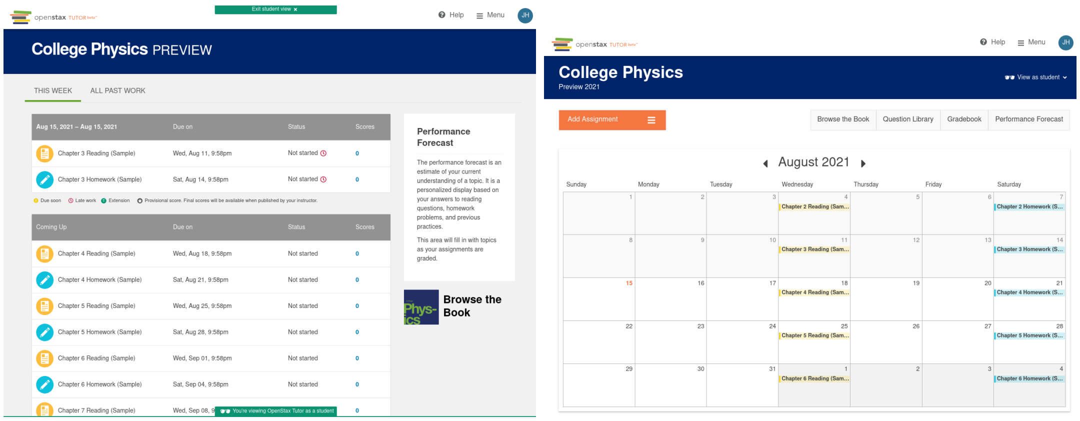


Figure 2.1: (Left) Student view of OpenStax Tutor. (Right) Professor view. In both pictures, reading assignments are in yellow and homework assignments are in blue.

students and I use OpenStax resources in all courses for which that is possible[6]. Without a homework system, professors of physics at Whittier College could spend 15-20 hours per week grading just homework. My colleagues and I have used a service called TheExpertTA that administers and grades homework while charging the student \$32.50. I'm pleased to share with you that during Spring 2021, my students and I learned to use OpenStax Tutor, the homework system fully integrated with OpenStax textbooks.

OpenStax Tutor costs the students only \$10.00, and the books are free. Tutor adds several key features beyond TheExpertTA. First, *reading assignments* can be created to incentivize the students to finish the reading before class. Second, the homework problems can be multiple choice, conceptual, or require a longer calculation. That adds flexibility for our students, as some learn at a faster or slower pace. Third, the OpenStax Tutor system uses machine learning to determine the concepts that cause an individual student to struggle, and assigns them customized practice problems. I receive statistical reports, and I act on them by covering those exercises in class with which many students struggled. Finally, the system summarizes the reading and homework schedule for the students in a calendar and notification system. Figure 2.1 gives an example of this. In summary, the system is more adaptable, more feature-rich, and more cost-effective for our students. Table 2.1 contains a list of all courses I have taught in my time at Whittier College, and includes the use of OER.

Open Educational Resources were also used in my advanced and liberal arts courses. In Computer Logic and Digital Circuit Design (COSC330/PHYS306), students design digital electronics on an integrated circuit board called the PYNQ-Z1 by Agilent (`https://www.pynq.io`). The Python3 software the students use to operate this device is open-source, and our department purchased the boards and laptops to go with them. There is zero cost to the student. In Digital Signal Processing (DSP), COSC390, the text is open-access and the course software is written by me in octave, an open-source programming language the students install for free. In INTD255, the course about Antarctic science, the students use the Open Polar Server (OPS) to access data about ice sheets and ice shelves around the world for climate science purposes. In INTD290, the course about Latin American science, students used WeVideo to create digital storytelling projects. Whittier College has a site license for WeVideo, at no cost to the students.

2.2.2 Making Arrangements for a Diverse Group of Students

Even before the pandemic, my students faced time-pressures. I observed how non-majors and introductory students took exams. The grading data revealed that most students would do well on homework but midterms and final exams caused some problems. Typically three-fourths of my students are KNS or Biology majors, who are *required* to take algebra-based physics (PHYS135A/B). They are also required to take courses like organic chemistry. When midterms in these courses coincide with my midterms, we have difficulties. I shifted away from a rigid testing schedule, and polled the students regarding the optimal date for midterms. The students really appreciated that, and I began to write take-home exam versions in case a student had to travel for sports or family on the day the class selected. The students appreciate flexibility, expecially when they work or care for family.

[6] There is a growing library of texts in areas beyond STEM. See `https://openstax.org` for more information.

Semester	Course	Credits	Students	Curriculum feature	OER Usage
Fall 2017	PHYS135A-01	4.0	24	Intro	OpenStax
Fall 2017	PHYS150-01	4.0	17	COM1/Intro	OpenStax
Spring 2018	PHYS135B-01	4.0	18	Intro	OpenStax
Spring 2018	PHYS180-02	5.0	19	COM1/Intro	OpenStax
Spring 2018	COSC330/PHYS306	3.0	6	Advanced	PYNQ-Z1
Fall 2018	PHYS135A-01	4.0	24	Intro	OpenStax
Fall 2018	PHYS135A-02	4.0	26	Intro	OpenStax
Jan 2019	COSC390	3.0	8	Advanced	open-access text
Spring 2019	PHYS135B-01	4.0	25	Intro	OpenStax
Spring 2019	PHYS180-02	4.0	9	Intro/COM1	OpenStax
Fall 2019	PHYS135A-01	4.0	24	Intro	OpenStax
Fall 2019	PHYS150-02/03	4.0	26	COM1/Intro	OpenStax
Fall 2019	INTD255	3.0	23	CON2	OPS
Spring 2020	COSC330/PHYS306	3.0	13	Advanced	PYNQ-Z1
Spring 2020	PHYS135B-01	4.0	23	Intro	OpenStax
Spring 2020	PHYS180-02	4.0	24	COM1/Intro	OpenStax
Fall 2020 (Module 1)	INTD100-21	3.0	14	Intro	–
Fall 2020 (Module 2)	PHYS330	3.0	11	Advanced	–
Spring 2021 (Module 1)	INTD290	3.0	26	CON2,CUL3	WeVideo
Spring 2021 (Module 2)	PHYS135B-02	4.0	17	Intro	OpenStax/Tutor
Spring 2021 (Module 3)	PHYS135B-01	4.0	25	Intro	OpenStax/Tutor
–	Total	78.0	–	–	–
Summer 2020 (Session II)	MATH080	3.0	11	Intro	OpenStax

Table 2.1: This table is a summary of courses taught in four years, plus Summer sessions. Not included: PHYS396 (Physics Research for Credit), and PHYS499 (Senior Seminar). OpenStax and OpenStax Tutor are examples of OER in STEM. The PYNQ-Z1 is a circuit board integrated with open-source software. WeVideo is a web-based video editing platform. OPS stands for Open Polar Server.

The flexibility techniques I was learning in 2019-2020 had to be turbo-charged for the module system and remote instruction. I learned about the Calendly booking service from an Wardman Library workshop. This taught me what a booking service is, and I quickly located a free version: `https://10to8.com`. The software synced with my calendar and provided a convenient booking page for the students (like a doctor's office). I ensured that my students could grab 30 minutes of my time when they were free. For example, I met with students while they were on break at work via Zoom to go over homework. Because the homework and book are open-access, the could see all course content.

My physics courses usually involve a student designed final project. In my early years at Whittier College, I noticed some students would create sophisticated projects using our lab equipment, and some would create them at home with household items. I could have jettisoned that part of my syllabus during remote instruction, given that the students had no access to our labs. However, the students really shine when designing and executing their own ideas. I decided it would boost inclusivity by allowing the students to demonstrate their projects for each other via Zoom, and to cheer for each other. Some students even presented DIY Arduino integrated circuits, similar to my students in the Artemis program.

2.2.3 Center for Engagement with Communities: Artemis Program

According to a demographic study done by the American Institute of Physics (AIP), women earned about 20% of bachelor's degrees and doctorates in physics in 2017 [36]. The overall graduate student enrollment has fluctuated around 3000 people in the United States in the decades prior to the release of the AIP report. This implies that there are only ≈ 600 women signed up to earn a PhD in physics in the USA *per year.* I remarked earlier in a footnote that this is a complex, multi-faceted issue with many variables not under my control. However, there are ways in which I can help foster inclusion in STEM at Whittier College.

In Fall 2018, Prof. Serkan Zorba and a program coordinator with the Center for Engagement with Communities (CEC) named Samantha Ruiz approached me about joining the Artemis Program. The Artemis Program fosters inclusion by inviting young ladies from local high schools to learn about Whittier College. They perform research with Whittier College professors, and CEC staff help them with the Whittier College application. I answered the call to serve, and began designing a Python3-based physics education project. This experience tested my teaching ability. I had to establish *order* creatively (Sec. 2.1, and asked the girls to write code together (*shared meaning*). They eventually presented their results at URSCA 2019, after they wrote Python3 code that gathered data about how quickly and accurately their fellow high school students solved physics problems.

In Spring 2020, I served the Artemis Program a second time. My idea was for the young ladies to create wearable Arduino circuit boards that would connect to WiFi. The purpose was to relay location information in case an elderly loved one got lost. I began with demonstrations and code examples, and eventually the girls got their boards to communicate via WiFi. Before we could work on making the little boards *wearable*, the pandemic struck and URSCA was cancelled. Nevertheless, the young ladies got to keep their boards and continue developing at home. I look forward to seeing some of them again this Fall.

2.3 Methods of Teaching Physics

In Sec. 2.1, I remarked that physics provides *order* and *shared meaning* within the liberal arts perspective. We have known students require evidence-based teaching methods to master the *order* of physics. Within order, there is problem-solving, analytical thinking, experimentation, and data analysis. To apply physics concepts to other disciplines (*shared meaning*), students need a variety of PER modules to apply the order they learn. PER modules must be balanced with TT modules that provide examples for the students to copy and remix. The students use laboratory activities (LA) to confirm basic physics concepts, and to practice analyzing graphical and numerical data. During remote instruction, the students experienced physics labs and simulations in online LA modules. I review each type of module below in Secs. 2.3.1 - 2.3.3.

Instruction of Students in Introductory Courses

Students are categorized as *non-majors* or *physics majors*. Non-majors encounter physics for two semesters in either *calculus-based* or *algebra-based* courses. Classical physics at the undergraduate introductory level is built upon single-variable calculus, with some multi-variable or vector calculus introduced in the second semester. However, students who have not taken calculus can still learn using tools from algebra and trigonometry. *Non-major* students therefore take PHYS135A/B, while those majoring in physics, engineering, math, and integrated computer science take PHYS150/180.

Three focuses are relevant for teaching at the introductory level:

1. **Curiosity**. Good instruction for non-majors should *entice curiosity*, which begins by encountering students' initial experience with physics. Before the pandemic, I would give colloquia and seminars at other schools, and public lectures to children and families in East Los Angeles. Experiencing people's curiosity forms a starting point, from which we build order. I have given lectures at Los Nietos Middle School and colloquia here at Whittier College, and invited speakers from UC Irvine to give colloquia as well. I planned to continue this practice at a Family Science Night at Granada Middle School, but the pandemic forced us to cancel. Within this teaching focus, I have three measurable goals:
   - Measurably increase student interest in physics as measured by questions 15 and 18 on the evaluation forms.
   - Teach the students to satisfy curiosity through self-designed experiments and pre-designed lab activities.
   - Coach the public speaking skills of the students to empower them to present results to peers.
2. **Improvement of Analysis Skill**. The order within physics requires analytical skill. Physicists help the students develop their problem-solving abilities. We apply PER modules in introductory courses to train students, and add a healthy mixture step-by-step examples. This involves calculations as simple as converting between units (i.e. kilograms to pounds) to plotting the trajectory of a particle in a vector field. Within this teaching focus, I have two specific goals:
   - Measurably increase the ability of the students to solve word problems (questions 12, 14, 19, and 20 on the evalutations).
   - Teach the students to measure with precision the correct result in laboratory settings.

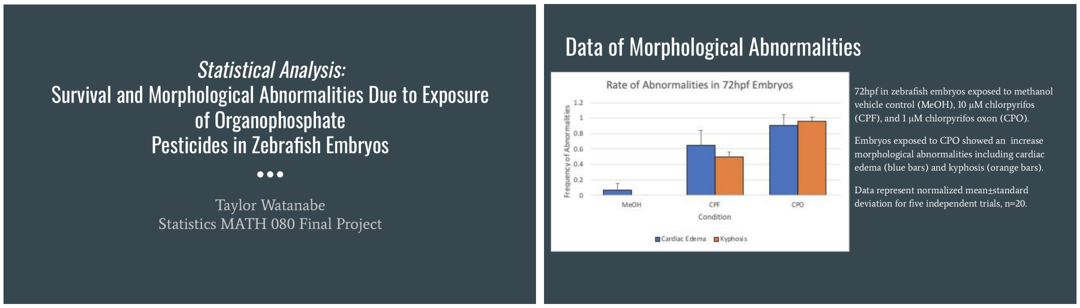


Figure 2.2: The title slide and key results of the final presentation of one of my students, Taylor Watanabe. I taught this student physics for a year, followed by statistics in summer session.

3. **Applications to Society**. Our students succeed in their technical careers if they can qualitatively explain phenomenon via the shared meaning of physics. In recent years, our OER [37] [38] have included medical and kinesiological topics. My students engage in special units, including human muscle motion (in PHYS135A) and nerve systems (in PHYS135B and PHYS180). The students design experiments for final projects, and sometimes these apply to their field. One excellent example is shown in Fig. 2.2[7] Another tool is the inclusion of student-led summaries of scientific articles, which encourage class discussions about the broader implications for society. Within this teaching focus, I have two measurable goals:

   - Empower the students to present and discuss articles they find relevant or interesting (see Supplemental Material)
   - Manage and aid in student-designed experiments that are presented to the class (see Supplemental Material)

Instruction of Students in Advanced Courses

Physics, ICS, and 3-2 program majors are the second category of students we encounter. I have created two upper-division computer science courses that are part of the curriculum in schools similar to Whittier College, but were missing before I joined the faculty (see [39] and [40] for examples). The first is Computer Logic and Digital Circuit Design (COSC330/PHYS306), and the second is Digital Signal Processing (COSC390). The syllabi for these courses are included in the Supplemental Material.

Three focuses are relevant for teaching physics, mathematics, and computer science majors at the advanced level:

1. **Mental Discipline**. These courses require mental discipline. The professor must foster this value in the students in two ways. First, the students need a professional curriculum requiring *analytical* and *creative* thinking. Second, the professor should demonstrate *expertise* and lead the students by example. In Digital Signal Processing I wrote code in MATLAB to demonstrate concepts, and the students modified it to suit their purposes for projects. I summarize mental discipline into two goals:

   - Challenge the students with course content that requires both analytic and creative thinking (questions 11 and 20 from the evaluation).
   - Provide the students with technical expertise and guidance (questions 12 and 19 from the evaluation).

2. **Strength in all Phases of Science**. Advanced course curriculum in physics, math, and computer science must include the following *phases* of scientific activity: abstract problem solving, numerical modeling/prediction, experimental design and execution, and data analysis. I have four goals in this area, corresponding to the four phases:

   - Measurably strengthen the abstract problem solving of the students (question 14 from evaluation).
   - Expose students to numerical modeling with computer code.
   - Assist the students with the design and execution of technical projects.

[7]Several examples are included in the supporting material.

- Strengthen the data analysis abilities of the students through technical projects.

3. **Communication**. A critical skill in technical fields is oral and written communication. Whittier College graduates in the fields of physics, mathematics, and computer science should be able to communicate technical ideas to their peers. To help my advisees practice, I made the theme of my INTD100 section scientific and technical writing. In my advanced STEM courses, the students write a longer paper and/or presentation with the goal of improvement of their technical communication. I set two goals:

    - Require the students to submit at least one major written or oral assignment.
    - Provide students the opportunity to refine the work in office hours before submission.

Department-Level Goals

The Department of Physics and Astronomy has eight goals. In the coming course descriptions, these goals will be referenced.

(a) Develop and offer a wide range of physics courses using the most effective pedagogical methods and styles. Such courses shall include appropriate contributions to the Liberal Education Program (currently COM1 and CON2).

(b) Create research experiences for physics majors that will engage and inspire them in their discovery of physics.

(c) Build a departmental community that is supportive and welcoming and that encourages students in their studies of physics.

(d) Keep the physics curriculum current so that students gain the skills necessary for success in todays scientific environment.

(e) Teach students how to teach themselves. Give them the intellectual tools necessary for independent thinking and learning.

(f) Train students to think "scientifically" i.e. critically, rigorously, quantitatively, and objectively, so that they can analyze problems and generate solutions.

(g) Train students to effectively communicate scientific ideas to others.

(h) Advise students about various career paths and help them along these paths.

2.3.1 Physics Education Research (PER) Modules

The PI and PhET modules are outlined below for more detail and clarity, since it is likely that they are only familiar to physics instructors.

PI Modules - An active learning strategy involving group problem solving and discussion [41] [42] [43]. Figure 2.3 contains data relevant to the following example.

- PI-based modules contain multiple-choice questions about a physical system. Suppose we ask the students the following question:

  If the slope on a graph of $x(t)$ vs. t is positive before t_0, zero at t_0, and negative after t_0,

  A) the acceleration of the object was negative before and after t_0.
  B) the acceleration of the object was positive before t_0, then negative.
  C) the acceleration of the object was positive before and after t_0.
  D) the object had no acceleration.

- Each student responds *anonymously* with a device, and their answers appear on-screen (see Fig. 2.3).
- Students know to press E if they are confused. As described in the text, this maintains inclusivity in class.
- One of two actions is taken next:

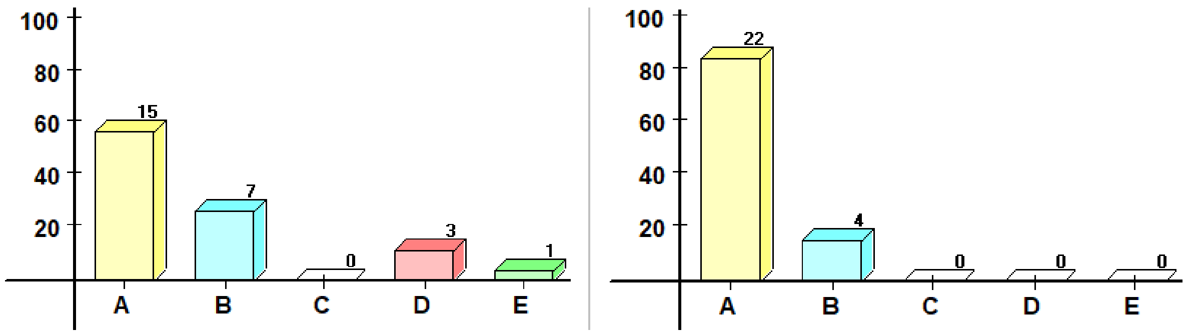


Figure 2.3: (Left) An answer distribution of my 25-student PHYS135A class (A was correct). This distribution triggered a table discussion. One student pressed E (indicating confusion) and I took appropriate action. (Right) After table discussions, the students responded and the fraction of correct answers was $22/25 = 0.88$.

1. If the fraction of correct answers is > 0.7, we proceed to the next exercise or new material[8].
2. If the fraction is < 0.7, the professor initiates **table discussion**.

- **Table discussions** take place between students at the same table. During this time the professor circulates, searching for and helping the struggling students. After 3-5 minutes, the discussion ends.
- A second poll of the class is taken after table discussions. The *shift* in the distribution towards the correct answer indicates improved understanding. The professor takes appropriate action if there is not a shift. If there are WATs (answer E), the material is re-addressed.
- The procedure is repeated for several exercises, and table discussions take place when necessary. After several exercises, the class proceeds to new material. See Fig. 2.3 for example PI data.

PhET Modules - These are interactive simulation tools published by The University of Colorado, Boulder [44]. They are based on proven PER and written such that any student can operate them.

- The OpenStax textbooks for our courses have built-in links to PhET tools, allowing students to illustrate concepts by visually.
- Several HTML5-based examples are here:
  1. Electric charge and electric field: `https://phet.colorado.edu/en/simulation/charges-and-fields`
  2. DC circuits: `https://phet.colorado.edu/en/simulation/circuit-construction-kit-dc`
- PhET simulations are incorporated into active learning in the classroom in four situations:
  1. When a PhET tool re-creates a laboratory measurement, it is useful and informative to first simulate the expected results and then compare to the real ones.
  2. PhET tools are used when an experiment cannot be constructed in the lab, such as altering gravity or changing the friction between surfaces. Students benefit by being able to fine-tune a system in order to understand it.
  3. PhET tools are used to *visualize* systems which are invisible. Examples are magnetic, electric, and gravitational fields, which are real but not always visible.
  4. In special units, such as studying the behavior of electrical signals in the human body, there are useful PhET tools from biology, chemistry, medicine, and earth science that help me engage the curiosity of students.

[8]The number 0.7 was the recommended fraction at the American Association of Physics Teachers (AAPT) conference I attended in 2017.

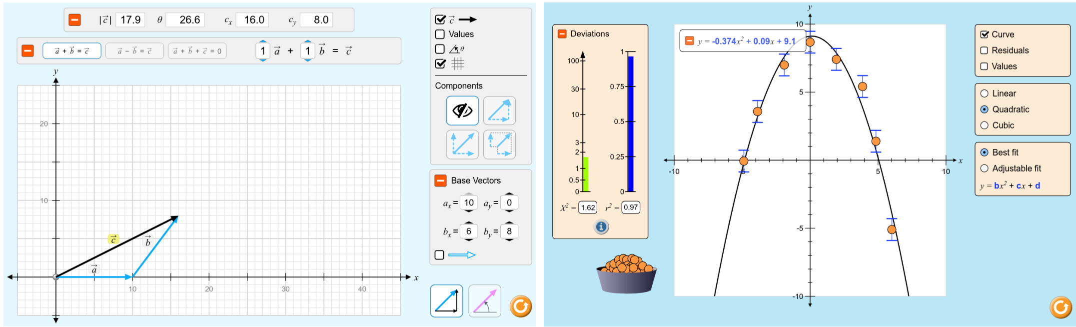


Figure 2.4: Two examples of PhET simulations used by my physics students in the lecture/laboratory formatted courses. (Left) Vector addition. (Right) Curve-fitting to data.

2.3.2 Traditional Teaching Modules

Traditional teaching modules begin with a reading assessment that serves as a warm-up exercise. These are graded for completion, and involve topics from reading done the 1-2 days before class. An example is displayed in Fig. 2.5. After the warm-up, we review the agenda, homework and reading schedule, and the memory bank. The memory bank is just a list of equations and concepts the students memorize through repeated application. We proceed with the solution to the reading assessment problem, and then expand to other examples and demonstrations on the board. From there, we proceed with a PI module, followed by either a PhET or laboratory module. I recall the suggestion by FPC that the modules and timing should be varied, since students run out of focus after two hours of introductory physics. I include a break between the TT module and the rest of the class period. Now that we are moving away from the module system to in-person semesters, I will return to the cadence suggested by FPC. During remote instruction, I created video recordings of TT modules for the students that could be downloaded via Moodle and YouTube. The students preferred to use these for asynchronous learning, so I posted them typically on Fridays to be discussed on Mondays.

2.3.3 Laboratory Modules

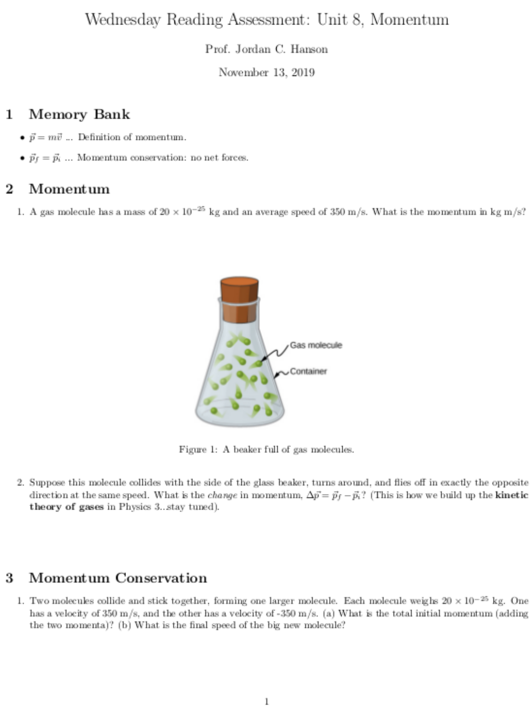
Laboratory activity (LA) modules usually follow the TT and PI modules. The students prefer to have tangible handouts, so I create worksheets for them[9]. Philosophically, the purpose of the laboratory activities is to establish the *order* of physics phenomena through tangible experimentation. The LA modules follow the warm-up, TT, and PI modules because the LA modules are done in groups. The students run low on energy after more than one hour of physics. Working together allows them to press on and learn from each other, which requires less mental energy. During remote instruction, my colleagues and I decided we valued LA modules enough to subscribe to `https://www.pivotinteractives.com`. The students collect data in the same way, but they control the experiment by playing a video of an assistant operating the apparatus. An example of such an online lab activity is shown in Fig. 2.6. Intriguingly, the students scored better on online LA through Pivot Interactives than they usually do on in-person labs. This is most likely due to the thorough "scaffolding" of the lab procedure available on Pivot Interactives. When given a choice between non-scaffolded and scaffolded, I chose LA modules with scaffolding.

2.4 Introductory Course Descriptions

The introductory STEM courses I have taught thus far at Whittier College are now introduced, with connections to departmental goals and learning focuses listed in Sec. 2.3.

Algebra-based physics (135A/B). Algebra-based physics, PHYS135A/B, is a two-semester integrated lecture/laboratory sequence covering Newton's Laws to electromagnetism[10]. PHYS135 is a requirement for majors such as KNS and CHEM. Students practice problem-solving with algebra, trigonometry, and vectors. I employ a mixture of TT and PER methods to satisfy **departmental goals 1, 4, and 6**. I have modified the balance of TT and PER in alignment with department and FPC recommendations.

[9] Example included in the supplemental material.
[10] See supplemental material for example syllabi.


Wednesday Reading Assessment: Unit 8, Momentum

Prof. Jordan C. Hanson

November 13, 2019

1 Memory Bank

- $\vec{p} = m\vec{v}$ ... Definition of momentum.
- $\vec{p}_f = \vec{p}_i$ ... Momentum conservation: no net forces.

2 Momentum

1. A gas molecule has a mass of 20×10^{-25} kg and an average speed of 350 m/s. What is the momentum in kg m/s?

Gas molecule
Container

Figure 1: A beaker full of gas molecules.

2. Suppose this molecule collides with the side of the glass beaker, turns around, and flies off in exactly the opposite direction at the same speed. What is the *change* in momentum, $\Delta\vec{p} = \vec{p}_f - \vec{p}_i$? (This is how we build up the **kinetic theory of gases** in Physics 3...stay tuned).

3 Momentum Conservation

1. Two molecules collide and stick together, forming one larger molecule. Each molecule weighs 20×10^{-25} kg. One has a velocity of 350 m/s, and the other has a velocity of -350 m/s. (a) What is the total initial momentum (adding the two momenta)? (b) What is the final speed of the big new molecule?

1

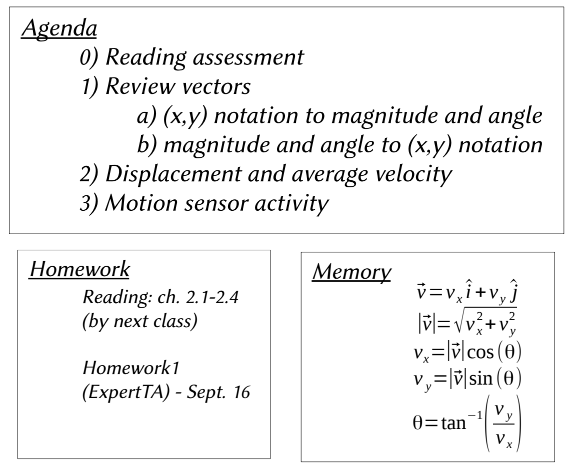


Figure 2.5: (Left) An example figure from the text, integrated into my reading assessment. (Right) The class agenda, memory bank, and homework/reading assignments are presented on the white board clearly and concisely at the beginning of class. The reading is broken into small sections, a practice following the suggestion of a student from 2018 section.

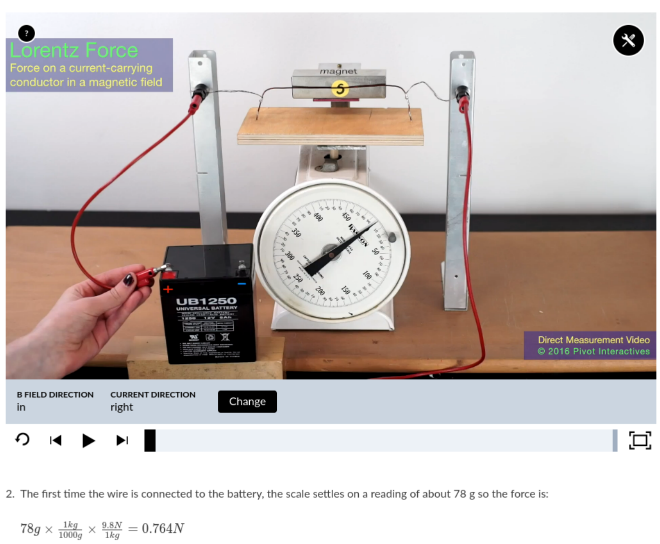


Figure 2.6: Laboratory modules are now done both in-person and through a service called Pivot Interactives.

The first learning focus for non-majors is **curiosity**, with the measureable goals stated in Sec. 2.3. To satisfy the goal of increasing curiosity, students may present at the outset of class a recent science journal article pertaining to physics. I incentivise this with extra credit, and I help them to practice oral communication of scientific ideas (**Departmental goal 7**). Once the students overcome nerves and try speaking in front of peers, they begin to choose content connected to their major. It is wonderful to see the students teach their peers.

A second method is to require the students to design a final project in small groups. The OpenStax textbooks contain many workable examples. Each group must first submit a proposal in the middle of the semester. I then help them refine it and ensure they have proper equipment. After data collection, the students practice presenting in office hours. The students design, build, and execute their projects, which gives them an avenue for their physics curiosity. Making this assignment an oral presentation also goes toward **Departmental goal 7**. Course evaluation data show that the students *report an increase in their curiosity for physics.*

The second introductory focus is **improvement of analysis skill**. I utilize PI modules and PhET simulations strategically. PI (Peer Instruction) modules were first developed by Eric Mazur [41], and have better measured performance than TT only courses. Physics concepts can be illustrated with PhET (Physics Education Technology) simulations, or used to perform laboratory activities we cannot consruct (e.g. altering the strength of gravity)[44]. These two modules are my main PER tools for boosting student problem-solving. Finally, I learned to use JITT modules [45] at a workshop for new physics professors given by the American Association of Physics Teachers (AAPT) in 2017. The students shared in 2017-2018 that they prefer step-by-step examples to JITT.

PER shows that students learn efficiently from peers explaining their reasoning. Table discussions encourage this type of learning and give me the chance to help the struggling students. Spending time with struggling students helps me build a relationship of trust, which alleviates some anxiety. After short table discussions, students submit their answers again. We observe the answer distribution shift toward the correct one (see Fig. 2.3). Further, if 70% of students answer correctly, we move forward. Thus, we accelerate the pace if the students understand. This creates the possibility of a few students being left behind, so I have added the concept of WAT[11]. WAT corresponds to answer E. If I observe a WAT, I revert to a TT example. *This strategy ensures inclusivity*, in that we strive to leave no one behind in class.

The second-half of the lecture/laboratory format is the lab activity or PhET module. An example of the interplay between labs and PhET occurs in PHYS135B and PHYS180 (electromagnetism). The students build DC electric circuits. If the circuit is constructable in our lab, they complete an LA module to measure voltages and electric current to verify Ohm's Law[12]. If the circuit cannot be easily built in our lab, we simulate it virtually with PhET software. Whenever possible, we first simulate the circuit in PhET, and then physically construct it to compare simulation and experiment. The PI modules, PhET modules, and traditional lecture content form a flexible and diverse strategy for improving the students' analysis skill (**Departmental goals 1, 4, and 6**).

My third introductory course learning focus is **applications to society**. The obvious routes are the applications in the OpenStax texts [37] regarding kinesiology and medicine. The students experience PI modules and example problems with topics such as motion/work/energy in the human body, nerve cells as DC circuit simulation, and lightning/weather. Which modules I select depends on the students' majors. Learning what interests the students and including content specifically pertaining to their majors is highly beneficial to keep students engaged. Dropping the JITT module also frees more class-preparation time to add material I know particular students will enjoy[13].

Two final methods for my third learning focus are article discussions and term-papers. Of the ways my students reach the third learning focus, these were the least used during remote instruction. Article discussions involve a student selecting an online article to present to the class before the TT module for extra credit on homework. Students practice oral communication of technical ideas, and summarizing quickly in front of a group. Occasionally, I suggest high-impact articles and offer extra credit on the midterm, which causes a flood of volunteers. Some brilliant term-papers have also emerged, including the history of the first measurement of the distance to the Sun[14]. The story of these first measurements is connected to the first explorations of Antarctica, and I included the astronomy/Antarctica connection in INTD255 (the Antarctica course). Students opt to create term-papers more rarely, but it does provide them a venue to practice technical writing (**Departmental goal 7**).

[11] e.g. "What?" A meme indicating confusion.
[12] Ohm's law states that the current observed is proportional to the voltage in the circuit.
[13] See supplemental material for an example of such a unit.
[14] Included in the supplemental material.

2.5 Analysis of Course Evaluations: Introductory Courses

A

Hickisy Pickisy

B

2.6 Advanced Course Descriptions

A

Elec

B

2.7 Analysis of Course Evaluations: Advanced Courses

A

Elec

B

2.8 Liberal Arts Course Descriptions

A

Elec

B

2.9 Analysis of Course Evaluations: Liberal Arts Courses

A

Elec

B

2.10 College Writing Seminar Course Descriptions

A

Elec

B

2.11 Analysis of Course Evaluations: College Writing Seminar

A

Elec

B

2.12 Outlook

A

Elec

B

Chapter 3

Scholarship

Whittier College faculty classify scholarship using the *Boyer* model [46]. My scholarship primarily falls within two categories: the scholarship of discovery, and the scholarship of application. I utilize physics education research (PER) in my teaching practices. When I tried my hand at advising a Whittier Scholars Program major, I found myself performing the scholarship of integration (see Sec. 4). In the following sections I reflect upon my scholarly work, and share my vision for the future. In Sec. 3.1, I describe my research field, giving it proper historical context. In Sec. 3.2, I share exciting news regarding my research and Whittier College. In Sec. 3.3, I organize my scholarship of discovery into five categories and list progress made by my students and I. I also draw a connection to my teaching and advising practices in each category, since they are interconnected. In Sec. 3.4, I describe my new venture into the scholarship of application. This has been a fruitful partnership with the Office of Naval Research (ONR). Finally, in Sec. 3.5, I propose an idea that for a partnership program has been shared with me by my colleagues at the ONR.

3.1 IceCube, Cosmic Rays, and Neutrinos from Deep Space

Cosmic rays are high-energy protons, electrons, and nuclei propagating through space near the speed of light. They carry information from other regions in the galaxy, and in some case, other galaxies. Since the discovery of extremely energetic cosmic rays more than a half century ago, the elusive quest to uncover the sources of these enigmatic particles has provided many challenges. Despite progress in experimental capabilities and theoretical insight, we do not yet know the acceleration mechanism for those particles with energies that have been measured in excess of 10^{20} electron-volts [47]. Being electrically charged, the paths of cosmic rays are curved by galactic and intergalactic magnetic fields. By the time the cosmic ray arrives at Earth, the arrival direction no longer points back to their origin. In addition, interactions with cosmic microwave background photons prevent ultra-high energy cosmic rays from propagating to the Earth, unless the sources are in our local galactic cluster [48] [49].

Neutrino astronomy offers a new and powerful tool to provide insight into the physics associated with the acceleration process, and complements and extends measurements not accessible through the observation of other *messengers*: cosmic-rays, gamma-rays, and optical photons. Charged cosmic rays which interact with gas, dust, or radiation near an accelerating object produce gamma-rays and high-energy neutrinos. These neutrinos are called *astrophysical* neutrinos. Whereas gamma-rays can be absorbed in dense environments, astrophysical neutrinos can escape and travel unimpeded to a detector ([3] and references therein). Neutrinos travel at the speed of light in straight lines, undeflected by magnetic fields. This allows for identification of sources, as well as the potential for finding sources that emit both neutrinos and gravitational waves, which also travel in straight lines [50].

The most energetic cosmic rays that do escape their source can interact with the cosmic microwave background en route to the Earth, generating cosmogenic neutrinos with a characteristic energy distribution peaking at 10^{18} electron-volts [51] [52]. The distance over which these neutrinos could physically propagate given the distribution of cosmic microwave background photons is larger than the known Universe. So despite the distance limitations of cosmic rays, neutrinos offer a window into regions of the Universe *far beyond anything possible* with other messengers.

The flux of neutrinos originating from outside the solar system with energies between 10^{13} and 10^{15} electron-volts has been measured by the IceCube collaboration [11]. Previous analyses have shown that the discovery of

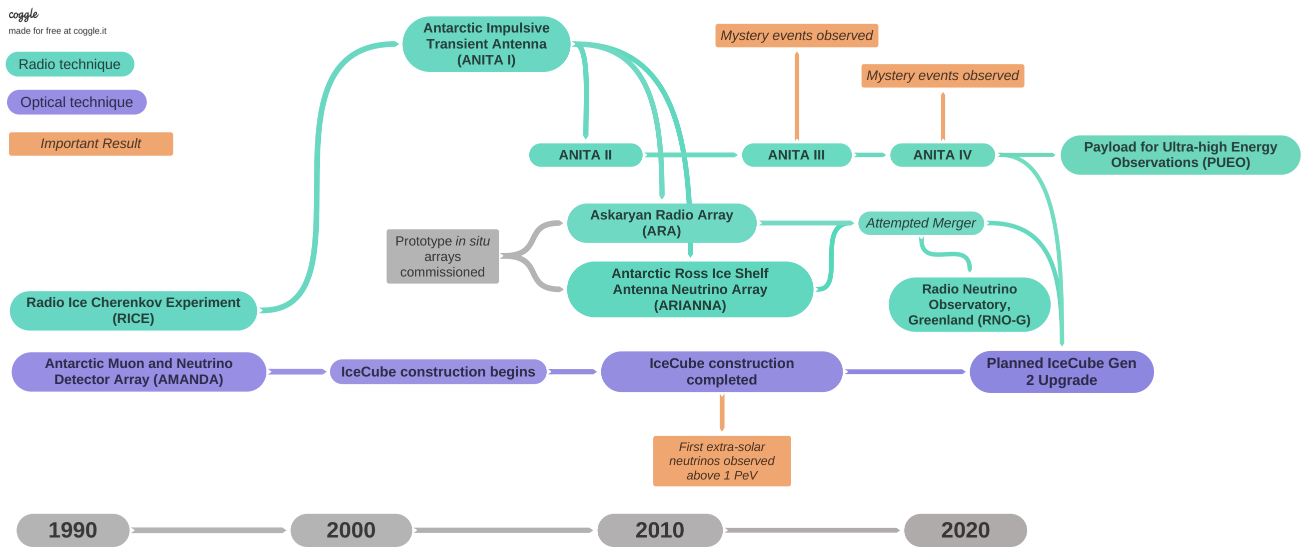


Figure 3.1: A general timeline of the UHE-ν sub-field of physics.

ultra-high energy neutrinos (UHE-ν, energy greater than 10^{15} electron-volts) will require an upgraded detector design with a larger effective volume because the flux is expected to decrease with energy [14]. Neutrinos with energies above 10^{15} are the ones that could potentially explain the origin of cosmic rays, and provide the chance to study quantum mechanical interactions at record-breaking energies when the UHE-ν interact in our detector [3] [4].

3.1.1 Why Antarctica?

Utilizing the *Askaryan effect*, in which UHE-ν creates a radio-frequency pulse, greatly expands the effective volume of UHE-ν detector designs. This effect is important for UHE-ν detection, because radio pulses travel more than 1 kilometer in Antarctic and Greenlandic ice [16] [17] [53] [54]. That means stations can be placed 1 km apart, and the volume of the overall array of stations is large enough to capture UHE-ν. The large volume is necessary for two reasons. First, cosmic rays and neutrinos at these energies are rare enough that a 10×10 km^2 target is necessary. Second, neutrinos do not always interact in dense matter quantum mechanically, unlike protons or heavy ions that always smash into some nucleus. To ensure that we catch the signals from the UHE-ν that do interact, we must construct a large detector. A third reason that attracted my field to Antarctica is that Antarctica is a well-organized open playground for cutting-edge science. This is a topic that I cover in one of my new *Connections 2* courses: *Safe Return Doubtful: History and Current Status of Modern Science in Antarctica.*

3.1.2 Radio Expansions: IceCube Generation 2

In Sec. 1.1.1, I reflected on my academic origin story and the contributions I have made to the field. The plot of that story has taken an interesting and favorable turn for Whittier College. Not only has the IceCube Collaboration finally recognized the necessity of radio-based detectors [14], but IceCube Gen2 designs now include specific designs inspired by ARIANNA. Further, Whittier College has been invited to become a member institution of The IceCube Collaboration through my scholarship. This will give us a seat at the table for cutting edge physics research. I provide a complete list of advantages in Sec. 3.2 below.

The diagram in Fig. 3.1 illustrates the progress my field has made in the last decade. IceCube is the largest neutrino detector in the world, and one of the more expensive physics projects in US history ($0.28 billion). In perspective, the Mars rover Curiosity cost $2.5 billion, and the Advanced LIGO gravity-wave detector cost $1.1 billion. IceCube was built from a predecessor called AMANDA, constructed at the South Pole for the ice quality and several-kilometer depth[1]. AMANDA and IceCube have relied on the *optical technique*, observing tracks of

[1]Being at the South Pole is like being atop a 2.8 km ice mountain. The ice thickness is needed to form the largest block of ice possible for the detector.

optical photons left by passing neutrinos. The optical technique requires *digital optical modules* (DOMs) to be deployed 1 kilometer below the surface, separated by 100 meters. Practically, this limits the detector volume to 1 km^3. After 20 years of detecting neutrinos that originate from cosmic rays striking the atmosphere, IceCube announced the observation of *extra-solar*[2] neutrinos with energies of 10^{15} electron-volts in 2013 [11].

This result broke the world record for highest-energy neutrino ever observed by humans. There is also nothing in our solar system capable of accelerating particles to those energies, so the neutrinos at least had to come from outside the solar system. Currently, IceCube has established a flux of neutrinos below 10^{15} electron-volts, and the arrival directions indicate they might have *extra-galactic* origin. Meanwhile, with the deployment of AMANDA came RICE, the earliest *in situ* Askaryan-class detector. Deployed before IceCube construction began, RICE operated for just over a decade.

In many ways, RICE was ahead of its time. Gurgen Askaryan predicted what we call the Askaryan effect in the 1960s. The radio pulses from neutrinos and other high-energy particles would be conveniently observable as radio pulses, but physicists did not take advantage of this until the 1990s. In the interim, the Askaryan effect was observed in the lab [8] [9]. RICE eliminated many of the earlier optimistic models for UHE-ν sources, and concluded in 2012 with its last publication [1]. The time came to build a UHE-ν detector capable of listening for signals from more ice. A brilliant idea was hatched: the detector could fly above Antarctica, observing all the ice at once. Thus, ANITA was born.

ANITA was a UHE-ν version of the long tradition of cosmic ray balloon flights. In fact, cosmic rays were originally discovered by Victor Hess and Domenico Pacini in 1911, and Hess used a high-altitude balloon to make observations. ANITA eventually did observe cosmic rays (which create radio pulses in the atmosphere), along with *the mystery events.* These mystery events are so-named because they look like cosmic ray signals, but coming up from the ice. Normally, they would be ideal UHE-ν signals, but neutrinos with energies above 10^{16} electron-volts do not penetrate through the Earth at the observed angles. Either fundamental physics is wrong, or the interpretation of the signals is. ANITA has flown four times, and the planned upgrade is called PUEO.

The main drawback with ANITA is that the balloon has to fly 20 km in the air (like a weather balloon). That means the radio pulse from the UHE-ν has to travel that much farther to the detector, and the amplitude diminishes. If the UHE-ν is extra-energetic, it makes an extra-large radio pulse which can be detected by ANITA. However, the higher the energy, the rarer the UHE-ν. Thus, ANITA has not observed the flux observed by IceCube, because the average neutrino in the flux has less than 1% of the energy necessary to trigger ANITA. The physics community decided to install two versions of ANITA *in situ* (in the ice), in order to be closer to potential UHE-ν signals: ARA and ARIANNA.

ARA and ARIANNA had to overcome a number of technical challenges. While a weather balloon is a standard piece of technology operated by NASA, deploying a physics experiment in the middle of Antarctica is as complex as deploying a satellite orbiting the planet. Power, communications, data collection, and deployment missions are all technically challenging. ARIANNA was deployed at Moore's Bay on the Ross Ice Shelf to take advantage of the ocean beneath the ice. The ocean reflects radio pulses, and thus gives detectors multiple chances to detect them. ARA was deployed at the South Pole to take advantage of the colder ice. Colder ice is more radio transparent. The competition to successfully develop a prototype array lead to seven ARIANNA stations in Moore's Bay, and later two at the South Pole. ARA deployed three stations at the South Pole, and data from two of them was published. Later, a fifth[3] ARA station was deployed at the South Pole with a *phased array antenna* (see Sec. 3.3).

ARA and ARIANNA can detect UHE-ν with energies of 10^{16} electron-volts, *just above* the most energetic portion of the IceCube data. We are tantalizingly close to breaking the world record for the highest energy neutrino observed, and opening a new window into physics and astrophysics. The National Science Foundation (NSF) will no longer fund ARA and ARIANNA separately. In 2018, the two collaborations were tasked with merging and to produce a final detector design at Ohio State University. The primary issue was the deployment strategy: the ARIANNA design utilizes solar power, RF antennas in the surface snow (called the *firn*), and satellite communications. The approach is simple and conservative, and hardened for deployment in a harsh environment. The ARA design calls for drilling boreholes in the ice, similar to IceCube, so that the antennas can be lowered to depths below the *firn*. The ARA design also involved fiber optics, line-of-sight WiFi, and more antenna channels. The added complexity leads to a more sensitive experiment, but comes with higher risk.

[2]Originating from outside the solar system.
[3]I never learned from my ARA colleagues what happened to the fourth ARA station.

The merger would have lead to approximately $250k in funding to Whittier College to work on antenna testing and fabrication. Unfortunately, the merger also required baby-boomers to compromise. Since that is impossible, the merger failed. Meanwhile, European physics foundations decided to fund RNO-G, a hybrid of mostly ARA and some ARIANNA designs to be deployed in Greenland. Thus, many from ARA floated over to RNO-G. Greenland can be accessed in the summer of the northern hemisphere, whereas access to Antarctica in general takes place during the northern winter (when the sun is up in Antarctica). Despite the pandemic, there is an ongoing mission to build the first RNO-G stations. Meanwhile, the IceCube Collaboration has adopted radio *in situ* arrays as a key design component into the next major upgrade, IceCube Gen2. Many in our field consider IceCube Gen2 inevitable once the pandemic lifts. *Whittier College has been invited to become a member institution (see Sec. 3.2).* Although this comes with no cost to Whittier College, it provides invaluable access to one of the most dynamic physics collaborations in history. Once complete, IceCube Gen2 will begin to detect the most powerful neutrino events in human history.

3.2 Invitation to Become a Member Institution of IceCube

Recently, I was invited to become an official member of the IceCube Collaboration. The IceCube Collaboration (`https://icecube.wisc.edu`) includes more than 300 physicists from 53 institutions in 12 countries. It began in 1999 with the submission of the first IceCube grant proposal, and many of the original members are still active on the project. Senior scientists, graduate students, technicians, software specialists, ice drillers, and engineers came together from around the world to build what is now the largest neutrino detector in the world. To be granted a membership in the group at the forefront of neutrino physics is an honor, and it represents a great opportunity for Whittier College.

My successful bid for IceCube Membership brings several advantages for Whittier College. Whittier College will be added to the *list of member institutions* (included in the supporting materials). This means that our students and professors would gain access to archived IceCube data and be able to use it for research. Whittier College will also gain visibility, and we would be the only Title V HSI on the list. Whittier College will be added to IceCube publications, and my students and I may submit papers on behalf of the IceCube Collaboration. Whittier students and professors could attend the annual IceCube Collaboration Meeting, which is like a physics conference specializing in neutrino physics and astrophysics. Finally, I could use my IceCube membership status to help with grant proposals for items like computer clusters (see Sec. 3.3.1).

3.3 Five Areas of Research Focus

In the following five sections, I highlight five key areas of impact into which my UHE-ν research activities can be classified. I explain how they relate to the goal of UHE-ν research, and how they are interconnected. In each section, I highlight how the activity connects back to my teaching and mentorship practices.

3.3.1 Computational Electromagnetism

Observable Askaryan signals originate in ice and propagate to *in situ* RF channels. The path they follow is called a ray-tracing solution, and it depends on the speed of light in ice versus depth. The ray-tracing solution is a curved path because the speed of light changes according to the *index of refraction*, n, which depends on ice and snow density. If v is the measured speed of light, and c is the speed of light in air, and n is the index, then $v = c/n$. The density (and thus the index) depends on depth because the surface is snow, with density ≈ 0.4 g cm^{-3}, that is compressed to solid ice ≈ 0.917 g cm^{-3} over millenia [16]. A classical physics approach called the Lagrangian method can produce the ray-tracing solution. Combining the Lagrangian approach with a smooth function that describes the oberved n results in a formula for the ray-tracing solution. The formula produces special cases: (1) straight-line paths in deep ice (where the speed is constant), (2) quadratic paths near the surface (where the speed changes), and (3) a general form stitching the two together.

The official simulation software used by IceCube Gen2 is named NuRadioMC [30]. NuRadioMC is built on four pillars: (1) UHE-ν generation, (2) Askaryan emission, (3) ray tracing, and (4) RF channel simulation. My analytic ray-tracing solution is pillar (3). We assume a functional fit for n that is motivated by glaciology. Snow accumulates at the top of the ice sheet at a rate that depends on the yearly conditions. Compressed over millenia, the snow steadily increases in density, which in turn decreases the speed of light within it. The function is constrained by density and radio measurements [29]. I note that having a liberal arts mindset allowed me to find this solution more quickly. While at Ohio State, I took a climate science course in order to understand the snow compression, which lead me to try solutions that follow real snow compression measurements. The key finding of [29], however, was RF *horizontal propagation* not predicted by ray-tracing. I showed in my PhD dissertation that the effect depends on frequency [55], and therefore cannot be explained with ray-tracing alone. Horizontal propagation has been noted as an interesting detection scheme for UHE-ν [56].

The inaccuracy of ray-tracing solutions is compounded by the selection of *phased arrays* as the main detection component of *in situ* stations. In this context, phased-arrays are vertical arrangements of identical antennas that work together. One can think of received signal in terms of relative timing between antennas. Imagine an ocean wave arriving at the shoreline, and each student in a line of equally-spaced students records when the wave reaches them. From these times, they would know the angle at which the wave hits the shore. A wave arriving straight on hits them all simultaneously, but an angled wave hits one student first, then another, and so on. Similarly, the arrival direction of plane waves from the Askaryan effect can be deduced from the relative timing of the signals in each antenna. However, this all assumes a constant index n, and we know it is not constant. Knowing that sensitivity of IceCube Gen2 *in situ* designs depends on the phased array precision, I have created a solution that leaves behind ray-tracing all together.

Beyond Ray-Tracing: Open-Source Parallel FDTD Methods

I have received two *Summer Faculty Research Internship grants* from the Office of Naval Research (ONR). My group focuses on phased-array radar development. My colleagues at other institutions that do not focus on the liberal mindset sometimes ask how radar development is related to IceCube Gen2. I identified a connnection between the two fields: phased-arrays are useful for testing other radar systems because they can mimic a radar reflection that moves. I adapted a Python3 software packaged called MEEP, originally designed for μm wavelengths, to work for radio wavelengths [35]. From there, I developed phase-array models in which I could control things like the speed of light versus depth (i.e. the problem we face in IceCube Gen2). I performed design studies for single-frequency and broadband arrays, and the computed properties matched phased-array antenna theory beautifully. Intriguingly, the work represents the first time MEEP, originally designed for μm-wavelength applications, had been applied to phased array design. The results have been published in Electronics Journal [57], where the work has been named among the Top 10 most notable articles of 2020-21[4].

I can envision a wide range of CEM applications for IceCube Gen2. The phased array trigger for IceCube Gen2 must be designed accounting for the changing index of refraction. *I plan to combine a Python3 machine learning package with MEEP to optimize and study phased array trigger output given the index of refraction profile and Askaryan emission properties.* These computations could be performed in parallel on a small dedicated cluster we would assemble. I'm currently searching for the right NSF grant to do this, however I do have some startup grant funding remaining that can be used for computer hardware. If successful, the *in situ* trigger would thus be trained to detect the smallest hint of a UHE-ν signal. Theoretically, we expect a higher UHE-ν flux with smaller amplitudes, so in this way we would be maximizing the scientific output.

My proposed CEM computation cluster would also serve the PUEO collaboration for another reason [58]. PUEO will seek UHE-ν signals with arrays of RF elements flown in the atmosphere. PUEO antennas are the same type as the ones I designed for the Navy, and would be flown on a weather balloon gondola. PUEO is therefore dubbed an *in air* version of Askaryan-class detector. PUEO faces a computational requirement that *in situ* detectors do not: the signal must refract through the rough snow surface and into the air. The Antarctic snow surface roughness has been measured [59], and it can degrade the signal. With the measured roughness as initial conditions, I can calculate the predicted signal in PUEO arrays with near-to-far-field projection. In my work published recently in Electronics Journal [57], I produced this type of refraction, but with a smooth surface. It would not be difficult to add the effect of the rough snow surface.

Connection to Teaching and Academic Mentorship

We always attempt to form connections between our research and teaching, and my work for the Navy has required me to teach. My contacts are Dr. Christopher Clark, Dr. Eisa Osman, and Dr. Gary Yeakley, who work on active seeking radar. Dr. Clark relayed a compliment I received from Dr. Yeakley, who had this to say about my 1-2 hour lectures given once per week in Summer 2020.

[4]The notice of these awards is included in the supplemental material.

> "One of the most stunning compliments Prof. Hanson received was from my Senior RF Engineer, Mr. Gary Yeakley (who has been working developing, designing, and testing radar since the 1970s), where Gary stated "every week I learn new RF Physics from Jordan [Prof. Hanson]."

I have included a letter of advocacy in the supplemental materials from Dr. Clark. Researching a new subject, mastering it, and teaching it to colleagues in the Navy was a rewarding experience, and I was grateful to serve. My Navy contacts invited me back for Summer 2021 to teach an RF Field Engineering Course. In practice, this amounted to creating tutorial videos my colleagues can download. This content will also be useful for digital signal processing (DSP), my upcoming January term course.

This past summer (2021), I included in this work a student named Adam Wildanger through a Fletcher-Jones Fellowship. Adam is a great help, because he has taught me computer assisted design (CAD). The process begins with me creating an antenna design using CEM tools. Next, Adam ports my work as a machine-readable design using his favorite CAD programs. Third, Adam sends the machine-readable design to our Navy colleagues, who fabricate it using a 3D printer. Finally, they have sent the fabricated components to me. Adam and I have begun to test them in the Science and Learning Center using equipment provided by ONR. The key is to use 3D printer material that conducts some amount of electric current at high frequencies. If successful, this collaborative effort has applications as diverse as UHE-ν research, radar development, 5G mobile communications, and remote sensing for climate science (`https://cresis.ku.edu/`). The key lesson here is that sometimes the mentor can learn new things from the student. I am working on securing Adam a position at the national lab where my ONR colleagues are based. That has been Adam's dream job throughout college.

3.3.2 Mathematical Physics

In 2015, I became a CCAPP Fellow at The Ohio State University, where I began to work on an analytic Askaryan radiation model. At the time, the simulation package for IceCube Gen2 (NuRadioMC) was under development. The two *in situ* groups, ARIANNA and the Askaryan Radio Array (ARA), relied on the MC codes ShelfMC and AraSim, respectively. Both ShelfMC and AraSim were derived from the same legacy code. We learned, however, that ShelfMC and AraSim did not always produce the same results, and were cumbersome to compare. Further, the Askaryan models in both were 5-10 years old, and derived from *semi-analytic* parameterizations.

The results of foundational work in Askaryan effect simulated every single sub-atomic particle in the cascade initiated by the UHE-ν, and the corresponding radiation [60]. Overall radio pulse amplitude was found to be proportional to the energy of the neutrino. A distribution of radiated power was observed to radiate in a special direction: the Cherenkov angle. Such models were called *full-MC* models. By tradition, physics simulations are sometimes called *Monte Carlo* simulations (MC). Semi-analytic parameterization models provide part of the electric field at the Cherenkov angle, and simulate the cascade development along the UHE-ν direction. Mixing these two results produces the electric field (radio wave) at a variety of angles [10].

Frequency-Domain Model

Missing from the 2018 ShelfMC/AraSim integrations was a common analytic understanding of Askaryan radiation. I responded by developing a fully analytic model[5] that accounted for several important effects [15]. The independent variable in the equations is the frequency of the radio wave, so the model is classified as a *frequency-domain* model. I was inspired by work by Prof. John Ralston and Roman Buniy [61]. Using simulations on the Ohio Supercomputing Cluster (OSC), we determined the shape of the electric charge distribution in the UHE-ν induced cascades with total energies of 10^{17} electron-volts.

We then wrote a function that followed this shape, and finished the ensuing electromagnetic calculations to obtain the radio wave. My model produces template waveforms for UHE-ν searches with IceCube Gen2 [15]. The community began to use the model after I presented it at workshops at KICP (Univ. of Chicago), and TeVPA conferences. Colleagues shared with me that a time-domain model at all angles relative to the Cherenkov angle would be highly useful. In the final section of [15], we did provide an example, but only if the viewing angle equals the Cherenkov angle.

[5] In this sense, analytic means a set of equations, not a simulation.

Time-Domain Model

There are four main advantages of analytic time-domain models. First, when they are matched to observed radio waveforms, UHE-ν cascade properties like total energy may be derived directly from waveform shapes. Second, evaluating a fully analytic model technically provides a speed advantage in software compared to other approaches. Third, when analytic models are combined with RF antenna properties (derived using CEM), the resulting template can be embedded in detector firmare to form a filter that enhances the probability that a passing UHE-ν signal is detected, rather than be mistaken for radio noise. Fourth, parameters in analytic models may be scaled to account for snow density in addition to ice density. This application is useful for understanding potential signals in the Antarctic firn, or the upper 100-meter layer of snow that rests on top of the ice. My student, Raymond Hartig, and I are proud to announce that our work will be published in Physical Review D [34]. My vision for the future of this work involves three tracks.

The first track involves UHE-ν template analysis. Our simulation for IceCube Gen2, NuRadioMC, is broken into four pillars (steps). Currently, UHE-ν are simulated first as *events* (NuRadioMC pillar (1)) and the *RF emissions* (Askaryan signals) are generated next (NuRadioMC pillar (2)). Our ability to match simulated waveforms to potential UHE-ν waveforms from the detector is limited because we cannot scan through properties of the simulated *cascades* of particles created by the UHE-ν, only the UHE-ν with a single RF emissions model. For example, two UHE-ν with the same energy could generate different cascades with different shapes of electric charge. The effect of the cascade shape is important for the interpretation of future IceCube Gen2 data. Conversely, if the effect of the cascade shape is well-understood, it becomes possible to measure the UHE-ν energy by templates to observed data [34].

The second track involves embedding the model itself in detector firmware. Since the detector cannot distinguish small signals from noise, both noise and signal data are saved to the hard drive. We try to isolate UHE-ν signals in large data sets comprised mostly of radio noise once the data has been transmitted to the USA. However, all data has to be shipped with limited bandwidth, and it is rarely possible to ship data continuously. Embedding the model on the detector would allow the detector to distinguish noise from signal, and flag priority events. The physics community expects IceCube Gen2 to provide this type of alert system so that other physics and astronomy detectirs could search for any UHE-ν or cosmic-ray sources we identify. This is not possible if the data has to be shipped and then searched offline, because this takes too much time. Flagging and transmitting events that correlate with analytic predictions is a strategy that solves the problem.

The third track involves the connection between CEM and our Askaryan model. In NuRadioMC the simulated signal is created by code in pillars (1)-(4) sequentially. That is, the basic Askaryan model is mixed with detector response *after* ray-tracing. In reality, the radiation flows immediately from the cascade according to the details of the index of refraction of the ice. It is a wave that *generally* follows ray-tracing, but that reflects from internal ice layers, propagates horizontally, and can change shape. All the effects *not captured* by the smooth index of refraction function, n, will affect the signal. In this regard, fully-analytic Askaryan models have a unique advantage: analytic equations can be implemented as MEEP sources, and MEEP *can* account for all those effects, while ray-tracing cannot. The analytic model is in a unique position to provide advanced insight into the effect of 3D propagation previously unexplored.

Connection to Teaching and Academic Mentorship

Researching mathematical physics and radio waves has sharpened my teaching of electromagnetism for obvious reasons. I taught our version of upper-division electromagnetism this past semester: Electromagnetic Theory (PHYS330). I included detail about this experience, which was wonderful, in Sec. 2.

I have been mentoring an undergraduate double-major in physics and mathematics named Raymond Hartig who plans to attend graduate school. Our partnership began in Spring 2020, when Raymond approached me for training in complex analysis. These are the mathematical tools necessary to perform some electromagnetic calculations. We then won the Fletcher-Jones Undergraduate Research Fellowship for that summer. The experience of coaching him in his development as a theoretical physicist has been rewarding, and I have taken note of a key skill project leaders must have.

Similar to teaching courses, one has to think pedagogically when explaining projects to young researchers. If they understand the direction at least as well as the syllabus of a course, they are more likely to succeed. *From the perspective of equity and inclusion*, my experience mentoring students pedagogically is useful. By structuring the students' time, and explaining goals and productivity expectations in advance, students from diverse backgrounds feel called to participate in the same sense that they feel invited to participate in the classroom. Sometimes research can make first-generation students, for example, feel that the work is not for them because it is too unfamiliar. By actively providing them with pedagogical structure, I am signaling to them that *they belong* in my lab.

3.3.3 Firmware, Software, and Hardware Development

Askaryan-class detectors must operate autonomously due to the limited Antarctic infrastructure. Stations must be powered sustainably with solar panels and wind turbines, and communications bandwidth is restricted to satellite modems and LTE networks [19] [62]. Every sub-system that can operate autonomously is another sub-system that does not use bandwidth. The ARIANNA stations, for example, send text messages via satellite modem to the server in the USA. Configuration files are sent by the server to the stations with operational instructions. This includes channel thresholds, which control the RF thermal trigger rate. When signal or noise is more powerful than the threshold setting, the station is *triggered* to record the data present in the channels. Otherwise, the data disappears. All radio and radar systems trigger on *thermal noise* as well as signal. A lower threshold increases the chance of hearing signals at the cost of recording more thermal noise. To adjust thresholds in response to fluctuating thermal noise (which can fill up detector memory), we have to analyze the data between satellite messages, optimize thresholds, and send the stations new instructions. This process, however, should be automated for hundreds of stations in IceCube Gen2.

The Multi-Mode Frequency Counter (MMFC) and ARIANNA

My student, John Paul Gómez-Reed and I developed firmware for the ARIANNA boards that would perform this automation. This was a two-year process that began when we won the Keck Fellowship in the summer of 2018. First, we learned to design and load firmware into circuits. John Paul named the system the Multi-Mode Frequency Counter (MMFC), because it is a digital counter that measured the rate at which particular ARIANNA channel was triggered by thermal noise. We demonstrated it could measure channel trigger rates from from 10 hits per second to 10 million hits per second. (When a channel is triggered millions of times per second, that is the effect of just noise and no interesting RF signal). The digital input was provided by RF lab equipment I purchased for Whittier College using my startup grant. John Paul presented the results at the Southern California Conference for Undergraduate Research (SCCUR) [32]. We then received ARIANNA systems from UC Irvine for systems integration. *In summer 2019, we won the Ondrasik-Groce Fellowsip.* Throughout 2019 and early 2020, we used that fellowship to integrate the MMFC into the ARIANNA circuitry. The circuit boards began to auto-adjust station thresholds. We were in the process of final testing when the pandemic forced us to pause. We did, however, present at SCCUR a second time [33].

Future Plans and Applications

To continue this research, I have submitted a grant proposal to the Cottrell Scholars Program[6]. The proposal outlines in detail the next three phases of this research, broken into concrete steps within each phase. The overall goal is to enhance the trigger capability of our detectors with my analytic Askaryan models (Sec. 3.3.2).

Phase 1 includes two main steps: (1) completing the integrated threshold automation firmware and software, and (2) completing the analytic Askaryan model. As of this summer, both (1) and (2) are complete. The integration of (1) into ARIANNA systems had to be put on hold due to the pandemic, but both the software and firmware are written. The latest version of the Askaryan model is complete, and will be published in Physical Review D [34]. **Thus, phase 1 is already complete.**

Phase 2 includes two main steps: (1) learning to match templates to data in firmware, and (2) demonstrating the system in an anechoic chamber[7]. The reliability of this process must be proven before the firmware is deployed in Antarctica. The key to step (2) is to calibrate the whole planned RF chain: a signal generator programmed with my analytic Askaryan model, transmitting and receiving antennas, amplifiers, filters, and digitization circuits. I have performed similar processes as a post-doctoral fellow at KU [28].

[6] This is included in the supplemental material.
[7] An anechoic chamber is a space that blocks all radio noise and reflections for the testing of sensitive RF equipment.

Phase 3 includes three steps: (1) publication of threshold automation and Askaryan model, (2) installation of the Askaryan-trigger firmware in detectors, and (3) field deployment. It is wise to have the components of this project peer-reviewed and published before installing them in many detectors. As of this summer, the Askaryan has passed peer review. Once the IceCube Gen2 collaboration has a chance to review the firmware, we could move forward with deployment.

Connection to Teaching and Academic Mentorship

There are important connections to mentorship and teaching within this work. First, John Paul Gómez-Reed is a Whittier local, and from a background under-represented in physics and engineering. I was able to coach him through courses, application processes, and two SCCUR conferences. We are currently working on graduate school and job applications. Working with him has honed my mentorship skills, including when to hammer out details in the lab with my students, and when to leave them to figure it out on their own. Working with a self-motivated student like John Paul required me to become attuned to that dynamic.

I have taught two courses connected to this research: Computer Logic and Digital Circuit Design (PHYS306/COSC330), and Digital Signal Processing (COSC390), which introduced an interesting synergy. I selected the Xilinx pynq-z1 digital logic education unit (`www.pynq.io`) for PHYS306. The circuit board allows students to operate a Unix-based processing system (PS) integrated with a programmable logic (PL) firmware layer using Jupyter notebooks (Python3). Jupyter notebooks are a tool for writing software and notes in a browser that works for all systems (Windows, Mac, Linux). Learning how to use Jupyter notebooks boosted my CEM research, because MEEP work is often done in Jupyter. Because this resarch is a DSP project, it can serve as an important unit in my DSP course.

3.3.4 Open-source Antenna Design

The MEEP-based phased array design technique has generated enthusiastic feedback. Currently, my phased array design paper is ranked top 10 most notable works in Electronics Journal for 2020-2021 [57][8]. Using my second ONR grant, we are exploring the possibility of 3D printing phased arrays with conductive filament. Additionally, UHE-ν collaborators are interested in validating antenna designs created with expensive, proprietary software against MEEP designs. Cross-checks help us to assess systematic errors. If we find similar results from both packages, we eliminate the need for the proprietary software, which reduces costs. Comparisons of antenna modeling software are also found in Electronics Journal [63], which insipired the selection of that journal in addition to it being open-access for our students. Using the aforementioned CEM cluster in Sec. 3.3.1, I could perform calculations that compare and optimize the antennas *themselves*, in addition to refining our UHE-ν signal predictions.

Connection to Teaching and Academic Mentorship

Creating RF antennas requires laboratory skill. I have been teaching several courses with significant laboratory components: Computer Logic and Digital Circuit Design (PHYS306/COSC330), and each year-long sequence of algebra-based and calculus-based introductory physics (PHYS135A/B, and PHYS150/PHYS180). These courses have laboratory components taught in an integrated online/lecture/laboratory format. I have also mentored students on occasion to work with our machine shop to build antennas, and to use the 3D printer. Although it would be a stretch, I could envision including student-led RF antenna design projects in DSP, PHYS180, or PHYS135B. The two latter courses are our introductory courses for electromagnetism.

3.3.5 Drone Development and The Whittier Scholars Program

A gap exists in Askaryan-based UHE-ν science. Although we have made detailed measurements of the ice properties necessary to create our detectors [16] [17] [18], we do not scan these same properties for kilometers of distance across the arrays. IceCube Gen2 radio will require a glaciological understanding of the ice across a 10×10 km^2 area. Though CReSIS[9] measurements have been used to constrain these properties across Greenland [53], there is little CReSIS data at the South Pole.

[8] See supplemental material.
[9] Center for Remote Sensing of Ice Sheets.

The Open Polar Server Data Gaps, and Drones

The Open Polar Server (OPS) is a service provided by CReSIS. Researchers may download radio sounding data from Greenland and Antarctica. The radio sounding data are recorded from plane flights over the ice. Radio sounding is like sonar in water, but the echo is a radio wave and the medium is ice. There are three disadvantages to the flight data. First, there may not be a flight near the detector. Second, flights only give a snapshot of the ice at the time. Third, the bandwidth of CReSIS radar does not always overlap with the proposed IceCube Gen2 bandwidths.

Even if there is flight data available, it comes with a trade-off. A plane flight covers hundreds of kilometers, but a plane might not return for years. Conversely, a fixed station records data over time, but only at one location. A dedicated drone could constrain the ice properties in both regimes. In the machine shop and my RF design lab in the Science and Learning Center, a student and I constructed a 3D printed drone with ≈ 1 kg payload. Before the pandemic hit, we had plans to equip it with solar charging and cold-temperature components. A similar effort is underway at CReSIS: Prof. Emily Arnold of the KU Dept. of Aerospace Engineering has begun an NSF CAREER grant to utilize RC military drones to study the Jakobshavn glacier in Greenland. Unlike the off-the-shelf drones, our drone design can be 3D printed and assembled from commercial parts for $<$ \$1k, but we need valuable insights from the CReSIS group on retro-fitting for cold temperatures.

Connection to Academic Mentorship and the Whittier Scholars Program

This project required me to mentor a driven engineering student named Nick Clarizio. We worked well together, and the work reminded me of designing ARIANNA. The student became my first physics double major (business, physics) to graduate as my advisee. Once we completed the drone, Nick was able to demonstrate it for my PHYS150 class, as an example of balancing forces. The drone has four motors, each with controllable thrust. Thus, if the thrust is lowered in two motors and raised in two others, the drone will move in a certain direction. Thus, my students received a hands-on demonstration of an important lecture topic. In Spring 2021, I advised another student to graduatation in this area, who chose to focus on glaciology as part of his Whittier Scholars Program final project.

I described my Whittier Scholars Program project with Nicolas Bakken-French earlier in this report (Sec. 1.1.1). The basic idea was to perform research in climate science as part of my connections to Antarctic expeditions and other polar research programs. The final project was part climate science, part cultural analysis of the role of glaciers in different areas, and part photographic essay focusing on past and current glacier structure and landscape. The project falls into the *Boyer* category of the scholarship of integration. One facet not yet mentioned was that Nicolas was able to learn some programming and help me with glaciological analysis of CReSIS data from Moore's Bay Antarctica. The work gave me a broader understanding of the ice near ARIANNA. I also helped him earn an internship at UC Irvine with my colleagues there. He helped them to develop a device that can melt a slot into a snowbank so that an RF antenna can be installed inside it. This enables more rapid deployment of both glaciology and physics experiments involving RF sensors. I had such a great experience working with Dr. Andrea Rehn and the WSP team that I have offered to serve on the Whittier Scholars Advisory Board. My offer has been accepted and I will begin in Fall 2021.

3.4 CEM and Engineering with the ONR

During 2019-2020, it became clear that not only were missions to Antarctica postponed, but that progress in my field will only resume once the IceCube Gen2 design is finalized. This is expected to happen in Fall 2021. I have been participating in the IceCube Gen2 radio task-force, which meets weekly to share results and plans for the design. In the mean time, I decided to widen my research profile so I could make meaningful progress during quarantine.

In the Fall of 2019, three separate individuals sent me emails, inquiring if I would be interested in the Summer Faculty Research Program, administered by the Office of Naval Research (ONR). An old friend from graduate school who works at the Naval Surface Warfare Center (NSWC) in Corona, CA, sent me a note. A contractor working for the Navy contacted me. Finally, my department chair, Prof. Seamus Lagan, forwarded me a message similar to that of the contractor. There is a long tradition of cross-over and cooperation between academics in physics, math, computer science, and research sponsored by the military. Because three separate people suggested I consider this program, I decided to apply.

I was contacted by Dr. Christopher Clark (NSWC), who explained to me that there is a division at NSWC that focuses on radar applications. The Navy relies on radar for defending ships and aircraft, and defending our nation from missle attacks. Scientifically, though, the Navy has always been at the forefront of *computational electromagnetics* (CEM) [64]. For example, CEM provides engineers a way to design and manage systems that manipulate microwaves for 5G telecommunications. CEM can be used for modelling electromagnetic effects in weather. In my sub-field of physics, CEM will be useful for understanding the propagation of radio waves through ice in precise detail. The Navy has created research programs much like those in civilian national labs (e.g. LANL, LBL) that provide the public with technological research (`https://www.onr.navy.mil/`).

I have been awarded this grant in Summers 2020 and 2021, and the connections to my physics research have been fruitful. In Sec. 3.3.1, I described the connection between my physics research and the CEM skill I gained from my Navy collaboration. In Sec. 3.4.1, I discuss the applications to radar and how they are useful for the ONR. My students and I use CEM to design radar antennas with useful properties like high bandwidth, low amounts of energy loss, and the ability to steer a radar beam in the right direction. In Sec. 3.4.2, I discuss the efforts of my Navy collaboration to use 3D printers to fabricate our radar designs. We are currently collecting data in our lab in the Science and Learning Center, and hope to have results to report soon. In Sec. 3.4.3, I review the potential applications for ONR, UHE-ν physics, and RF antenna design in general.

3.4.1 CEM Phased Array Design for Radar

In Sec. 3.3, I described how *phased arrays* will be useful for UHE-ν physics. Imagine a radio antenna radiating power at some frequency. The direction corresponding to the maximum power is called the *boresight.* The antenna always radiates some power away from boresight. The *radiation pattern* is a graph of this relative power versus angle from boresight. The radiation pattern of a single radio antenna is just a function of the fixed shape of the antenna. The field of RF antenna design is concerned with clever ways to find shapes that have efficient radiation patterns for a given frequency range. To track moving targets, the radar antenna must be *steered* so that the target falls within the strong part of the radiation pattern. There are disadvantages, however, to mechanical steering.

A phased array is simply an arrangement of identical radio antennas that vary in phase or timing. By cleverly arranging the phases or relative timing of signals radiated by each array element, the overall radiation pattern *steers* without any moving parts. Imagine a line of pebbles dropped in a pond. If they are each dropped at the same time, the water wave of each pebble helps to form one large wave proceeding in a direction perpendicular to the line. Now imagine that the first pebble is dropped, then a fraction of a second later the second, and then a fraction of a second later the third, and so on. The ensuing wave will proceed in a different direction. Phased array radar is this principle but applied to electromagnetic waves instead of water waves.

I summarized our CEM development in a recent publication [57]. For our CEM code, I selected the open-source Python3 package MEEP[10], and used it to produce single-frequency and broad bandwidth phased array designs. I explored Yagi-Uda antennas (lines of dipoles much like a TV antenna), and horn antennas (shaped like a lily). The radiation patterns match theoretical predictions beautifully. I experimented with *one-dimensional* and *two-dimensional* phased arrays. The term one-dimensional refers to the line of identical RF elements mentioned above in the water analogy. A two-dimensional phased array is the same idea, but a grid of antennas. A grid allows for beem-steering in two angles (azimuth and zenith angle). This work was remarkable for at least three reasons.

First, I believe my work represents the first time it has been shown MEEP can produce RF phased array designs. RF antennas are usually designed with expensive, proprietary software[11]. MEEP is open-source, so my students and I can create designs for free. MEEP was originally designed for applications with micrometer wavelengths (optical photonics). However, Maxwell's equations that govern electromagnetism demonstrate *scale independence.* For example, if an object is a few micrometers across, then it probably emits radiation with micrometer wavelengths when energized. But if I scale its size to a few centimeters across, the radiation is the same pattern, but with centimeter wavelengths. We adapted MEEP to describe phased arrays where antennas are centimeters long. The authors of a review of open-source results for simple antennas in Electronics Journal ([63]) contacted me out of the blue, to offer congratulations and to request code examples so they could utilize these tools[12]. They have used my CEM MEEP code to reproduce my results, and to learn a new way to create antenna designs.

[10] MIT Electromagnetics Equation Propagation: `https://meep.readthedocs.io/en/latest/`.

[11] For example, xFDTD by RemCom costs between $5k and $10k, depending on the desired features.

[12] Correspondence included in supplemental material.

Second, IceCube Gen2 will utilize phased arrays to detect UHE-ν in an environment with non-constant index of refraction (see Sec. 3.3.1). The index of refraction is usually called n, and the speed of light is c. In a medium with an index of refraction, electromagnetic waves travel at speed $v = c/n$. If n changes with ice depth, the path of radiation through the ice is curved and complicated. Normally the software used by the IceCube Gen2 and RNO-G collaborations (xFDTD) to design phased arrays does not account for depth-dependent index of refraction. In our recent work [57], I explored the effect of the depth-dependence of n on our phased array designs. In future work, I will incorporate our knowledge of the internal ice layers frozen into the *firn* (upper portion of the ice sheet made of snow and ice). These layers act like hidden mirrors and can alter the results of IceCube Gen2. A similar work by a colleague uses a slightly different method [65].

Third, the results show that our design forms the proper wave ≈ 10 cm in front of the antennas. The system would be compact enough to install in an *anechoic chamber*, acting as a model radar echo to test other radars. A large anechoic chamber is a room where there are no RF reflections. Normally, RF pulses bounce off of flat surfaces (hence, radar). Anechoic chambers have shapes built into the walls that cancel RF reflections, making testing a radar system possible without the confusion of reflections. Anechoic chambers large enough for radar are rare[13]. Smaller ones designed for smartphones are more common. Our design is so compact and forms the wave in such a short distance that it could potentially fit in the small variety. Our design enables the following type of experiment. Imagine bringing in a radar system that has been deployed in the field for years. It has not been recalibrated, and has been banged around at sea. When placed in front of our system, it would see a variety of signals changing direction and we could identify any systematic error in the radar output to recalibrate it. This is one of a variety of applications we envision for the Navy.

3.4.2 3D Printing of RF Antennas

This summer, my ONR colleagues and my student, Adam Wildanger, and I have begun fabricating RF antennas with 3D printing. Adam and I were awarded the Fletcher Jones Fellowship. Adam has shown me a variety of computer assisted design (CAD) programs useful for creating 3D models of our antennas. I have identified one CAD program that can render a design into a format that can be imported to both MEEP and 3D printers. This was a huge leap forward over last year. Last year, I simulated my antennas like children's blocks. I would write Python3 code that would define a small piece of metal, and then in a loop, I would assemble the antenna from hundreds of pieces. Now, we draw in the CAD program any shape we need and load it into MEEP. Thus, I can model the radiation of the design with CEM *and* manufacture the same design with a 3D printer capable of using the CAD file. Using a 3D printer has a number of unique advantages. The main one is that strangely shaped antennas designed with machine learning can have highly useful radiation patterns and bandwidth [66] [67]. Manufacturing such antennas with standard shop tools is time-consuming. With a 3D printer, CAD file, and appropriate print material, the process is automated. We are now experimenting with different printing materials.

3.4.3 Applications to Mobile Broadband

This work could have an impact in a number of broader applications. Progress in high-gain ultra-wideband radar development is hindered because desireable parameters compete with each other. The authors of [66] created a highly intriguing system that appears to have beaten some of these limitations, but have to manufacture it by welding and printing circuits using standard methods. This is time-consuming because the antenna has a very peculiar shape involving very tiny and very large features. One intriguing application for the private sector is applying 3D printing to such antennas for 5G mobile broadband. The mid-band designation for 5G is [2.5-3.7] GHz, right where our design and others radiate efficiently. If we can show that 3D printing may be used to create phased arrays of complex antennas in this range, it represents the potential for reducing the cost of 5G antenna system production.

For UHE-ν physics, the 3D printing strategy is promising for phased array design and construction for at least two reasons. First, learning to use CEM tools like MEEP will eliminate the cost of expensive proprietary software, and foster equity and inclusion in the design process. The process for IceCube relies on xFDTD, a proprietary software package that costs thousands of dollars for each installation. When open-source software is selected, any collaboration member (i.e. a Whittier Undergraduate) could participate in the detector design. Requiring proprietary software implies that only students at institutions that control significant financial resources can create the designs. Second, our design process utilizes 3D printing, which addresses a peculiar challenge faced by

[13] For example, the CReSIS anechoic chamber: `http://chamber.ku.edu`.

IceCube Gen2. We would like to drill boreholes in the ice and hang our antennas down the boreholes. Simulations show that our detector is more sensitive to UHE-ν signals with deeper antennas. However, this means our antennas need to be shaped like the borehole (a cylinder). This is not a problem if the radio pulse *polarization* is vertical. If it is horizontal, our antennas will not sense a strong signal. With 3D printing, we can fabricate novel antenna shapes sensitive to horizontal polarization that still fit in a cylindrical hole.

3.5 My Vision for Collaboration between ONR and Whittier College

According to an economic analysis by the Los Angeles County Economic Development Corporation in 2016, Southern California plays a vital and increasingly large economic role in the aerospace and defense sectors [68]. This sector is responsible for the Global Positioning System (GPS), Mars rovers, missle defense systems, and radar development for new aircraft. Southern California is home to world reknowned engineering leaders like NASA Jet Propulsion Laboratory (JPL) and SpaceX Corporation. Young engineers graduating from college understand that their skills are needed in this dynamic sector of the regional economy.

Students know that these roles are quality employment. The industry is expected to create 5630 new job openings over the next five years, with 3380 of those labeled replacements. Replacements are created when a worker retires or is promoted. Thus, the industry is creating new opportunities, but also needs young people to step forward. Of all new jobs, 40% will require a bachelor's degree. Over 90,000 people in Los Angeles County are employed in aerospace alone, and that figure is over 100,000 if public institutions like JPL are included. Since 2004, the guided missle and space vehicle sectors have experienced 62% growth. The average yearly salary is $106k per year, making these employees among the highest paid in the region. Included the entire supply chain, the Southern California aerospace sector employees approximately 300,000 people.

Several partnerships between higher education and the industry are documented in the report [68]. The report specifically mentions The Aerospace Corporation for its involvement in STEM programs. One of our physics graduates from Whittier College, Kaitlin Fundell, moved into a Research Associate position at the Aerospace Corporation. Our department has a contact there, Prof. James Camparo, who is an adjunct professor at Whittier College, and who specializes in atomic clocks. Kaitlin initially worked in Prof. Camparo's laboratory. Two other programs of note at The Aerospace Corporation are the Greater Los Angeles Education-Aerospace Partnership (Great-LEAP) program, and the Mathematics, Engineering, and Science Achievement (MESA) program for disadvantaged students. These specialized programs can be built into curricula so that graduating seniors are amply prepared for the workforce. One example given is USC engineering, where the seniors participate in year-long design challenges that link them to alumni and industry experts.

3.5.1 Building Student Success after Whittier College

When I began to interact with the Office of Naval Research, my contacts raised the possibility of a more formal partnership with Whittier College. If we consider the numbers above, the industry will need ≈ 1200 new engineering participants per year over the next five years. The breakdown of the type of roles versus time has also been stable over the past decade. Adding up all aerospace engineering graduates from Southern California UC schools, CSU schools, plus CalTech and USC gives 300 graduates per year. For mechanical engineering, the total is ≈ 1300, but some large fraction of those will move industries other than aerospace and defense. Thus, there is a shortage in the industry, including national laboratories like NSWC Corona where my contacts work. They seek to build partnerships with colleges in the region, and Whittier College is just 40 miles away. Additionally, Whittier College has an advantage as a small liberal arts college with simple bureaucracy and a diverse group of students.

To date, I have advised five physics and engineering students toward graduation (not counting my WSP student)[14] Three of them are attempting to join the aerospace and defense sector in Southern California: John Paul Gómez-Reed, Nicolas Clarizio, and Adam Wildanger. Noting that a large fraction of our STEM students might be considering this sector, we should reflect on the nature of a fruitful partnership program with the ONR. In a nutshell, we work on engineering research relevant for the ONR, while they provide resources and guidance to our students.

The obvious starting point is to provide research experiences with NSWC Corona staff. If I continue working with my contacts, I plan to advise 1-2 students per academic year on radar and additive manufacturing (3D printing)

[14] Students: Cassady Smith, John Paul Gómez-Reed, Nicolas Clarizio, Nicolas Bakken-French (WSP), Raymond Hartig, and Adam Wildanger.

Student/Professor	Grant Opportunity	Amount	Dates
Jordan C. Hanson	ONR Summer Faculty Fellow	$16.5k	Summer 2021
Adam Wildanger	Fletcher Jones Fellowship	$5k	Summer 2021
Jordan C. Hanson	ONR Summer Faculty Fellow	$16.5k	Summer 2020
Raymond Hartig	Fletcher Jones Fellowship	$5k	Summer 2020
John Paul Gómez-Reed	Ondrasik-Groce Fellowship	$7.5k	Summer-Fall 2019
John Paul Gómez-Reed	Keck Fellowship	$5k	Summer 2018
Cassady Smith	Keck Fellowship	$5k	Summer 2018

Table 3.1: A listing of the grant opportunities awarded to my group.

Equipment	Purpose	Bandwidth	Cost
Jordan C. Hanson	ONR Summer Faculty Fellow	$16.5k	Summer 2021
Adam Wildanger	Fletcher Jones Fellowship	$5k	Summer 2021
Jordan C. Hanson	ONR Summer Faculty Fellow	$16.5k	Summer 2020
Raymond Hartig	Fletcher Jones Fellowship	$5k	Summer 2020
John Paul Gómez-Reed	Ondrasik-Groce Fellowship	$7.5k	Summer-Fall 2019
John Paul Gómez-Reed	Keck Fellowship	$5k	Summer 2018
Cassady Smith	Keck Fellowship	$5k	Summer 2018

Table 3.2: A listing of the equipment provided to our labs by the Office of Naval Research.

projects. Thus far, I have been awarded two ONR grants (Summers 2020 and 2021) that have provided me funding. My students and I have been awarded *internal* Keck Fellowships, Fletcher-Jones Fellowships, and the Ondrasik-Groce Fellowship, providing them with stipends (see Tab. 3.1). I would like to shift the student financial support onto the ONR. In exchange, I assume they will want students to perform research tasks related to ONR goals. *Since a large fraction of my students want to perform this research anyways,* it should be possible to assemble. I am hoping to coordinate this as a team effort between Whittier College Advancement and ONR personnel. I can apply for the ONR Summer Faculty Research Fellowship for Summer 2022. After Summer 2022 I am eligible to reapply at a higher compensation level (Senior Fellow) in Summer 2024. The *cooling-off year*, 2023, is a Navy requirement. If I am awarded tenure, my sabbatical would coincide with the cooling off year, so the timing is perfect.

3.5.2 Equipping Whittier College Laboratories

My colleagues at NSWC have already provided my laboratory in the Science and Learning Center with equipment for RF measurements like characterizing radar antennas. Table 3.2 contains a list of all the components, their purpose, and estimated value. This equipment is on loan for the six month period starting with August 2021, with the possibility to renew after that. Table 3.2 shows the level of committment my ONR partners have to our small liberal arts college. Several facts about this equipment are worth explaining, to appreciate the science that becomes possible with access to it.

To measure microwave power vs. frequency, we require a network analyzer. In 2017, I acquired a multi-domain oscilloscope (MDO) with my startup funding that also included a spectrum analyzer. The purpose of the MDO is to provide a way to graph analog and digital signals versus time and frequency. At around $6k, this device is capable of graphing the power vs. time received by some antenna under test (AUT) up to 200 MHz. The 200 MHz limitation is called the bandwidth because we can measure from [0-200] MHz. Typical mobile phones operate at a frequency of around 900 MHz, but FM radio is less than 100 MHz. As the bandwidth increases, the price increases rapidly. The Rhode and Schwartz network analyzer can measure received power and phase versus frequency[15], over a bandwidth of [0-6000] MHz or 6 GHz. Thus, my students and I can access a whole new bandwidth and consider new designs that operate in that bandwidth.

My ONR colleagues have also loaned us a signal generator with the same bandwidth as the network analyzer. The signal generator creates a sine wave, or other signal, at some frequency and feeds it to a transmitting antenna with well-understood properties. From there, the electromagnetic radiation leaves the transmitting antenna,

[15]The phase is an additional piece of information about the signal at a given frequency. If a signal $s(t)$ is a sine wave, $s(t) = A\sin(2\pi ft+\phi)$, then A^2 is proportional to the power, and ϕ is the phase.

passes through air, and excites the AUT. Both antennas are mounted on rotatable mounts, and we have a variety of test antennas. Finally, we have special tools to calibrate the major pieces of equipment, and RF connectors and cables to link everything together. Thus, we have a complete system for understanding a new microwave antenna.

3.5.3 Financial Support

From Tab. 3.1, I can receive $16.5k per summer as a Summer Faculty Research Fellow through ONR. At the next level, Senior Fellows receive $19.0k per summer. To qualify for Senior Fellow, one must have been awarded tenure as an Associate Professor at an institution accredited by the U.S. Department of Education. One also must have published one paper per year since receiving a doctoral degree. If awarded tenure in academic year 2022-23, I would meet both requirements for the 2024 application round. Regarding sabbatical, the ONR does have another program designed for professors to complete research projects while on sabbatical for 1 or 2 semesters. This funding makes a big difference for my family, and we are proud to work hard for Whittier College and our students as they help serve ONR. Regarding student financial support, I am hoping to coordinate that this year as a team effort between Whittier administrators and ONR personnel.

3.6 Conclusion

Since my last supplemental PEGP in 2019, my students and I have made wonderful progress, and I am proud of them. In particular, I am excited to share with you that I have been publishing again. During the attempted merger of ARA and ARIANNA (Sec. 3.3), my field experienced turmoil. It seemed I was going to have to find a new field all together. The radar research has given me insight into my field, and the mathematical physics paper was a great achievement. My colleagues in my department have shared with me our guidelines regarding tenure and scholarship. One pathway is to publish at least three original works in physics *scholarship of discovery* during our pre-tenure period. Below are three papers I have published since Fall 2017 as the main author:

1. J.C Hanson *et al.* "Observation of Classically Forbidden Electromagnetic Wave Propagation and Implications for Neutrino Detection." Journal of Cosmology and Astroparticle Physics, n. 7 p. 55 (2018). `doi:10.1088/1475-7516/2018/07/055` *and* C. Glaser *et al.* "NuRadioMC: simulating the radio emission of neutrinos from interaction to detector." The European Physical Journal C, vol. 80 n. 2 p. 77 (2020). `doi:10.1140/epjc/s10052-020-7612-8`

2. J.C. Hanson. "Broadband RF Phased Array Design with MEEP: Comparisons to Array Theory in Two and Three Dimensions." Electronics Journal, vol. 10 n. 4 p. 415 (2021). `doi:10.3390/electronics10040415`

3. J.C. Hanson and R. Hartig. "Complex Analysis of Askaryan Radiation: A Fully Analytic Model in the Time-Domain." *Accepted to Physical Review D.* `arXiv:2106.00804` (2021).

The papers in item (1) deal with the issue of ray-tracing and radio propagation in ice. I produced a ray-tracing solution that accounted for real ice properties, while arguing that the observation of special cases of horizontal propagation was not explained by ray-tracing. For the second paper in item (1), I was not the corresponding author, but my results were used to create our main simulation package NuRadioMC. Item (2) is my award-winning phased-array design paper using open-source software. Item (3) is our mathematical physics paper on Askaryan radiation. This list is by no means complete. In my field, collaborations of 10-100 people are common, and every name goes on the author list in alphabetical order regardless of contribution level. Since 2017, I have helped to write many papers for which my work was an integral part, but I am not the "corresponding author." For a full list of publications, I have provided my CV in the supplemental material.

Thankfully, my field has recovered from the turmoil, and we look forward to many discoveries ahead. Finally, I have decided to move my remarks about the Whittier Scholars Program to Sec. 4, Advising and Mentoring, because my part of that project was much more about guidance and management than hands-on research work. It falls under the *Boyer* catagory *scholarship of integration*, and deals with a holistic study of the impact and changing nature of glaciers.

Chapter 4

Advising and Mentoring

4.1 Connections to Teaching and Service

4.1.1 Inclusion, Community, and a Sense of Belonging

4.2 Advising and Mentoring First Year Students

A

4.2.1 First Year Advising, by the Numbers

B

4.2.2 Navigating the First Year

C

4.2.3 Discernment of Major

D

4.2.4 Equity of Access

E

4.2.5 Inclusion and Belonging: Activities with First Year Advisees

4.3 Advising and Mentoring Majors in Physics, ICS, and 3-2 Engineering

A

4.3.1 Discernment within STEM: Major Selection, and Diverse Pathways to Graduation

B

4.3.2 Graduate School

C

4.3.3 Private Sector

D

Reverse Engineering Social Media

E

4.3.4 Letters of Recommendation

F

4.4 Advising and Mentoring Whittier Scholars Program Majors

A

4.4.1 Interdisciplinary Connections and Recruiting Students

B

4.4.2 Organization of Field Deployments

C

United States Antarctic Program

Describe the attempt to deploy Nicolas to Antarctica

4.4.3 Organizing the Program of Study and Executing

E

4.4.4 Polishing the Finished Product

F

Chapter 5

Service

5.1 Committee Service

Admissions sub-committee, data analysis, maybe a graph

5.1.1 Enrollment and Student Affairs Committee, Years 1 and 2

Write about how I learned about orientation issues from these meetings
Interactions with Falone Serna

5.1.2 Educational Resources and Digital Liberal Arts Committee

Creation of senior thesis archival program

5.1.3 Whittier Scholars Program Advisory Board

I was invited! Sort of.

5.2 Departmental Service

This one can be stronger, maybe

5.2.1 Departmental Self-Study

5.2.2 Departmental Annual Assessment

5.3 First Year Orientation

A

5.3.1 Connection to Teaching and Advising

B

5.3.2 Inclusion and Belonging

C

5.4 Open Educational Resources (OER) Workshops

openstax, oercommons, and openstax tutor, dspguide.com

5.4.1 Open Educational Resources (OER) and Equity

5.4.2 The Tradition of Open Access/Open Source in STEM

The OpenStax Platform

Integrations with Machine Learning

Open Access in Digital Signal Processing

5.4.3 Lectures at Wardman Library Collaboratory

5.5 Center for Engagement with Communities: The Artemis Program

A

5.5.1 Equity and Inclusion in STEM

B

5.5.2 Connections to Teaching at Whittier College

5.6 Summer Working Group Contribution

A

Elec

B

Chapter 6

Conclusion

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Chapter 7

Supporting Materials

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