Professional Evaluation and Growth Plan

Jordan C Hanson, PhD

September 6, 2021

Contents

Chapter 1

Introduction

1.1 Beginning

Friends,

I have compiled a report on my progress as a liberal arts educator for the period of 2019-2021. 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 students are being served well, and that meant a great deal to me. I understood your suggestion to enrich my teaching 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 our 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 the importance of weaving a personal narrative. Thus, I have shared a section about my academic origins and my vision for multi-disciplinary teaching and scholarship (Sec. 1.2). I have also written about my family and working during the pandemic (Sec. 1.3). I hope these sections prove useful, and I understand that you all are pressed for time. Thank you in advance for what is sure to be a difficult year of service. My family is also grateful that we were allowed to postpone the PEGP for one year. It helped us to avoid a difficult situation. My spouse is considered an essential worker, and was called back after a shortened maternity leave. Since that time, have been working as a full-time professor and a full-time parent *by myself*. Thankfully, my *suegra* (mother-in-law) has stepped in to help after we got vaccinated. I look forward to seeing you this Fall, and we hope you are well.

Sincerely, Prof. Jordan C. Hanson

1.2 Academic Origins

As professors, we all share the experience of being inspired in college and graduate school. When I was an undergraduate at Yale University, my family nudged me towards engineering. My curiousity kept returning me to physics. In my heart, I knew that I wanted to help create discoveries, and I fell in love with enlightening others. I learned that the laws of physics morph and merge into one another as systems move near the speed of light. I 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 of cosmic ray origins has remained unknown for 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 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. Neutrinos propagate in straight lines through the Universe, while any electromagnetic field exerts force on the charged cosmic rays, bending the trajectory. Thus, unchanged UHE-ν trajectories could reveal the locations of the cosmic ray accelerators, thereby teaching us about unexplored laws of physics[3] [4] [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 has published the observations of extra-solar neutrinos at energies below the Askaryan threshold that could originate from unique objects near our galaxy [11]. 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 would reveal the source of cosmic rays and new physics. The authors of [14] conclude that Askaryan-class detectors are the logical next step. We 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 the radio pulse. It turns out that radio waves travel ≈ 1 km in *Antarctic ice* [16] [17] [18]. Thus, we can create RF detectors separated by 1 km to cover enormous volumes of ice [19]. The volume is necessary because the expected UHE-ν flux is low. When a potential signal arrives, stations will capture the radio pulse [20]. The dataset will then be 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 build a prototype *in-situ* array: the Antarctic Ross Ice Shelf Antenna Neutrino Array (ARIANNA).

We began by measuring the ice shelf thickness and radio transparency in Moore's Bay, the location of ARIANNA [23]. We deployed prototype stations in two separate missions. I designed systems that managed station power consumption and recorded environmental data [19] [24]. We demonstrated with simulations that a 30×30 array would reach target UHE-ν sensitivity. Further, the sensitivity doubled in Moore's Bay through *reflected* events, in which RF signals reflect from the ocean beneath the ice shelf. Over several years, we completed the prototype array, and published upper limits on the UHE-ν flux [25]. We observed cosmic rays [26] (though we cannot determine their original direction), and completed a second UHE-ν search [27]. Quantum mechanics dictates that UHE-ν interact more rarely in dense matter, meaning the detectable flux is lower than that of cosmic rays. With IceCube Gen2, we will increase the number of stations by more than an order of magnitude, and we expect to finally 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 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 Askaryan physics and the 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].

When I became a professor, I turned my attention to the complex path taken by Askaryan pulses through

[1] Center for Cosmology and Astro-Particle Physics

Antarctic ice. The path is curved because the speed of light depends on the ice density, which changes with depth. In 2017-2018, a student and I found solutions for the ray-path [29]. These calculations became one of the four main pillars our current software that computes detector sensitivity to UHE-ν [30] [31]. Meanwhile, a student and I designed firmware upgrades for the RF detectors and presented the results at SCCUR, twice [32] [33]. These tools facilitate automation of our *in situ* array. The pandemic has prevented deployment, but they can be incorporated in IceCube Gen2. For both projects, I included undergraduate students. The first was a young lady who went on to become a researcher for the gravity-wave detector LIGO, and who is now a gradaute student at Yale. The second was a student of color and Whittier native who majored in ICS/Math, and who is currently 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. 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. This equipment is prohibitively expensive, and thus our partnership is opening new doors scientifically. If we succeed, this research has applications to UHE-ν physics (by creating new and better antennas), 5G mobile, and radar. I describe the partnership in Sec. 3, and how it will benefit our students.

Finally, I would like to highlight my contributions to the Whittier Scholars Program (WSP). I met with a student who showed me photographs of glaciers he had taken while visiting family in Norway. He shared an idea to perform a comparative photographic analysis with historical photos of glaciers all over the world. The goal would be 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 my new *Connections 2* course about the history and current status of science in Antarctica (INTD255). The research was at the intersection of glaciology, climate science, comparitive cultural perspective, and environmental justice. 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 imquired about serving the WSP Advisory Board, and my offer was accepted. Thus, I have come full circle regarding the FPC invitation to serve in the liberal arts.

1.3 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. After immigrating to Los Angeles, they were forced to deal with gangs and poverty. My wife and all six of her siblings studied hard and graduated college. My wife and I share our Catholic faith, and we strongly value higher education for our children.

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. She remarked that this was the first time she had seen a STEM professor audit a language course. It turned out to be wonderfully useful, 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 divisive trends that have arisen within our broader culture, and as someone who tries to be a loving person, I felt the desire to share with you the story of our family for what it says about the true value of acceptance of those who are different.

I recognize 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. Before the pandemic, sometimes colleagues would try to teach me about "the first-generation experience," assuming that the white male physicist would not understand. I always smile inwardly, since my entire family has shared this experience with me.

I am keenly aware of the importance of our curricular theme of *belonging.* Despite the challenges brought 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 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. Inflexibility would have made class accessible only for wealthy students. Regarding belonging, I am often reminded of a basic fact: *even though my heritage is different from my family, 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.

1.3.1 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.* There was a hunger for this course, and students needed to see that *all* of our ancestors performed science. We encounter a false historical contrast of *central* and *peripheral* scientific communities. Taking STEM courses alone might give the impression that European and American cities have been central to scientific progress, and that Latin American communities have been *peripheral.* By honestly covering the colonial period in Latin America, we find examples in which Latin American communities were *central.* A more accurate description would be a full two-way exchange of knowledge (Sec. 2). I invited Sonia Chaidez to introduce my students to digital storytelling. The students created 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 1910-11. Second, we cover current science in Antarctica. Third, we perform 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, where he spent time with indigenous Canadians. I share the rest of the story in Sec. 2. The course therefore connects inclusion and belonging to survival and exploration.

1.3.2 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 reports. 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.* 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

[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 made a chapter of Notes of A Native Son the summer reading assignment for my College Writing Seminar.

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 just in India. Another rule I had to make for class: you can't be naked. This is a family establishment. Please put a shirt on. I don't wanna see that. After 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. The next time you hear someone complain about masks, just think of how close my baby was to being born in a RAV4.

Sometimes I had to fight for my students. We made sure to purchase enough bandwidth for our house 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. Whyyyy. The Education Blocking Device was removed, 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 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. Baby wakes up, class paused. 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. I dreamed often of turning that blasted rooster into tacos.

Despite the quirks of life in East Los Angeles, we take great pride in maintaining the community. Except on 4th of July. Then we blow it to smithereens. 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 professors 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. He had two beautiful daughters with my cousin. 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. We have all suffered. But we can still find hope, joy, and even laughter, knowing our community is still here. Whittier College needs us. The students have returned, and Whittier College will once again 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. 1.3. 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. Sometimes I would meet with students while they were on their break at their jobs to help with homework. The students responded positively to the flexibility. 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 hear 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.

[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.

After more experimentation, we find the results are identical no matter where we are in the Shannon Center Auditorium. It is a *universal experience.*

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 lower 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 song 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 as the water froze. 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.

[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.

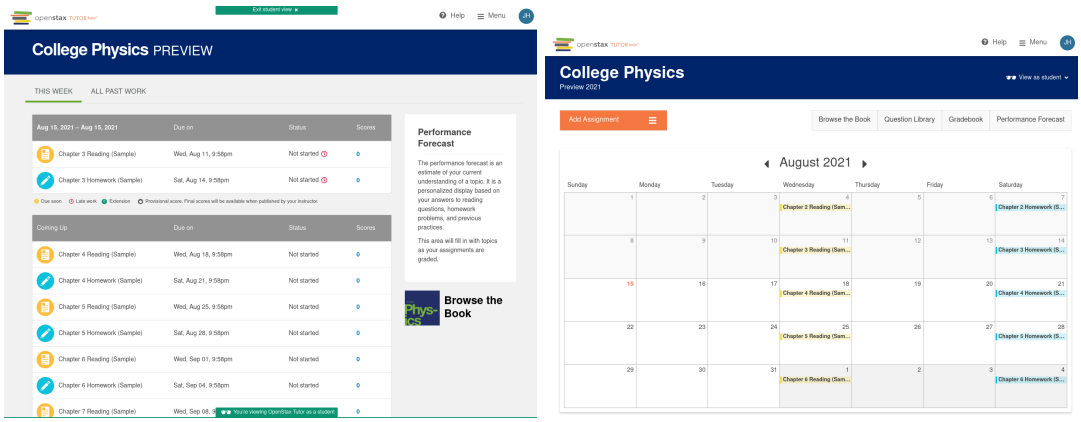


Figure 2.1: (Left) Student view of OpenStax Tutor. (Right) Professor view. In both pictures, reading assignments are in yellow and homework assignments are in blue.

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 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

[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.

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.

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:

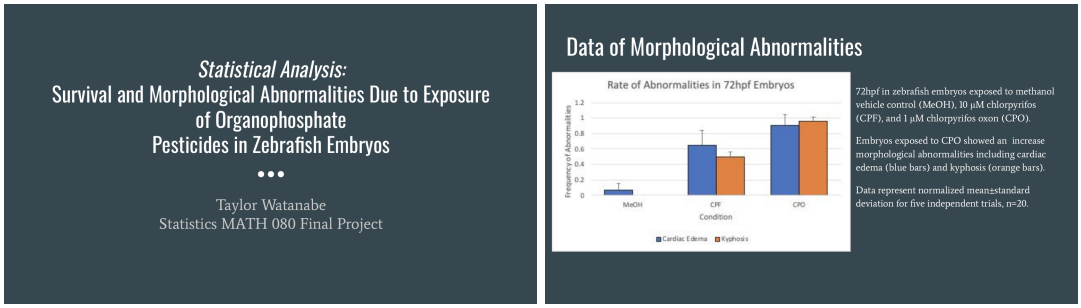


Figure 2.2: The title slide and key results of the final presentation of one of my students, Taylor Watanabe. I taught this student physics for a year, followed by statistics in summer session.

- 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.

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, and several examples are included in the supporting material. 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. The first is Computer Logic and Digital Circuit Design (COSC330/PHYS306), and the second is Digital Signal Processing (DSP, COSC390) (see [39] for an example of computer logic and [40] for an example of DSP). 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. For example, in DSP, I write computer code to illustrate graphical and computational concepts, and the students modify it 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.
- 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 today's 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).

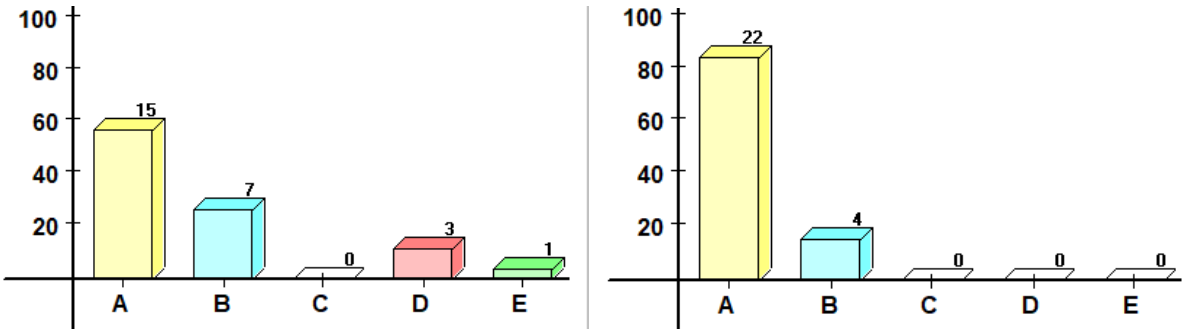


Figure 2.3: (Left) An answer distribution of my 25-student PHYS135A class (A was correct). This distribution triggered a table discussion. One student pressed E (indicating confusion) and I took appropriate action. (Right) After table discussions, the students responded and the fraction of correct answers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

- 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:
  1. If the fraction of correct answers is > 0.7, we proceed to the next exercise or new material[7].
  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 course concepts by visualizing and manipulating them.
- 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.

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

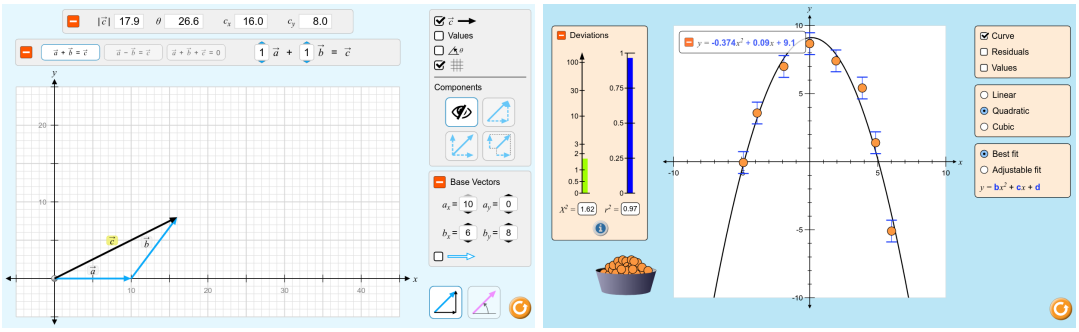


Figure 2.4: Two examples of PhET simulations used by my physics students in the lecture/laboratory formatted courses. (Left) Vector addition. (Right) Curve-fitting to data.

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 1-2 days before class. An example is shown in Fig. 2.5. Next, we review the agenda, homework, reading schedule, and the memory bank. The memory bank is a list of equations the students master through repeated application. We proceed with the solution to the warm-up, and then expand to other examples on the board. From there, the TT ends and 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. I now include a break between the TT module and the rest of the class period[8]. 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 worksheets[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. When students are running low on energy, working together allows them to press on and learn from each other, which refreshes them and requires less energy. During remote instruction, my department 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 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 "scaffolding" of the lab procedure. When given a choice between non-scaffolded and scaffolded, I chose LA modules with scaffolding.

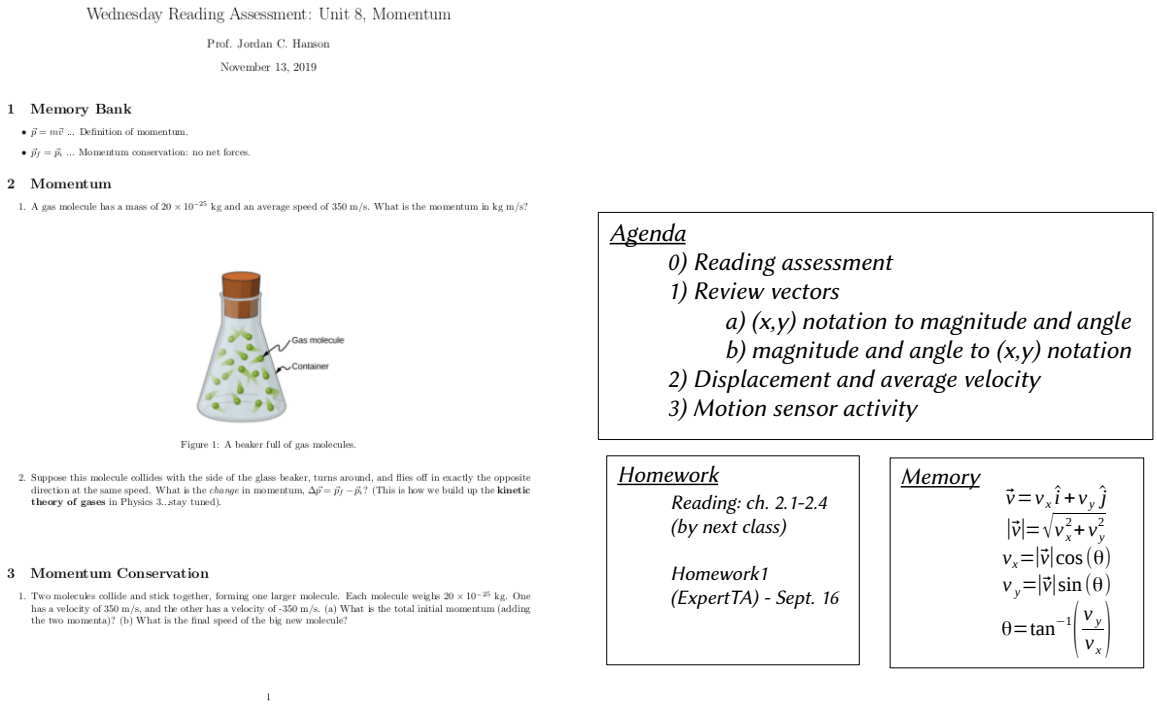
2.4 Introductory Course Descriptions

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.

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

[8] During the module system, classes were shorter.
[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?

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

Agenda

0) Reading assessment
1) Review vectors
a) (x,y) notation to magnitude and angle
b) magnitude and angle to (x,y) notation
2) Displacement and average velocity
3) Motion sensor activity

Homework

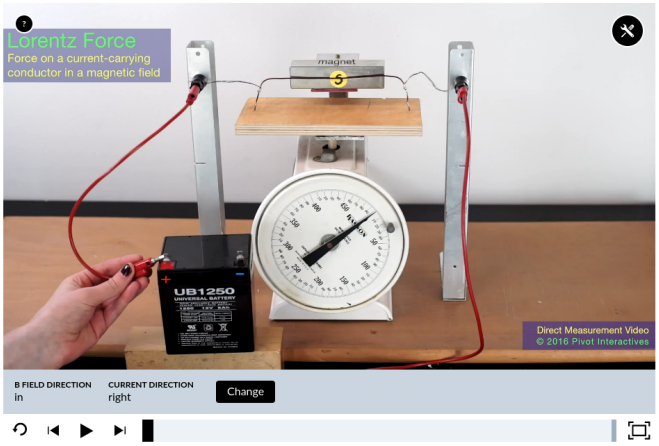
Reading: ch. 2.1-2.4 (by next class)

Homework1 (ExpertTA) - Sept. 16

Memory

$$\vec{v} = v_x\hat{i} + v_y\hat{j}$$
$$|\vec{v}| = \sqrt{v_x^2 + v_y^2}$$
$$v_x = |\vec{v}|\cos(\theta)$$
$$v_y = |\vec{v}|\sin(\theta)$$
$$\theta = \tan^{-1}\left(\frac{v_y}{v_x}\right)$$

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.



2. The first time the wire is connected to the battery, the scale settles on a reading of about 78 g so the force is:

$$78g \times \frac{1kg}{1000g} \times \frac{9.8N}{1kg} = 0.764N$$

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

to physics. I encourage the students with extra credit, and I help them to practice 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* (Question 15).

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.

PI modules work because students learn efficiently when explaining ideas to peers. The PI module also gives me achance to help the struggling students during discussions. Spending time with struggling students helps me build a relationship of trust, which alleviates some anxiety. After short table discussions, students re-submit answers to the exercise they began by themselves. We observe the answer distribution shift toward the correct one (see Fig. 2.3). If 70% of students answer correctly, we move forward. Thus, we accelerate the pace in proportion to the students' understanding. This creates the possibility of a few students being left behind, so I added the concept of WAT[11]. WAT corresponds a special button on their classroom device. If I observe a WAT, I revert to a step-by-step example. *This strategy ensures inclusivity*, in that we take care to leave no one behind.

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 modules 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. These were the least used during remote instruction. I hope to bring them back this semester. Article discussions involve a student selecting an 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 write term-papers more rarely, since they are optional. I assess them on the technical writing and attention to detail (**Departmental goal 7**).

Calculus-based physics (150/180). Calculus-based physics, PHYS150/PHYS180, is a two-semester lecture/laboratory formatted sequence that covers calculus-based kinematics, mechanics, work/energy, and

[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.

electromagnetism[15]. The format of these courses is similar to algebra-based physics, mixing PER and traditional content (**departmental goals 1, 4, and 6**). I employ PI modules [41] and PhET modules [44]. In addition, these courses require tools from calculus[16]. Students new to calculus benefit from PhET tools, which help to visualize calculus concepts like vector addition and vector fields.

My PHYS150/180 classes are taught in the same fashion as PHYS135A/B, but include the calculus intrinsic to introductory physics. Calculus and Newton's Laws were developed concurrently, often by the same people, making them interconnected. I occasionally pose a calculus problem during the warm-up phase to familiarize the students with a technique that helps solve problems in the current chapter. Occasionally the physics requires concepts that the students will first encounter in Calculus III, or MATH241 (which covers electromagnetic fields). I gauge the comfort level of the students, and typically restrict my calculus content to traditional examples or an occasional PI module. *As a rule, we do not place calculus concepts on exams that the students have not encountered in pre-requisite or concurrent courses.*

Elementary Statistics (MATH080). Elementary statistics is an introductory math course involving descriptive and predictive statistics, probability and probability distributions, confidence intervals, and modeling data. My section of MATH080 was created after discussions with Profs. Radoniqi and Kronholm in Spring 2020. After Prof. Radoniqi called for new summer session courses, I contemplated offering a data science course. I was not alone, as Profs. Piner and Kozek are now offering such courses. After a discussion with Prof. Radoniqi during a teaching workshop at Wardman Collaboratory, we felt that elementary statistics would be a good service to the students. MATH080 is a course many students need to graduate. It was not standard procedure in the Department of Mathematics to teach online courses until Spring 2020. As we slowly realized *all* courses were going online, Prof. Kronholm informed me the Math Department was going to give it a chance.

I was grateful for the opportunity to teach a math course in Summer Session II of 2020. I taught this course as if it was algebra-based physics. I made no assumptions about the students' mathematics preparation, and instead used the lessons learned from PHS135A/B and PHYS150/PHYS180. The students engaged in warm-ups, TT and PER modules, and PhET modules. Alhtough PhET stands for Physics Education Technology, that organization now has statistics simulations. There are modules that are particularly useful for illustrating probability distributions. Our theme for the course was to *keep it simple.* After the students completed their final projects, they shared very positive reviews about the course[17].

2.5 Analysis of Course Evaluations: Introductory Courses

The course evaluations for introductory STEM courses described in Sec. 2.4 are shared below. On the original course evaluation forms, questions 10-16 pertain to the course, and questions 17-25 pertain to the professor. Table 2.2 lists the standard questions. In the analysis below, I discuss response rates separately from the scores. I have also chosen to include my summer session course, as the data reveals something interesting.

Algebra-Based Physics

The course evaluation data for algebra-based physics is shown in Tab. 2.3. Table 2.3 (left) contains the results for the course, while Tab. 2.3 (right) contains the results for the professor. The question definitions are listed in Tab. 2.2. The data cover four courses in this category from Fall 2019 through Spring 2021. The courses taught in 2021 were taught through the module system, while those in 2019 and 2020 were done through semesters. Fall courses (135A) cover units and vectors, kinematics, forces, energy, and momentum. Spring courses (135B) cover electromagnetism topics like charge, fields, current, DC circuits, and magnetism.

In general, the results are much higher than in my first years at Whittier College. I attribute the successes to FPC recommendations and the hard work of my students. I am pleased to find that my section of PHYS135B section 2 (module 2) received near perfect scores from those that responded, despite being taught in the module system. The seven week module posed serious challenges for introductory physics students. Those near perfect scores were earned when both students and professors were experiencing burnout. Desite all the student success, several trends are visible in the algebra-based physics data that merit discussion.

[15] See supplemental material for example syllabi.
[16] MATH141/142 may be taken concurrently.
[17] Example final project presentations are included in the supporting materials.

Question Number	Text
10	This course had clear goals and objectives.
11	This course was academically challenging.
12	This course offered useful learning tools (such as lectures, discussions, readings, assignments and/or examinations).
13	This course had grading criteria that were clearly identified.
14	This course improved my understanding of the material.
15	This course increased my interest in the subject matter.
16	Overall, I would recommend this course to others.
17	The professor used class time effectively and demonstrated preparation for class.
18	The professor's teaching style and/or enthusiasm for the material strengthened my interest in the subject matter.
19	The professor was able to explain complicated ideas.
20	The professor challenged students to think critically and/or imaginatively about the course material.
21	The professor provided clear and timely feedback.
22	The professor encouraged meaningful class discussions.
23	The professor was receptive to differing views.
24	The professor was available for help outside of class.
25	Overall, I would recommend this professor to others.

Table 2.2: The listing of standard course evaluation quesions.

Question	F2019	S2020	S2021 (1)	S2021 (2)
10	4.8	4.9	4.6	5.0
11	4.7	4.9	4.8	4.9
12	4.7	4.7	4.5	5.0
13	4.8	4.8	4.5	5.0
14	4.5	4.6	4.3	5.0
15	4.0	4.2	4.1	4.9
16	4.5	4.7	3.9	4.9

Question	F2019	S2020	S2021 (1)	S2021 (2)
17	4.6	4.7	4.5	4.9
18	4.6	4.4	4.4	4.9
19	4.3	4.5	4.2	5.0
20	4.6	4.7	4.4	5.0
21	4.8	4.9	4.0	5.0
22	4.6	4.6	4.4	5.0
23	4.7	4.8	4.8	5.0
24	4.8	4.8	4.9	5.0
25	4.7	4.5	4.5	4.9

Table 2.3: (Left) Course evaluation results for PHYS135, course questions. (Right) Course evaluation results for PHYS135, professor questions. F2019: Fall 2019, PHYS135A. S2020: Spring 2020, PHYS135B. S2021 (1 or 2): Spring 2020, PHYS135B sections 1 and 2.

I have been watching Question 15 results since Fall 2017. The question asks the student about increasing interest for physics. One key point to understand about algebra-based physics comes from Question 9 (not shown in Tab. 2.3): "I had a strong desire to take this course." Students regularly enter 3.0/5.0 for that question. The online PEGP reports now provide data regarding why many students take the course, which is something I knew intuitively. Students *have to take it* for their major. I know that about nine of ten students are either biology or KNS majors, and both programs require a year of physics if the student wants to be involved in medicine. I have to inspire a genuine appreciation for physics in students who are being forced to take a course they do not want to take. For this reason, I introduced article bonuses and self-designed projects, to reach the *curiosity* learning focus, and the overall theme of *shared meaning* from my teaching philosophy. The average for all four instances of 135 is 4.3, which is higher than my last PEGP (2019), when I found 4.25.

The second trend I noticed was one I was expecting. Although most of the results in Tab. 2.3 are high, the Spring 2021 section 1 (module 3) are lower on average than the others. There are three reasons why this occurred, and all can be remedied. This was my module 3 course that followed the module 2 PHYS135B (section 2). I was blocked from seeing the course evaluations for module 2 before teaching module 3. In module 2, we *barely* reached the topic of applications of magnetism. While teaching section 2 (module 2, 135B), I kept remembering my mantra to *control the pace,* learned from prior FPC recommendations and experiences. It turns out even the module 2 students were sharing that the pace was pretty quick, especially given that the course delivery was online and only seven weeks.

Module 2 came to an end before we could address all the magnetism content, but the students that responded gave me high scores. Although I planned to cover magnetism in more detail, there was just not enough time. The module system and the pandemic took my magnets! (Do you remember that phrase from the curricular

Question	F2019	S2020
10	4.8	5.0
11	4.9	5.0
12	4.9	4.9
13	4.9	4.9
14	4.7	4.9
15	4.3	4.7
16	4.8	4.9

Question	F2019	S2020
17	4.9	5.0
18	4.7	5.0
19	4.6	4.7
20	4.8	5.0
21	4.8	4.9
22	4.7	4.9
23	4.8	5.0
24	5.0	5.0
25	4.8	5.0

Table 2.4: (Left) Course evaluation results for PHYS150/180, course questions. (Right) Course evaluation results for PHYS150/180, professor questions. F2019: Fall 2019, PHYS150. S2020: Spring 2020, PHYS180.

discussions? Don't take my magnets! Good times.) Ask any physicist: can your students learn electromagnetism in seven weeks, meeting five days per week? The answer would likely be that *human beings* cannot learn physics that fast. So the first reason the module 3 scores were lower was this: I felt that it was an issue of integrity that I try to cover more magnetism for the module 3 students. The module 3 students, however, were burned out, and some wrote exactly that in the written response section. Had I been able to read the module 2 data before teaching module 3, I would not have tried to gain the extra week to cover different magnetic effects.

The second reason the numbers are lower for that section had to do with grading. Module 3 turned out to be my perfect storm of course work, committee service, finishing a research paper, advising thirty students, and caring for a one-year-old. In retrospect, I should have exchanged my written midterm for something automatically graded using OpenStax Tutor. When the students began to submit their midterms on Moodle, I realized I was not going to be able to finish grading them quickly. Now that we are returning to the semester format, this problem will be solved both through better midterm design and having a longer semester.

The third reason Spring 2021 135B section 1 scores were lower has to do with the topic of *vectors*. An example of a vector is force, which is both an amount and a direction (150 lbs. *downward*). To understand electromagnetism, one needs to be able to multiply vectors. Knowledge of electric and magnetic forces, and the ensuing effects in circuits, motors, and generators relies on this knowledge. In PHYS135B section 1 (module 3), I noticed students struggling more than usual with vectors. Vectors are usually practiced in 135A, but I was not the intstructor in Fall 2020 for PHYS135A. When I polled the students in PHYS135B in module 3 to learn if vectors were covered in 135A in Fall 2020, they uniformly said "no." I recalibrated my course on-the-fly, reviewing vector content. Had I known that vectors had been dropped, I would have planned for that. This comming Fall 2021, however, I will be teaching all sections of 135A. I will help the students practice more with vectors, and this should make 135B go more smoothly for them.

Calculus-Based Physics

The data in Tab. 2.4 pertains to two sections of calculus-based physics. I taught PHYS150 in Fall 2019, and PHYS180 in Spring 2020. Like algebra-based physics, mechanics is covered in the first course and electromagnetism is covered in the second. Upon examining the numbers, I do not identify any significant downward trends relative to my supplemental PEGP from 2019. The scores from PHYS180 in the supplemental PEGP were near perfect, but the class size was $N = 8$, rather than $N = 26$ (PHYS150) and $N = 24$ (PHYS180) for this round. The exception to these remarks is the usual Question 15 (PHYS150), but that is not unexpected from a large sample of students. Some students take PHYS150 thinking they want to major in physics or 3-2 engineering, for example, and switch majors when they realize they are more interested in applications like ICS/Math. For example, I had one advisee this year switch from physics to Digital Art and Design.

After reading through the written assessments, I noticed several comments for which I can provide a remedy. First, some students mention problems with *ExpertTA*, and I have moved to OpenStax Tutor. Some students mentioned that three shorter midterms worked well for them, and others mentioned that the third one falls too close to finals season. I have since switched to two midterms designed to take 1 hour each. In algebra-based physics, I am moving to one midterm, and the final project design is due when the second midterm would have occurred. In both algebra and calculus-based physics, the final project is still presented towards the end of the class, and the final exam is optional. Most of the other comments were positive, especially for PHYS180 during the rapid transition to remote learning. One student suggested keeping the tutorial videos going even after

Question	Result
This course had clear and objective outcomes.	4.8
This course was academically challenging.	4.5
This course offers useful learning tools.	4.8
This course had grading criteria that were clearly identified.	4.8
This course improved my understanding of the material.	4.8
This course increased my interest in the subject matter.	4.5
This course provided interactions between students that were meaningful.	4.5
This course is as rigorous as the typical on-campus course.	4.3
Overall, I would recommend this course to others.	4.8

Question	Result
The professor demonstrated preparation for the class.	4.8
The professor's teaching style and/or enthusiasm for the material strengthened my interest in the subject matter.	4.5
The professor was able to explain complicated ideas.	4.3
The professor challenged students to think critically.	4.8
The professor provided clear and timely feedback.	4.5
The professor encouraged meaningful discussions.	4.5
The professor was receptive to differing views.	4.8
The professor was available to help.	4.8
Overall, I would recommend this professor to others.	4.8

Table 2.5: (Top) Course evaluation results for MATH080, course questions. (Bottom) Course evaluation results for MATH080, professor questions. Su2020: Summer 2020. Note: the questions for summer online courses are slightly different than courses during the academic year. See text for details.

returning from quarantine. I am prepared to do this for electromagnetism, but will have to create new videos for mechanics (PHYS135A and PHYS150).

Elementary Statistics

Teaching elementary statistics (MATH080) in Summer 2020 was a useful experience, and I really enjoyed working with my students. I thought it would be worth while to point out the the numbers in Tab. 2.5 are not that different from Tabs. 2.3 and 2.4. Before the pandemic, online math courses were not allowed by Math Department policy. I was likely the first Whittier College professor to ever teach one. I am grateful to the Math Department for trusting me with the responsibility of teaching MATH080. I taught this course in the same way I teach PHYS135A/B: reading assessment warm-up, TT and PER modules, and PHeT simulations. I included tutorial videos and a student-designed final project. Before we agreed to teach the course in the Summer, there were concerns from math professors that *quality control* is what stops us from teaching math online. Similar to algebra-based physics, students are taking a must-pass course for graduation, but need help sharpening math skills. Instructors are under pressure to reduce content and slow the pace. I found that the students learned the material and applied it successfully in their final projects[18]. Of the $N = 4$ students that responded, they shared that the course was *almost* as rigorous as the semester-long version (4.3/5.0). However, they also report that the course had useful learning tools, that it increased their interest, and that it improved their understanding.

2.6 Advanced Course Descriptions

The advanced 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.

Computer Logic and Digital Circuit Design (PHYS306/COSC330). Computer Logic and Digital Circuit Design is cross-listed as PHYS306/COSC330. My first goal for the students was to impart my advanced learning focus of **strength in all phases of science**, and **to satisfy departmental goals 4-7**. This is a 300-level course that satisfies core requirements in the following majors: Physics, ICS/Physics, ICS/Economics, 3-2 Engineering/Math, 3-2 Engineering/Computer Science. Such a broad course that serves a wide variety of students should touch on at least the following sub-topics:

1. Binary mathematics, non-decimal base systems, and boolean logic
2. Basic digital components, clocks and gates
3. Implementation of boolean algebra with digital components

[18]Examples in supporting material.

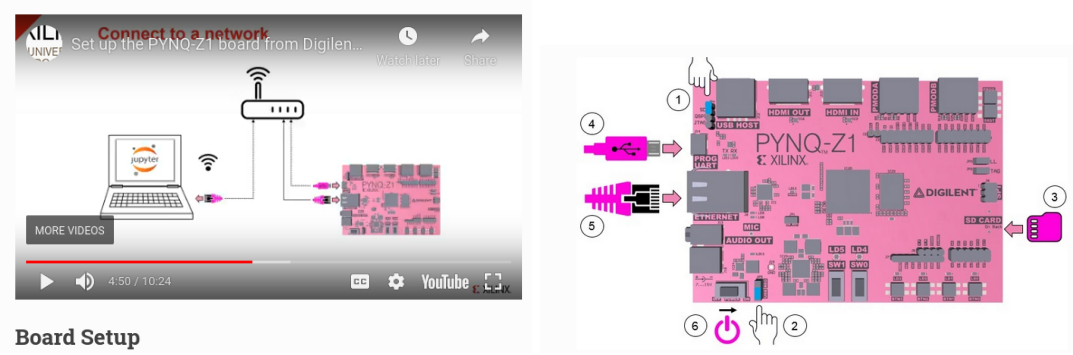


Figure 2.7: (Left) A setup video explaining how to connect a laptop to the PYNQ-Z1 system. (Right) A diagram of the PYNQ-Z1 system-on-a-chip (SoC). The board has a microprocessor, programmable logic, ethernet and USB connections, and a small operating system installed on an SD card.

4. Complex digital components
5. Creation of digital circuits and projects
6. Analysis of digital data, analogue-to-digital and digital-to-analogue conversion

Covering the topics above with challenging content is how I reach my first advanced course learning focus of *mental discipline.* Additionally, any good digital design course must evenly cover the following phases of the field: *mathematics, computer programming and modeling, hardware design and testing, and digital data analysis* (strength in all phases of science)[19]. The final learning focus is *communication*, and we reach this learning goal through final group-projects. The students submit a project proposal before beginning work, and we polish presentations in office hours in advance of the final presentation.

Half of each class period is dedicated to making progress on the digital design labs using the PYNQ-Z1 system-on-a-chip (SoC). To set up a system for the student pair, I install a Linux operating system on a laptop, and use it to download an operating system for the SoC. The PYNQ-Z1 is called a SoC because it has both programmable logic firmware (PL) and a processing system (PS) like a small computer. The default operating system for PYNQ-Z1 contains basic examples that show the students how to use the digital components of the SoC. By the end of the course, the students are writing code in Python3 that literally creates digital circuits inside the SoC. They use the boards to learn, and to build projects. Diagrams of the system are shown in Fig. 2.7.

Using the boards, I provide a bridge to another course, digital signal processing (DSP, see below), by leading the students to a special activity. The students capture analogue voltage signals from an external source, digitize it using the SoC, and graph it using Python3. This lab activity is a model for how sensors work, and the starting point for DSP. The final projects for this course were stiffled by the remote learning situation in Spring 2020. My hope is that the students will design sensors, timing-based systems like traffic-light controllers, and video processing. Personally, I have processed HDMI video and remote audio with the PYNQ-Z1 SoC. Though these projects might be more challenging for the students, I know one or two groups will give these a shot.

The other half of COSC330/PHYS306 class periods are spent learning number systems like binary and hexidecimal, boolean logic and boolean algebra, and logic functions. When woven together, these concepts give the students a basic understanding of how embedded digital systems function. Imagine a system designed to fill bottles with pills via a conveyor belt and valve. Imagine how the number of pills would be counted in binary, and how that result would control both the conveyor and the valve. The students devise solutions to situations like the pill bottle one, using conceptual tools from lecture period. We also cover how these tools have applications in business. One main example is how to simplify a logic function, and how that technique can simplify a business workflow.

Digital Signal Processing (COSC390). Digital Signal Processing (DSP) was listed as COSC390 in January term of 2019. COSC390 is a 300-level integrated computer science course that satisfies core requirements in the

[19] An example syllabus is in the supporting material.

following majors: Physics, ICS/Physics, ICS/Economics, 3-2 Engineering/Math, 3-2 Engineering/Computer Science. I also keep in mind **Physics Department goals 4-7** when implementing this course.

DSP encompasses the myriad of ways we capture, process, and filter analogue signals like audio signals, medical sensors on the heart and brain, and images. DSP gives students vital skills such as loading, cleaning, manipulating, and graphing data. DSP is used by a wide variety of students in fields beyond engineering. For example, at Rio Hondo Community College, students apply DSP in Sound Design [40]. Our students also practice a vital skill in DSP: Fourier analysis. This technique allows a student rearrange data comprised of *time-dependent* signals into *frequency-dependent* signals, like tuning a radio to the right frequency. One economics student, for example, was able to find periodic trends in the stock market using this technique.

When I last taught DSP, the students were a diverse group. Their majors ranged from business, economics, WSP, ICS/Math, and Physics. My students were 60% people of color, and ranged from sophomores to seniors. The minimum number of students for a course was five, so I actively recruited students. I got permission to promote my new course in person in pre-requisite courses like COSC120 and MATH141. The students for whom January term was not booked signed up excitedly. My diverse group of students had great success, and learned key career skills. Finally, they did not pay a cent for books or software because it was 100% open access. I will be teaching DSP for the second time this coming January term, and I plan to expand my recruitment to majors like Art and Digital Design, and music. I mention diversity and inclusion here only because one professor emailed me with a question about inclusion and DSP.

To reach my first advanced learning focus of *mental discipline*, my students engaged with modules requiring analytic and creative thinking. Because this was a January term course, we met for three hours each morning for three weeks. Homework sets were assigned each day, and kept *short*, but challenging. This is the first time I tried such a style, but the students found it refreshing and efficient. The style ensured that the problems I assigned came straight from the lecture of that day (or occasionally one day prior). Another benefit of the cadence was that if a student was struggling, I could identify and help them very quickly.

The second learning focus for advanced courses is *strength in all phases of science.* COSC390 follows COSC330/PHYS306 conceptually. One can think of COSC330/PHYS306 as learning the building blocks of digital components. Some of those components help create scientific instruments that sample and digitize analog data. Digital Signal Processing (DSP) is the subject of what follows *after* the sampling and digitization (i.e. the next phase). I broadened the content to sub-topics like financial data analysis, which may be analyzed with DSP. One of the student-designed projects in COSC390 was an analysis of Federal Reserve interest rate data over many decades using DSP. Other presentations included image processing within the context of criminal justice (facial identification), and audio capture and processing of the guitar music of a student. For the projects, the students engaged more in the final two phases I identified in Sec. 2.3, whereas they engaged more in the first two in COSC330/PHYS306.

Electromagnetic Theory (PHYS330). Electromagnetic theory is a course taught in every department of physics. It is an advanced theoretical physics course utilized by 3-2 engineering, chemistry, and physics students. It builds upon vector calculus (MATH241) and PHYS180, and vector calculus is built from single-variable calculus (MATH141 and MATH142). I taught this course under the module system for the first time in Fall 2020. I utilized my standard fare of warm-up exercises, TT modules, and PER. However, the students in this course are mostly juniors and seniors whom we have already engaged in pre-requisite courses. Thus, they prefer more TT modules and fewer PER modules.

The first learning focus is *mental discipline*, so I begin the course with a rigorous review of vector calculus, augmented with custom videos (See Fig. 2.8). With the module system, students had to develop final project plans early in the course before they had seen most of the material. We had to strike a balance between going too fast (in order to introduce them to enough material to create final projects), and going too slow (to prevent students from getting lost). We use the ubiquitous textbook for this course entitled *Introduction to Electrodynamics, 3rd ed.* by David Griffiths. When I was in college, we used the 2nd edition and spent one 14-week semester covering most of the book. Other institutions spend two full semesters covering the whole book[20]. My task was to cover the first half of the book in just seven weeks[21].

[20] I took this course in 2004 at Yale University, whereas a friend I met at Los Alamos National Laboratory told me her course in the same year was half the pace, for two semesters, at Northern Arizona University.

[21] For more information, see my syllabus in supporting material.

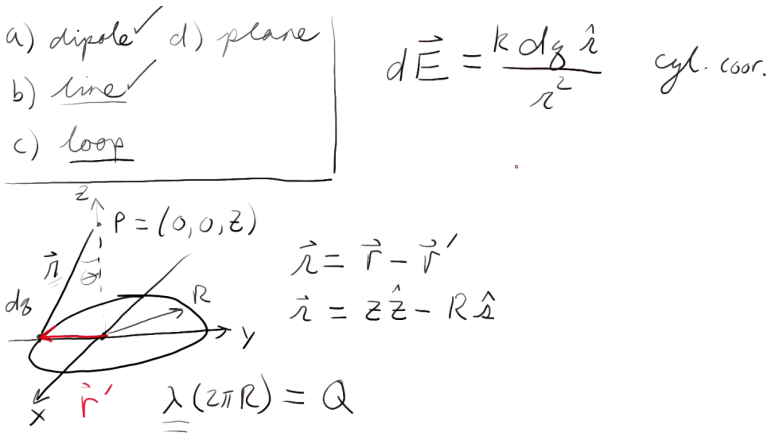


Figure 2.8: A screenshot of a video I produced for my students to help refresh their memories regarding electromagnetism and calculus.

Question	S2020
10	4.8
11	4.8
12	4.7
13	4.7
14	4.6
15	4.8
16	4.8

Question	S2020
17	4.7
18	4.8
19	4.6
20	4.8
21	4.8
22	4.4
23	4.7
24	4.8
25	4.6

Table 2.6: (Left) Course evaluation results for COSC330/PHYS306 pertaining to the course. (Right) Course evaluation results for COSC330/PHYS306 pertaining to the professor.

The second and third learning focuses are *strength in all phases of science,* and *communication.* PHYS330 is one of our upper-division electives that is centered on abstract problem-solving and numerical prediction/modeling, so there is rarely any focus on the third and fourth phases. Although most of our time is spent on building theoretical ideas that the students will use in engineering or see once more in graduate school, I did include some demonstrations of modern electromagnetism: CEM. CEM stands for computational electromagnetism, and I discuss it further in Sec. 3. I coached some students through some CEM calculations for their final projects, while others demonstrated how to solve particularly challenging homework problems for the class. Final projects included topics like electromagnetic radiation, the intersection of quantum mechanics and electromagnetism, and the electric fields of interesting shapes of electric charge. Most students took the course to apply towards their major, and reported that they learned the material well, if only for seven weeks.

2.7 Analysis of Course Evaluations: Advanced Courses

The course evaluations for advanced STEM courses described in Sec. 2.6 are shared below.

Computer Logic and Digital Circuit Design

The course evaluation results for COSC330/PHYS306 are shown in Tab. 2.6. The results are very good, in general. I would have liked a higher result for Question 25, but this simply prompted me to look through the written responses for clues. This course took place during the rapid transition to online teaching. As we examine the written responses, we see that the students were inspired by the laboratory portion of the course. They were disappointed, though, that what they see as vital skills (lab training, circuit boards, python programming) were diminished by the pandemic. After the transition to online learning, I created a solution that enabled the students to perform some of the digital logic labs on the PYNQ-Z1 boards *from their homes.*

Figure 2.7 (left) contains a diagram showing how one can control the PYNQ-Z1 board via a laptop running

Question	Jan 2019
10	4.75
11	4.75
12	4.75
13	4.75
14	4.75
15	4.6
16	4.5

Question	Jan 2019
17	4.75
18	4.75
19	4.5
20	4.6
21	4.9
22	4.1
23	4.2
24	5.0
25	4.75

Table 2.7: (Left) Course evaluation results for COSC390 pertaining to the course. (Right) Course evaluation results for COSC390 pertaining to the professor.

Jupyter notebooks. Jupyter notebooks allow a student to run python and other programming languages regardless of the operating system (platform independent). I realized as long as they could control the laptops, they could control the boards, provided the boards were hooked together correctly. I installed TeamViewer on the laboratory computers. TeamViewer is an open-access remote-desktop solution, and I passed the access codes to the students. I tested the system by logging in to a pynq board from my laptop through my home router and running a lab example. Once that was working, I repeated the procedure with the students observing via Zoom. Eventually, the students were logging into laptops in the lap, and controlling the circuit boards from there. One student said this made her feel like a hacker, in a good way.

We see in the written responses that the students appreciated all my effort to give them back some lab activities remotely. The students suggest more time, in fact, for labs. This is good to know for Fall 2021 because we are offering the course again. Normally it is a Spring course, but the math professors and I realized we did not want COSC330/PHYS306 overlapping with other 300-level COSC and PHYS electives. We now have 14 students enrolled, and I will expand the time these students can work on the labs. Finally, teaching in person will allow the students to create final projects using the PYNQ-Z1 boards. I anticipate HDMI video, audio processing, and analog-to-digital conversion (ADC) projects. Hopefully that will satisfy the students' curiosity and meet the suggestions they shared in course evaluations.

Digital Signal Processing

The results for DSP (COSC390) are shown in Tab. 2.7. Note that this course number may now correspond to another course, because this course was offered as a special topic within computer science. Technically, these evaluation data were included in my last PEGP report submitted in Fall 2019 after I taught the course in January 2019. I include them here because I will be teaching this course once again in the upcoming January term. The primary feedback the students shared was that the material is really interesting, but that it should be spread over the course of a semester. Although the students shared that feedback, the results in Tab. 2.7 are generally very good.

Questions 22 and 23 pertain to encouragement of class discussions and accepting different viewpoints. Although my students know that I am always accepting of different viewpoints, we do not really hold group discussions in advanced STEM courses as the quesions suggest. What we do have is lab partners. For COSC330/PHYS306, the partners work together on one system (laptop plus PYNQ-Z1) to solve the problems in the laboratory activity. So in that sense, I do encourage them to discuss the issues within the labs, but with each other. For the January term version of DSP, we could have partners work on extended examples in the same manner as the COSC330/PHYS306 students. When I taught this course in January 2019, there were seven students. Thus, three pairs plus myself working with the additional student may have helped. I will try this out in the upcoming January term.

Electromagnetic Theory

The course evaluation results for PHYS330 are shown in Tab. 2.8. In general, the results are good. I was aiming for a higher mark on Question 16 (recommend this course to others), which prompted me to search through the written responses for clues. Several students shared that this course is not really appropriate for seven weeks. I gave examples of how this course is normally distributed through the weeks of a semester in Sec. 2.6. There were other suggestions, though, that were interesting and useful for next time. One student related that if there are

Question	F2020
10	4.9
11	5.0
12	4.9
13	4.9
14	4.6
15	4.6
16	4.4

Question	F2020
17	4.9
18	4.8
19	4.6
20	4.6
21	4.5
22	4.7
23	4.7
24	4.9
25	4.9

Table 2.8: (Left) Course evaluation results for PHYS330 pertaining to the course. (Right) Course evaluation results for PHYS330 pertaining to the professor.

going to be videos, they would be better if they included traditional teaching in addition to example problems. Another student suggested that in an online advanced course, warm-ups should be shortened, or done as a group.

Most of my reflection on my teaching lately has been geared towards the introductory physics courses. Now we see that the students in advanced physics courses have slightly different preferences. These issues are made easier in a semester system, and I will take them into account the next time I teach PHYS330. More traditional teaching, and perhaps more CEM, will satisfy the students. If I notice struggling students, though, I will still be prepared to use some PER modules. When asked if they would change anything, the students mostly remarked that two modules, or more time, would have been better. Finally, one student gave me a boost when he wrote: "I miss the physics boys. This was nice." I miss you too, bro.

2.8 Liberal Arts Course Descriptions

The liberal education courses I have taught thus far at Whittier College are now introduced, with connections to the teaching philosophy described in Sec. 2.3.

Safe Return Doubtful: History and Current Status of Modern Science in Antarctica

In 1913, an advertisement appeared in a London newspaper that read "Men wanted for hazardous journey, small wages, bitter cold, long months of complete darkness, constant danger, **safe return doubtful**, honor and recognition in case of success. - Ernest Shackleton, 4 Burlington St." Ernest Shackleton, who was to set several records in Antarctic exploration in the early 20th century, was calling for volunteers for the first expedition to cross Antarctica ocean-to-ocean. There is a wonderfully rugged and inspiring batch of historical accounts of the modern exploration of Antarctica, from first landing to the triumphant arrival of humans to the South Pole for the first time. This literature is included within the broader category of *exploration literature.*

I have been to Antarctica twice. I recall that people who succeed on missions there share something in common, even though they are as diverse a group as any: they know themselves. They understand their goals and their personal limitations. People who travel to McMurdo Station, United States Antarctic Program (USAP) are scientists and engineers, explorers, pilots, mechanics, medics, and workers who help the base function. They do not mind being uncomfortable, as long as they know they are serving the right purpose. They work *hard,* often for little recognition. They train thoroughly, but can also improvise and survive. My aim for our students is to encountered traits like these, and learned to incorporate them in their studies through *shared meaning* (see Sec. 2.1).

To that end, I have created INTD255: *Safe Return Doubtful: History and Current Status of Modern Science in Antarctica*, a *CON2*-style course. We include three main themes. First, we cover the race to be the first humans to arrive at the South Pole in 1911. Second, we cover current scientific projects in Antarctica. Third, we write weekly journal entries that invite the students to look inside and see their potential for true exploration. Themes like inclusion arise as we learn that the first group to the South Pole took indigenous science seriously. Led by the same captain who completed the Northwest Passage, this group incorporated methods of travel and survival from indigenous people in Northern Canada. We build *order* and *shared meaning* (Sec. 2.1) between topics like physics, chemistry, biology, history, and indigenous technology. The students learn about scientific results and endeavors currentlty active in Antarctica, and historically. Examples of journal activities invite students to describe a time

they were in a dangerous situation and how they handled it, or a time they were called to lead. I chose to conclude the course with a lecture on leadership [46].

Much like my physics courses, I include active learning strategies to keep the students engaged with the science modules. One example was an activity in which the students accessed ice-core data from a NOAA database and graphed measured oxygen isotope ratios from trapped air bubbles. This is how we estimate global average temperatures over hundreds of thousands of years. In another example, the students planned a navigation from Ross Island (the location of McMurdo Base, USAP) to the Central Trans-Antarctic Mountains that lead to the South Pole. The exercise requires students to plan how they would move both themselves and their food, assuming people and pack animals consume a certain number of calories per day. These activities connect environmental and biological science with historical exploration. Students must pay attention to detail in order to not starve or get lost. Eventually, we applied the navigational technique of triangulation on a group hike to the summit of Hellman Park. The students use a compass and the baseline between SLC and the summit in Hellman Park to calculate the distance to Downtown Los Angeles[22]. Finally, I include lecture content about Antarctic wildlife, neutrino physics (see Sec. 3), and climate science.

For reading, we tackle "The Last Place on Earth" by Roland Huntford. Like an expedition, I plan out the students' trek through this book, and we complete short weekly reading quizzes to keep everyone accountable. The book is an expansive history of polar exploration, and I wish *every single one* of the physicists in my field would read it for the contrasting examples of leadership styles. The author paints portraits of the Norwegian Roald Amundsen, who led the first group to the South Pole, and Englishman Robert Falcon Scott, who arrived second but died on the return journey. We see them planning years in advance, and failing on purpose just to learn what works. We see scientists assuming their navigational calculations are correct, only to find out in the field they missed something and pay dearly. We see explorers learning to eat strange food and move across terrain in ways used by indigenous Canadians. An example: everyone trying to explore Antarctica kept developing scurvy. Captain Scott and the British canned limes but the Vitamin C was rendered less potent in shipment. Captain Amundsen noticed that the *Netsilik* tribe never developed scurvy, despite having no access to fruit like the British, or berries like the Scandanavians. Where is the nutrition above the Arctic Circle? The answer is under the sea, so the Netsilik eat things that bring the vitamins from the sea: seals. The Norwegians did not bother bringing limes or lingenberries, but instead ate seal meat in Antarctica.

We also include the wonderful writings of Barry Lopez from "Horizon."[23] One chapter deals with his travels to the side of Antarctica explored originally by Shackleton, Scott, and Amundsen. Lopez describes the daily lives of scientists in Antarctica by chronicling a mission to retrieve meteorites from the outer solar system that land on the ice sheets. In another chapter, Lopez describes riding south on a large ice-breaking research vessel to the side of Antarctica nearer to the Southern tip of Latin America. Lopez writes about the life of indigenous people in that area, and the effect the land has on culture. We also include "News at the Ends of the Earth" by Hester Blum, which is a collection of essays regarding the writings and printed work of the polar explorers. It turns out that some polar explorers transported whole printing presses to Antarctica in order to create shipboard newspapers and other scientific chronicles. The writing deals with topics like a changing climate, and the possibility of no remaining places on Earth unexplored. I am grateful to Profs. Michelle Chihara and Warren Hansen for suggesting these books as helpful additions. Prof. Hansen audited my course, and we enjoyed discussing the reading together.

A History of Science in Latin America

As I shared in Sec. 2.4, I was inspired by my family and our students to create a new course entitled *A History of Science in Latin America*. The course was assigned a *Culture 3* and *Connections 2* designation. Twenty-six students took this course in Spring 2021 (module 1). The high enrollment was due in part to the *CON2* and *CUL3* designations. I observed that the students' selection of final project topics often involved the country of origin of their ancestors or historical anecdotes from their families. Thus, I drew the conclusion that the students were hungry for a course that covered science in Latin America. I had been thinking over the course idea since 2017-18, but finally got the chance in Spring 2021 to offer it.

One aspect of the course students encounter first are the ideas of scientific communities, and which are central or peripheral communities. Taking STEM courses alone might lead a student to believe that European and American

[22] Though we had a wide range of math preparation in the class, as a group we got the right answer to within 6%, according to Google Maps.

[23] Rest in peace, December 2020.

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.

For example, two cures for syphilis were brought back to Europe by Spanish colonials: chinaberry bark and sarsaparilla root. Even Spanish sources acknowledge that these treatments (which exploded commercially starting in the 1600s) were revealed to the colonials by indigenous doctors. There is a similar story behind quinine production from *cinchona* bark to treat malaria. Spanish colonials would have been operating from the medical theory of the *four humours,* and the Mexica and other Nahua peoples had a wholly separate spiritual and scientific worldview that involved the human body. No matter which was more correct, the people who produced a working treatment were simply those who had the data from the native plant.

The students also encountered the idea that mathematical and scientific systems developed all over Latin America in the pre-Columbian era. We learned to translate numbers from our system of Arabic numerals to Mayan, Incan, and Aztec systems. This required the students to learn a piece of a branch of mathematics called number theory. The students then were able to perform calculations regarding land use and agriculture using the numerical systems of the era[24]. We branched into the mathematics and the astronomy of the solar system, because the 1600s-1700s saw rapid development in this branch of science worldwide. Universities founded by Jesuits and Dominicans in what are now Columbia, Perú, and Venezuela held interesting debates about the structure of the solar system. Meanwhile, the construction of Latin American technical colleges was underway and funded primarily by the very mineral extraction (for example, silver) the viceroyalties valued so highly. Often, native mining techniques were shown to be more efficient than those imported from Europe. As the Scientific Revolution spread through Mexíco, Columbia, Perú, and Río de La Plata, several fascinating examples of science performed by indigenous citizens emerged.

Thus, the students absorb a more complex and complete picture of the Scientific Revolution that demonstrates both Latin Americans and Europeans working towards the truth. Mexican scientists participated in the first measurements of the distance to the Sun using Venus transits. By timing the transit of Venus across the face of the Sun, and comparing times from opposite sides of the planet, the distance to the Sun can be derived. Measurements from Europe alone would have been insufficient. Teams were dispatched from Britain and France to Russia, Tahiti, and Baja California. Mexican scientists, rather than European visitors, completed the Baja measurements and the data helped establish the correct (and astonishing) value to within a few percent error. Some of the same Mexican scientists found and explained the connection between sunspots and the aurora borealis. The answer has to do with the cosmic rays in the solar wind (Sec. 3) and the magnetic fields of the Earth and Sun. This discovery was based on data from a Northern aurora that flared as far South as Mexico City and Zacatecas. One Mexican scientist even recreated the aurora light *in the lab* using charged particles striking gas. Some European scientists adopted a theory that the aurora originated at the North Pole from inside the Earth. Humans would not reach the North Pole for more than one hundred years.

Through our activities, the students absorb a more complex and complete picture of the Scientific Revolution that demonstrates both Latin Americans and Europeans working towards the truth. The students perform activities asynchronously and engage in some group work. Since it had to be taught online, I asked the students how much time we should spend in breakout rooms. They told me that less time spent in breakout rooms was preferable. I also created videos and activity worksheets for the students to complete. Supplemented by our excellent reading, *Science in Latin America, A History*, edited by Juan José Saldaña, we proceeded from the 1500s up to 1900. This book appears to be one of only a few histories of Latin American science written in the last 10 years. As long as I provide context from physics, mathematics, and chemistry, the students seemed to follow it. We would have liked to go further, but we were restricted due to the seven week limitation of the module system. For final project design, I contacted Sonia Chaidez from Wardman Library to introduce Digital Storytelling to our students. The students learned to use WeVideo, a web-based video editing tool. Whittier College has a site license, so this was free for our students. The students performed brilliantly, and we learned about everything from silver mining in Mexico to cosmic rays and Mayan mathematics.

[24] A sample assignment is included in the supporting material.

Question	F2019
10	4.8
11	4.7
12	4.7
13	4.7
14	4.8
15	4.4
16	4.6

Question	F2019
17	4.9
18	4.8
19	4.7
20	4.8
21	4.9
22	4.8
23	4.9
24	4.9
25	4.8

Table 2.9: (Left) Course evaluation results for INTD255 pertaining to the course. (Right) Course evaluation results for INTD255 pertaining to the professor.

2.9 Analysis of Course Evaluations: Liberal Arts Courses

The course evaluations for liberal arts courses described in Sec. 2.9 are shared below.

Safe Return Doubtful: History and Current Status of Modern Science in Antarctica

The course evaluation results for *Safe Return Doubtful: History and Current Status of Modern Science in Antarctica* are shown in Tab. 2.9. This course represented the first time I have taught anything outside the STEM area. Although I included content from my research, and some of the other topics were familiar, I knew I was teaching outside of my comfort zone. I also knew from conversations with the students early in the course that any physics or math I included had to be kept to simple.

The numerical results in Tab. 2.9 are generally high. I begin by reflecting on the comments of the students who seemed to like the course. One student remarked that "This course was by far the most interesting course I have taken at Whittier College ... it taught life skills while also teaching about the physics of movement and energy as it pertains to humans. It also was very introspective and made the students think much about their own lives and experiences and relate them to the course." This comment is uplifting because I was aiming to teach an interesting course that involved science, history, and life skills. The life skills upon which we reflected as a class are about knowing one's full capabilities and limitations, and one's ability to lead. Another student remarked that "your teaching style was great; I normally do not relate to as much information given in lecture format, but I did in this course ... " That is also nice to hear, because sometimes I felt like a square peg teaching a round hole. *Are any of the students appreciating this? Am I doing it right?* Apparently, the students thought I was doing it right. Another student summarized their experience with "I am not very good at science or math but you made it very easy for me to understand." This last comment is important to remember, given that the students shared a variety of preferences for the math detail included.

Another student wrote: "I thought that Professor Hanson was a very good enthusiastic professor. He always listened to what his students had to say and tried to help them in the best way possible." By Fall 2019, I had learned to become attuned to the specific set of students in a class. I included the physics of friction (a simple linear formula) in the course, and I demonstrated how the formula is used. The effects of friction, force, and work controlled the race to the South Pole, and it was interesting how the *Netsilik* solved the problem in Canada. But another student was right to say that "... this class has no prerequisites, don't assume that everyone has taken a physics class before." About one week into the class one student told me in office hours that he didn't expect to see a physics equation and that he was worried. I am always surprised to see such fear of a simple linear equation. However, I have learned by now how to guide students first to a sense of *order*, and then *shared meaning* (see Sec. 2.1).

The students were reassured and later wrote wonderful essays and journal entries. I understand how students feel when they have to do a bit of math after we do not require them to do any math for several years. I was paying attention to the perceived difficulty level, and for most students I think the balance worked. For one student, any math at all would have been too much: "The (professor) assumed I would know how to do the math and didn't explain how to go through the equations very well." Well, I did give the students a review unit at the beginning to slowly prepare them to apply numbers. I would increase and simplify the review next time, while not increasing the technical content, which is necessary to understand what is happening in *The Last Place on Earth.* A final remark from a student summarizes how the students and I both felt: "This course was great because it was

Question	S2021
10	4.8
11	4.8
12	4.8
13	4.6
14	4.8
15	4.6
16	4.6

Question	S2021
17	4.8
18	4.8
19	4.8
20	5.0
21	4.4
22	4.7
23	5.0
24	5.0
25	4.8

Table 2.10: (Left) Course evaluation results for INTD290 pertaining to the course. (Right) Course evaluation results for INTD290 pertaining to the professor.

untraditional and very insightful. We learned physics through stories of exploration and I believe this method made students much more interested and involved." Finally, I must have been doing something right, because Prof. Warren Hansen attended all of my class sessions and told me I did a great job. He even recommended more exploration literature from which to draw next time.

A History of Science in Latin America

The course evaluation results for *A History of Science in Latin America* are shown in Tab. 2.10. Even though this course had to be taught in the module system, the students learned a great deal and seemed to appreciate the course theme. Their final projects indicated that they understood the connection between the Scientific Revolution and Latin America, and that science in Latin America has always had pre-Columbian roots. The numbers in Tab. 2.10 are high on average, and I include some further analysis of the students' written remarks below. Most of the students shared very positive comments about the general topic and style of the course. One wrote "You did an fantastic job making the course material engaging. Its difficult to do over zoom, and a lot of professors struggle with it ..." Another wrote: "I really loved this class ... While meeting every day at 8 am seems like it would be a drag, I actually felt that meeting so frequently was the key to how much I learned in this class ... I also could tell how passionate the professor was about both the material and teaching his students, which made me want to show up and do well in the class."

This was the first time I had taught outside the STEM area via remote instruction. I am not surprised that students shared a variety of technical comments about course structure, because at this point in the calendar I was really feeling the burn of the modules and balancing teaching and family. The students understood, and it turned out some students in the course were also caring for children and younger siblings. Some students wrote the pace was rushed or slow, and shared remarks similar to INTD255 about mathematics content. Part of this course, however, required arithmetic practice so the students could engage with *ethnomathematics*, the idea that pre-Columbian civilizations had independent numerical systems.

Many students admitted they would have preferred this course be taught in person and for a semester. I noticed the students' comments that Zoom breakout rooms were not useful. Once I found out, we dialed back the use of breakout rooms. Some students would have preferred only three synchronous days per week instead of the four we used. I did not know I could do that. I felt I owed the students as much face-to-face time as I could give them. Another student suggested that the course schedule be set up by week instead of by unit. At a teaching conference I attended in 2017 (focused on STEM), I was taught the exact opposite, that setting the course stucture by unit rather than weeks minimizes stress on the students. My students in INTD290 probably preferred the fixed schedule for the certainty. One student shared something useful that also occurred to me as the course was coming to a close:

> Professor Hanson, I had such a great time in this course! I really enjoyed how you blended history with your field of study in a way that worked really well with the aim of the course. I definitely wish that we were able to do this course on campus, but I think that you were able to transition it to online very well. I know that there were a lot of adjustments to the course schedule, but I would have liked to have a more solid timeline on how to prepare for the final presentation. We were introduced to the concept of Digital Storytelling early on, but it wasn't until Sonia Chaidez came in the last few weeks of class that that final project option was fully explained to us. It would have been more beneficial to explain digital storytelling halfway through the course so that students could have more time and information

> to decide between doing a paper or doing a presentation. Overall, I know that you had to balance your teaching and personal life throughout this course, and I appreciate the help and availability that you offered us. I felt that I was very supported and that my work was valued in this course.

This student was not alone in liking the digital storytelling projects. The students did a really nice job on them, and I only wish I had inquired if Sonia was free earlier in the module to deliver her introduction to WeVideo. I created an example video for the students involving traveling on an Antarctic expedition (see Sec. 3), and shared it with about 10 days go in the module. Had I done this halfway through the module, the students would have had double the time to prepare their projects, but only been exposed to half of the course content. In person, and in a semester-long format, the WeVideo tutorial could be introduced at the half-way point and the students would have a nice balance of time and exposure to course topics to really enhanced their WeVideo projects. Overall, I am proud of what we accomplished in this course, as it was offered for the first time under strange circumstances and still received high marks from the students. I conclude with this interesting thought by one of the students about digital storytelling:

> My favorite part of the course was that majority of the class did not decide to write a basic final paper, but challenged ourselves to make a digital story, and I think going forward for this course, this should be the mandated final. It makes things different, and gives them a break from writing redundant papers.

2.10 College Writing Seminar Course Descriptions

In Fall 2021, I taught my first section of INTD100: College Writing Seminar. Of all the courses I have taught, this one was the most different from my field of expertise. I imagine describing my course objectives and activities for my section of INTD100 will sound wrong or different to a professional writing or English instructor. To better conform with what has been done in the past in INTD100, I met with Charles Eastman during Summer 2020. Charlie gave me helpful advice regarding the recommended length of assignments, and how to assess writing. The theme of the course was scientific and technical writing, with emphasis on clarity, conciseness, passive voice, and the use of carefully planned structure for larger tracts of writing.

Although the course was centered around scientific and technical writing, we began with summer reading from *Notes of a Native Son* by James Baldwin. Given the events of Summer 2020, I felt that I had to incorporate *something* that spoke to the need for social justice. My family watched *I Am Not Your Negro*, directed by Raoul Peck, which focused on Balwin's writings about the history of racism and the civil rights movement. I decided to actually read the book, and Balwin's contrasting descriptions of burroughs around New York City resonated with me, especially his writing about Harlem. The reason has to do with where my family and many of our students live. I asked my advisees (who were also my students in INTD100) to get the book and read a particular essay about the author growing up in Harlem. I asked them to do five things: 1) practice summarizing the events of the essay in 120 words, 2) again, but using only 20 words, 3) to discuss an extended metaphor the author uses to describe the gut feeling of experiencing poverty in a crowded city, 4) to analyze the use of tangible evidence regarding a riot that took place in Harlem, and finally 5) a bonus assignment to draw links between the first chapter and a different chapter about the author's experience writing for newspapers in Harlem.

I found that the students completed this assignment and their answers to be reasonable, but they seemed hesitant to discuss the reading as a group. We had some discussion in breakout rooms, and we also did some icebreaker activities. After icebreakers and initial discussions about the summer reading, we moved forward with the main syllabus. Our first topic was making writing more concise and clear. I do grade papers occasionally in my STEM and liberal arts courses, and I find that students use more words than necessary. I created videos in which I edit example paragraphs of scientific writing. The students see how the writing becomes more precise by eliminating unnecessary words. I showed them an interesting and open-access visual tool for creating two-dimensional outlines called `coggle.it`. The students began reading articles about the discovery of things like gravitational waves, and creating the outline of the article using `coggle.it`. In this way, they learn how technical writing is structured.

Having built the main ideas of conciseness and outline structure, we developed skills like organizing details into proper hierarchy (general to specific), using citations and quotations, and analogies. The students learned how to select their own scientific articles and tracts of writing for practice and analysis. I added videos about these sub-skills. In small groups the students began to generate summaries of scientific topics like COVID19 outbreaks, gravity waves, the first picture of a black hole, and neutrino physics, using the skills they had learned. Although I

Question	F2020
10	5.0
11	4.0
12	4.9
13	4.9
14	4.9
15	4.6
16	4.8

Question	F2020
17	5.0
18	4.9
19	4.9
20	5.0
21	4.9
22	5.0
23	4.7
24	5.0
25	5.0

Table 2.11: (Left) Course evaluation results for INTD100 pertaining to the course. (Right) Course evaluation results for INTD100 pertaining to the professor.

gave them examples of sources, the students began to locate their own. One group chose to describe the purpose of the IceCube neutrino detector (Sec. 3), and absolutely nailed it. They demonstrated clarity, conciseness, and correctly cited sources while accurately summarizing the topic. The work of the other groups was also good, and it appeared the students were succeeding[25]. Finally, we read an essay on leadership (the same one I assigned in INTD255), and I asked the students to write an essay about a time they had to be a leader. Following advice from Charles Eastman, subsequent class sessions were spent editing example tracts of the students' writing. I remember from my conversation with him to *let the students' writing drive the discussion.*

We moved forward in the syllabus with technical description and specific writing structures like laboratory reports. The technical description involved removing numerical ambiguity from sentences and describing a scenario or scene such that it cannot be misinterpreted. In one assignment, the students provided instructions for how to prepare their favorite recipe, as if they were leaving these instructions for a classmate who was to prepare it themselves. More than just a recipe, this involved describing *precisely how* to locate ingredients and operate the kitchen appliances. The students applied these skills to a final 1000-word essay on a scientific topic encountered in the course. Their writing included diagrams, citations, summarizing content, and was writing with conciseness and clarity. We concluded the course by playing games together online, since these students were also my first-year advisees.

2.11 Analysis of Course Evaluations: College Writing Seminar

Table 2.11 contains the course evaluation results for my section of INTD100: College Writing Seminar. I taught this course in the Fall of 2020. I taught fifteen students who were also my first-year advisees. The scores are in general high, and I analyze the written remarks below.

Regarding the useful feedback section of the written evaluations, one student suggested more breakout rooms, and another added to put them more toward the middle of the class session. This is actually the first time I have seen any student ask for more breakout rooms, for in my other courses the students preferred less usage of them. One rough patch in my teaching for all my courses as been Moodle and grades. I have always calculated my grades in spreadsheet programs, and updated the students on their progress. I do that because in my STEM courses, a student could be doing well on homework (working with friends) and then do poorly on a midterm, only to recover on the final exam. The projected grade in that case only stresses the student and may not predict well the final outcome. Some students wrote about more clarity in the grading system and posting projected grades to Moodle. I will think about how to best honor that type of request.

When asked what they would change about the course, many students wrote that they liked it the way it was. Some gave the common remarks that more asynchronous days is preferable, more time in the module or class, and to start the class after 8 am. Some students shared that they were unsure about specifics regarding assignments. I agree that my assignment descriptions were sometimes more open-ended because I am inexperienced at assigning and grading writing. For shorter assignments, I would tell them exactly what to do and they would do that. For longer assignments (the final essay was about 1000 words), I could reflect more on how to create an essay prompt that structures the assignment without telling them exactly what to write. I chose a shorter final essay length after speaking with Charles Eastman about it, when he cautioned that some students have not written long pieces. In such a short module, I am happy with the results the students produced.

[25] Writing examples included in the supporting materials.

2.12 Outlook

Since January 2019, I have taught introductory and advanced STEM courses in a variety of disciplines. I have also created and taught brand new liberal arts courses in exploration and history of science. I stepped forward to volunteer for College Writing Seminar, and gained wonderful advisees in the process. Having reflected on my teaching practices, I find that my students are regularly succeeding, despite learning in a difficult period. Algebra-based physics continues to be the most challenging course to teach, but my students in general are learning well. I have discovered that I can teach courses beyond the traditional STEM area, and I will continue to serve that part of the curriculum. Though teaching College Writing Seminar was a stretch for me, the students responded well, and now a subset of them are in my STEM courses this semester. I look forward to observing their writing skills.

Perhaps the last piece of the puzzle in my teaching portfolio corresponds to the more advanced physics courses. This is not to say that I should sacrifice my liberal arts courses or writing course in order to teach advanced physics courses. I only remark that I should teach, at some point, courses like experimental physics lab, quantum mechanics, computational physics, and statistical physics. This would ensure that I know how to teach them well, as my colleagues do, so I could step forward to teach them should the need arise. I am very grateful to my colleagues for their continued support and feedback.

Chapter 3

Scholarship

Whittier College faculty classify scholarship using the *Boyer* model [47]. 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. 5). 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 [48]. 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 [49] [50].

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 [51].

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 [52] [53]. 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

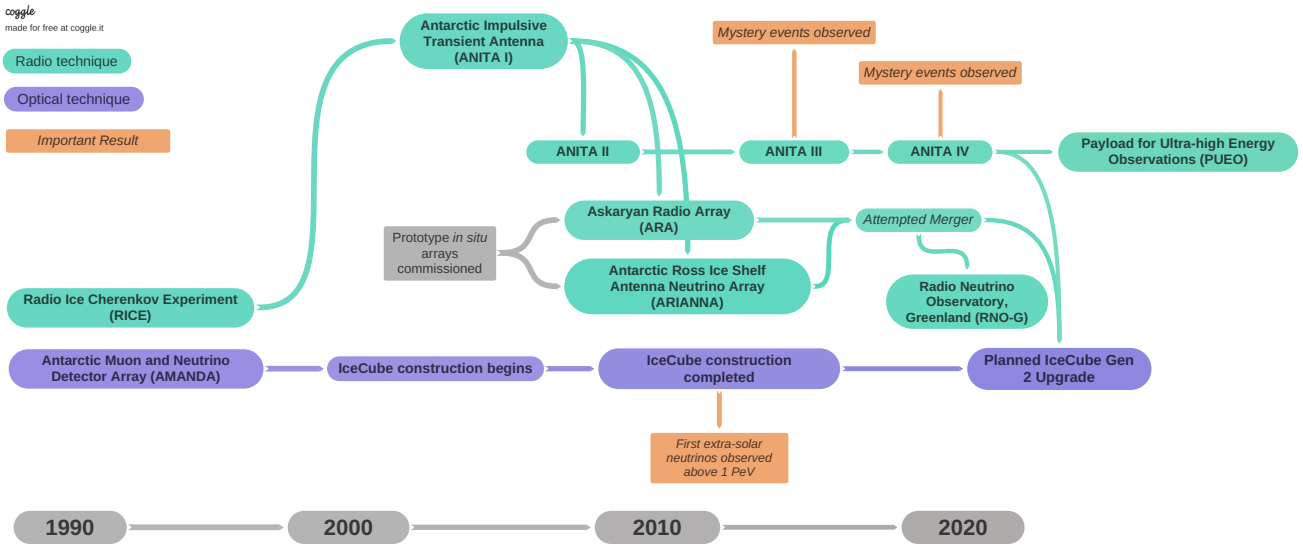


Figure 3.1: A general timeline of the UHE-ν sub-field of physics.

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] [54] [55]. 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. 1.2, 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 [56], and therefore cannot be explained with ray-tracing alone. Horizontal propagation has been noted as an interesting detection scheme for UHE-ν [57].

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 [58], 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 [59]. 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 [60], 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 [58], 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 [61]. 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 [62]. 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] [63]. 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 [58][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 [64], 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 [54], 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. 1.2). 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) [65]. 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 [58]. 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 ([64]) 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 [58], 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 [66].

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 [67] [68]. 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 [67] 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 [69]. 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. Including 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 [69]. 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.

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.

Finally, there is precedent for awarding NSF grants along these lines. For example, in *STTR Phase I: Additive Manufacturing of Radio Frequency and Microwave Components from a Highly Conductive 3D Printing Filament* (NSF Award no. 1721644), a small company called Multi3D LLC was seeded with funding to create conductive 3D printer filament from which we are currently trying to create microwave antennas. Some groups have already created some designs, but none have created phased arrays yet [70] [71]. Once we have our first working antenna model, I plan on creating a grant proposal along the same lines as the Multi3D grant for phased array development. With such a grant, we could acquire a 3D printer, conductive filament, and the associated tools. Along with the testing equipment from the Navy (Tab, 3.2), we would be able to experiment with new designs and publish results.

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, passes through air, and excites the AUT. Both antennas are mounted on rotatable mounts, and we have a variety

[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.

Equipment	Purpose	Bandwidth	Cost
Rohde and Schwartz ZVL6 Network Analyzer	Measuring RF power and frequency	9 kHz to 6 GHz	$20k
Rohde and Schwartz NRP-91 Power Sensors (2)	Measuring RF power	9 kHz to 6 GHz	$8k
Aeroflex 3416 Digital RF Signal Generator	Creating RF signals	250kHz to 6 GHz	$12k
Calibration antenna kits (2)	Receiving and transmitting	Varies by antenna	$2k
Calibration test kits for Network Analyzer (2)	Network Analyzer Calibration	6 kHz to 9 GHz	$6k

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

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. 5, 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

Service

A key part of our mission as professors is to share in the governance of our institution. In this chapter, I reflect on how I have done my very best to help Whittier College function. I have realized, as part of this reflection, that I have a strong desire to participate in the Whittier Scholars Program. This realization came about also as part of my advising practice (see Ch. 5). In Sec. 4.1, I discuss committee work achieved from 2018 to the current semester. In Sec. 4.2, I discuss my involvement with First Year Orientation. In Sec. 4.3, I describe workshops I helped to give on Open Educational Resources (OER) in collaboration with Wardman Library. Finally, in Sec. 4.4, I reflect on a service I performed for the local Whittier Community.

4.1 Committee Service

When I arrived at Whittier College in Fall 2017, my department had arranged my schedule such that I did not serve on a committee for the first year. By Fall 2018, I had developed the idea that I could serve Whittier College by utilizing my skills in data analysis. I was also interested in the connection between the high school preparation of our students and their ability to pass introductory courses required for their major. After signing up for the Enrollment and Student Affairs Committee (ESAC), in Fall 2018, I learned that this is a sensitive topic with which many administrators and intructors had been struggling. I spent two years working on ESAC, and I watched as our committee carefully approached consensus while remaining respectful of the diverse perpectives that included athletics, student life, and instructors. In the second year, we began discussions with Falone Serna, Vice President of Enrollment Management, to implement the policy result of the prior year. It was in my second year of ESAC that I began to learn more about first year orientation, for which I volunteered in 2019 and 2020.

In 2020-21, having served two years on ESAC, we decided it would be good for me to experience service with other types of committees. I had taken an interest in the Digital Liberal Arts, and educational technology, after writing my Cottrell Scholars Grant[1]. I decided to join the Educational Resources and Digital Liberal Arts Committee (ERC/DLAC) for a year. Though the onset of the pandemic restricted our ability to procure educational resources, we studied the curriculum proposals and then decided to create two new initiatives. The first initiative was to participate in the Center for Teaching and Learning. The second was to create a policy for archival of all undergraduate senior projects in the Poet Commons.

4.1.1 Enrollment and Student Affairs Committee, Years 1 and 2

I joined ESAC in Fall 2018, and our charge included the creation of recommendations for altering admissions criteria, discussing the criteria for athletics participation for students on probation, and organizational issues surrounding the creation of INTD101. Our committee chair was Prof. Ayesha Shaikh. Early in the year, Prof. Shaikh formed a sub-committee on admissions data analysis. I volunteered to partipate with Prof. Charles Hill, and the vice president of enrollment (at the time) Kieron Miller was also included. Working with Fritz Smith and others, we gathered educational data on several thousand students going back six years to examine what leads to the admission of students that do not proceed the Fall of their sophomore year.

The admissions data sub-committee began meeting in Fall 2018. Our discussions were broad at first, focusing on the the balance between admitting enough students with the need to admit students we know we can support and

[1] Provided in supporting material.

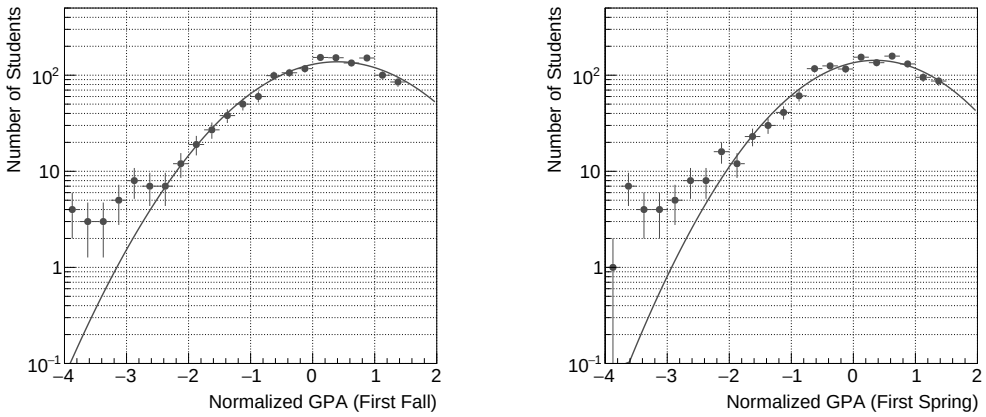


Figure 4.1: (Left) A histogram of GPAs for 1,346 Whittier College students in the first semester. (Right) Same, but for the second semester.

retain. I learned a lesson about management: adminstrators and instructors more experienced than me spoke more frankly in sub-committee, but in more diplomatic language in the main meeting. ESAC had members from admissions staff, the athletics director, members of CAAS, and professors from different divisions. Eventually we received archived data in the form of spreadsheets for $N \approx 3,000$ students in their first two semesters at Whittier College. I found a number of interesting effects regarding student GPA, standardized test scores, the financial aid gap, and student retention through the Fall semester of their sophomore year. I presented my findings twice to the main ESAC committee[2].

In my first presentation, I began with the basic finding that student GPAs during their first semester at Whittier College do not follow the expected statistical distribution. Given a random sample from a population of students, one expects a *normal distribution* (bell curve). Figure 4.1 contains the results we observed, after limiting the analysis to just the students for which we had complete data from high school and Whittier College ($N = 1,346$). The fitted curves to the data points follow normal distributions. There is a clear set of outliers on the left side each graph, meaning students are receiving lower grades at a rate much larger than we expect statistically. The left plot corresponds to the *normalized* GPA distribution of Whittier College students in their first Fall semester. Normalized GPA is just the GPA minus the average GPA, divided by the standard deviation in GPA. Thus, a value of zero in Fig. 4.1 simply means those are the students getting the average GPA[3]. A value of -4 means those are the students who receive a GPA of four standard deviations below the mean (a GPA of approximately 1.0). Fig. 4.1 (right) contains data from the same students for their second semester at Whittier College.

The next step was to try to identify the low-GPA students in advance using the data we had historically. Decisions based on the findings would be by consensus, and with input from the whole committee. My job was to find clues as to why we observed students receiving GPAs three to four standard deviations below the mean at a rate 10 times higher than expected. I ran a series of statistical analyses using a software package called TMVA, which was part of the ROOT C++ framework used in particle physics (see `https://root.cern/`). I found that for students that *do* proceed to the sophomore year, data from high school and college, and data from the first and second semester in college, is highly correlated. For example, if we have the high school GPA of a student we know is going to proceed to sophomore year at Whittier College, we can predict first semester GPA at Whittier College accurately. For students that we know do not proceed to sophomore year, the data yields no strong correlations. I tried two machine learning methods to factor the data into statistical parameters that would reveal the difference between students that do and do not proceed. Although the algorithms could classify the extreme cases, I felt there was too much overlap to use them effectively, and that there had to be more to the story.

As part of the first analysis, I was fitting normal distributions to statistical data generated by our students. One data column that came with the original files was named "financial aid gap." As I understand it conceptually, a

[2]These presentations are included in the supporting material.
[3]I was intrigued to find that the average GPA in this analysis was exactly 3.0, with a standard deviation of about 0.5.

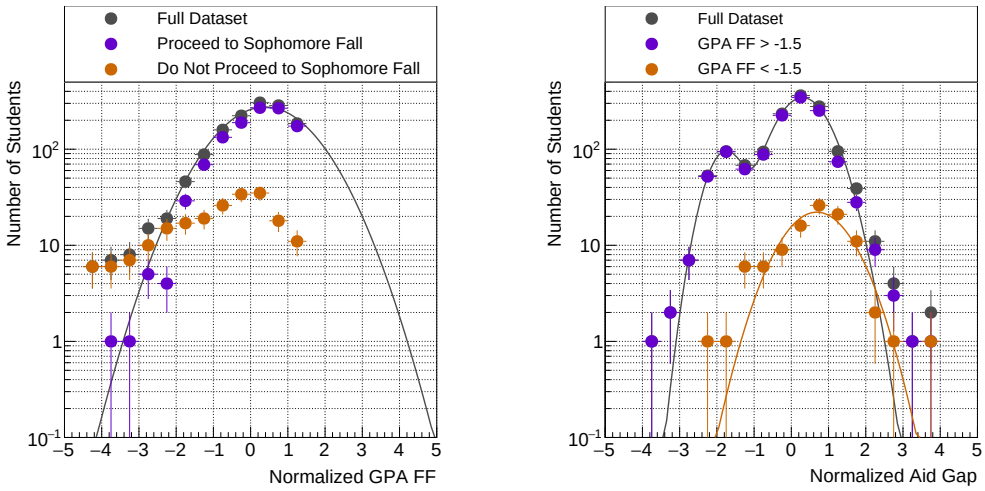


Figure 4.2: (Left) Histogram of normalized GPA for students' first fall semester for all students (black), those that proceed to sophomore year (purple), and those that do not (orange). (Right) Same color scheme as (Left), but for aid gap.

positive aid gap means that a student is receiving various forms of financial aid that total less than what they owe in tuition, after accounting for the expected family contribution[4]. I noticed that I could not explain the distribution of student financial aid gap with *a single* normal distribution, and that a better fit was *two normal distributions.* Statistically speaking, this finding implies that the data sample is drawn from two populations of students. One had an average *negative financial aid gap*, and the other had an average *positive financial aid gap.* It appeared that one group was receiving aid and scholarships that exceeded their tuition, and another group was receiving less. This was the topic of my second ESAC presentation.

I was able to show that aid gap is predicted by many things. If a student has an SAT score (in any category) that is 1.5 standard deviations below the mean (or lower), then that student is almost always in the positive aid gap group. The same is true for first and second semester GPAs. What struck me the most was that if I graphed the aid gap distribution for just the students who did not proceed with sophomore year, a large fraction of those students were in the positive aid gap group (receiving less). It is worth pointing out that the impetus for the analysis in the first place was Fig. 4.1. Figure 4.2 contains the aid gap distribution. What if the positive aid gap group and the low Whittier College GPA group were connected? Figure 4.2 contains evidence of this. However, I note that the data can be messy, and the proper claim is not simply that positive aid gap leads to low GPAs. Rather, if a student receives a GPA of 1.5 standard deviations below the mean in the first semester, it is highly likely that the student has a positive aid gap.

4.1.2 Educational Resources and Digital Liberal Arts Committee

Our main achievement on the educational resources committee during 2020-21 was to create a policy and process for archival of senior thesis presentations. We discussed a number of issues surrounding archival of senior projects. First, there was the notion of quality control. Some students take their senior projects very seriously, and treat the work as their first potential step into a professional world. We created a form that documents the decision process for the entry of the senior project into the archive. Both student and advisor must agree that the work is of sufficient quality. Second, the student can control the searchability of their work. A project may be visible to the broad internet, just those with access to Poet Commons, or simply archived but not visible for a period of time. The period of time can be temporary or permanent. This action protects the privacy and intellectual property of the student, while preserving their work for future members of the Poet community to understand. Third, we included feedback from other committees regarding the structure of the form, and the implications of a decision now on the future visibility of a the senior project.

[4]VP of Enrollment Management, Falone Serna, was kind enough to explain it to me in detail in my second year in ESAC, but during the first year this is essentially how I understood aid gaps.

4.1.3 Whittier Scholars Program

Having served two years with ESAC and one with ERC/DLAC, I reflected this past semester on how my committee work could be the most productive for Whittier College. I was grateful for the opportunity to serve on ESAC and ERC, but I came away with a strong impression of the Whittier Scholars Program (WSP) after advising a student to graduate through the program (see Sec. 5). In conversations with Prof. Andrea Rehn, director of WSP, I learned that working on the WSP advisory board is, on average, more work that most committees. However, it is the *type* of work that I can do well. The main function of the WSP advisory board is to review student applications, which are educational roadmaps. We interview students and advisors as a team, and get them to think carefully about the design of their major given the intellectual landscape involved. Providing intellectual guidance that relies on both broad knowledge and critical thinking is the kind of work I think I can do very well for our community.

With ESAC and the admissions criteria, for example, my impression was that the majority of our effort was spent in negotiation between people with different viewpoints. Some thought absolutely no numerical limits to admissions criteria should be allowed, and some thought there must be some. I performed my analysis as best I could while balancing my other responsibilities, but in the end the issue was resolved through political negotiation. I agree that this was a necessary path forward, and we did end up developing a consensus. However, it seems to me that others are more adept at those negotiations than I am, and that my analytical skill would be better utilized in other committees. On the other hand, sometimes the administration needs us to help out where the help is needed, regardless of the type of work, and I am always open to serving where I am needed.

I decided in Spring 2021 to inquire about serving WSP. I spoke with Prof. Andrea Rehn, who excitedly welcomed me to join the WSP advisory board. She added that it was a three-year service term, and I agreed that it made sense to have continuity. Although it became official that I was to join the WSP program this Fall, we received word from the Faculty Executive Committee (FEC) that I was needed on the Educational Policies Committee (EPC) due to the loss of personnel. *I feel in this situation that it's important to be a team player*, knowing that there will be a time in the near future that I can serve WSP. I am grateful to all of my committee chairs and fellow members for their hard work, and I look forward to serving in the future.

4.2 First Year Orientation

In the Fall of 2018, I was invited by Prof. Seamus Lagan to help with the first-year orientation. The goal was to observe and help with the activities Prof. Lagan had planned for his new advisees. We ran icebreaker activities, discussed majors and classes with the students, went over summer reading assignments, and toured campus. Some of Prof. Lagan's first-year advisees later became my advisees as they graduated (see Sec. 5). It was an important experience, because it served as a trial run for the following year when I volunteered to teach College Writing Seminar (INTD100), and take on more first year students as my own advisees.

In Fall 2019, I added a group of new first year advisees to my roster while teaching INTD100 for the first time. I applied the lessons of 2018 to my first solo run for first-year orientation. My student coordinator and I did our best to give the students the sense that they *belong* to this community. One social activity that I find works well for the students is to game with them, as in online gaming and board games. The majority of my students that year turned out to be athletes, so they were not free to do the field trips to downtown LA, for example. I found times to meet with them (for both advising and social activities) that worked with their schedules. In my first PEGP, I wrote about how I participated for more than a year very closely with the student organization CRU (a Christian fellowship for Whittier undergraduates). Mentoring first-year advisees felt similar to that experience.

Finally, I taught INTD100 in Fall 2020, taking on another group of first-year students. This was during the height of the pandemic, before anyone was vaccinated. We had to build a sense of community and belonging via Zoom. I decided to serve the INTD100 program because it seemed in need of help and not enough instructors were stepping forward. Though it was difficult building a sense of community with my students remotely, I kept encouraging them to perservere until the end of the semester. Then, we gamed to our hearts content. We played online card games, and Among Us, laughing the whole time. Then we "went home" for the holiday break. I will elaborate more on advising my students' course and major selections in Sec. 5.

4.3 Open Educational Resources (OER) Workshops

I was invited to give two lectures at OER workshops organized by Sonia Chaidez and Azeem Khan[5]. I considered these a form of service to my colleagues, in that some of us might not be aware of how much course content in our field my be made open-access using OER. One number that I keep in my head is that about 1 in 5 students have difficulty buying textbooks (see 2.2). My students use the OpenStax framework whenever possible, and this is true of courses in other STEM areas. However, our OER workshops also covered the use of `https://www.oercommons.org/`, which provides open access resources in the humanities. I also pointed out that there has been progress in the social sciences within the OpenStax framework, and how the OpenStax tools are used in my classes (see Sec. 2.3).

The OpenStax Tutor system costs the students only $10.00, and the OpenStax textbooks are free. Tutor is a flexible reading and homework assignment system that grades student work, and uses artificial intelligence to provide students extra practice in areas where they need to grow. The OpenStax texts help me teach my courses by providing example projects my students can construct as their final projects. They also have built-in PhET simulations, to help the students illustrate concepts through experimentation. I receive statistical reports from the Tutor system, and I act on them by covering those exercises in class with which many students struggled. All reading and homework assignments are summarized in a calendar and notification system. The system is an adaptable, feature-rich, and cost-effective for our students.

In my OER lectures, I also gave examples of OER usage in advanced courses. In Computer Logic and Digital Circuit Design (COSC330/PHYS306), the PYNQ-Z1 by Agilent (`https://www.pynq.io`) provides the students an open-source environment with which to learn software and firmware development. I also gave an example of an open access text outside the OpenStax and OER Commons areas, for Digital Signal Processing (DSP), COSC390. I write the course software +in octave, an open-source programming language the students install for free. So DSP is an example of an advanced course that is completely open access, top to bottom. It is my goal to inspire and lead my colleagues to use OER whenever practical, to help foster equity and inclusion in our educational environment.

4.4 Center for Engagement with Communities: The Artemis Program

In Sec. 2.2.3, I wrote about my experiences serving the Artemis program. To avoid covering the same ground twice, I give just a simple summary of the facts here. I have served the Artemis program twice in the past, and will volunteer in the future as soon as I am able. In 2018-2019, we accepted applications for the Artemis program. I volunteered to teach a group of three young women from local high-schools. We created a Python3-based project involving physics education research (PER). The young ladies used the code to collect data from their classmates and presented the results at URSCA 2019. In 2019-2020, we again accepted applications for the Artemis program. I volunteered to teach a group of four young women from local high-schools. We designed a wearable Arduino microcontroller project to interface with WiFi in order to track down a lost family member. Following examples we created, the young ladies learned to re-program the firmware of their boards and connect to WiFi. We were beginning the phase of creating the wearable devices from the boards when the pandemic forced us to pause. We will return to this project the next time I serve the program.

[5] See supplemental material.

Chapter 5

Advising and Mentoring

I reflect on my role as an advisor and mentor at Whittier College below. I have mentored both first-year students, before they select their department and major, and majors in the STEM area. In Sec. 5.1, I reflect on the connection between advising and teaching. Also in Sec. 5.1, I reflect on mentoring and welcoming first-year students to Whittier College. In Sec. 5.2, I review my experiences guiding Physics, ICS, and 3-2 engineering majors to graduation. Finally, in Sec. 5.3, I reflect on my experience guiding a student to graduate through the Whittier Scholars Program.

5.1 Connections to Teaching, Advising First-Year Students

Advising and mentoring students resembles our teaching practice, because we must create a sense of *order and shared meaning* in the mind of the student surrounding the curriculum. The curriculum must be broken into its constituent parts, and the student must be shown how the parts fit together into a whole. Good advising also follows the teaching form of discovering the perspective of the student in a student-teacher partnership. This partnership takes on different forms, depending on the type of student. It is important to note that I have already given examples of *developing a sense of belonging* with the first-year students in Secs. 2 and 4, so I will move forward with details about my advising practices. What follows is a reflection on the type of advising that is appropriate given the types of students we encounter.

Physics professors often classifiy students into two broad categories: *non-majors* and *majors* (see Sec. 2.1). Most of our advisees as teachers fall into the first category. Table 5.1 contains the distribution of my advisees since 2019. In fact, according to Tab. 2.1 (Sec. 2), I have instructed 402 students since Fall 2017, and 206 students were non-majors taking algebra-based physics. This implies that that 51 percent of my students are non-majors. Thus, I am accustomed to teaching and advising outside of my field. Like teaching, advising students outside of my field of study requires emphasis on different goals than my students that are STEM majors. I have taken first-year advisees on two occasions: Fall 2019, and Fall 2020 (Tab. 5.1), for a total of about 30 advisees.

Advising non-majors follows a basic progression: introducing them to the curriculum and campus (*order*), beginning a conversation surrounding major selection (*shared meaning*), and future course selection. First-year students need careful instructions on how to best take advantage of our liberal arts curriculum. If the students are first-generation, they might need an introduction to the structure of college in general. In Fall 2019, along with the help of a wonderful student coordinator named Kat Garrison (KPOET radio), we introduced my new advisees to the curriculum. We find another classification useful for first year advisees: those are are certain of their major selection immediately, and those are still deciding.

One advisee of mine named Shengyi Liu felt comfortable taking 19 credits, and he had the desire to go to medical school. He knew what major to choose and he was highly organized. Thus, I shifted my advising to discussions about passing college writing seminar, letters of recommendation, and research. An example of a student that was not at all sure about major selection was my advisee Andrea Wainwright. She excelled at French in high school, but I could tell from our conversations that she was interested in art history and history as well. I led her towards the Whittier Scholars Program, in addition to encouraging that she master French in our time with us. Another first-year mentee of mine, Wyatt Killien, was at first interested in physics. After our conversations, we realized it was not actually physics that he wanted, but merely physics as a means to an end in graphical design and digital

Semester	**Number of First Year Advisees**
Fall 2019	15
Fall 2020	14
All semesters	**Physics, ICS, and 3-2 Majors**
	Cassady Smith (Physics '20)
	John Paul Gómez-Reed (Math/ICS '21)
	Nicolas Clarizio (Physics, Business Admin. '19)
	Alex Ortiz-Valenzuela (3-2 Engineering/Physics '22)
	Raymond Hartig (Physics and Math '23)
	Adam Wildanger (3-2 Engineering/Physics '21)
	Matthew Buchanan Garza (ICS/Physics '23)
	Natasha Waldorf (ICS/Physics '24)
All semesters	**Whittier Scholars Program Majors**
	Nicolas Bakken-French (WSP '21)

Table 5.1: A summary of my advisees, broken into three categories: first-year advisees, STEM majors, and WSP majors. There are some first year advisees who have chosen ICS/Math for their major, for whom I remain a mentor. One example is Emily List (ICS/Math '23).

art. After he discussed the change with his family, we directed him to the Art and Digital Design program.

Some students require more conversation to identify their main reason for attending college. Student-athletes, for example, want to play varsity sports but are unsure what courses make sense for them. Others have only the general area but not a specific idea for a major. For the students who have more uncertainty about their path to a degree, I have begun the practice of completing a LinkedIn Profile with them. We use the job search feature to locate geographically the firms they feel match their employment goals. Then I have them examine the skills required, and we try to arrive at a major selection that aligns with these skills. This approach works because it helps the students to *order* their thinking in a practical way. It also creates a sense of *shared meaning*, because the students and I share an understanding of their goals after graduation. A side benefit of this procedure is that we remain connected on LinkedIn after graduation, and we can contact each other.

Though advising STEM majors is a smaller fraction of the work I have done in the area of advising and mentoring, it is a more involved process. In my experience, people who wish to major in the STEM areas listed in Tab. 5.1 already have a firm idea of major selection before they arrive at Whittier College. Part of the challenge is to assess the mathematics and computer programming skill they gained in high school, and guide them to the correct introductory courses. The next task is to draw from the student their ideas about the purpose of their major selection, and whether it falls under any broad category like theoretical physics, experimental physics or engineering, or business applications. I pay extra close attention when I have an advisee in the 3-2 program, because the core requirements plus liberal arts requirements must all be satisfied in three years.

The connections between research (both mine and the students') and course/major selection also becomes apparent in these conversations. Students in the STEM area often base their major selection on the kind of research or job role they prefer in the long run. For this reason, completing LinkedIn profiles with my STEM students is also a good idea. For Cassady Smith and John Paul Gómez-Reed, I worked closely with the Career Center staff to help them craft resumés. Recently, I have restarted that practice, since my students will be applying for internships with the Navy research laboratory (see Sec. 3). However, it is also my role as an educator to introduce them to the intellectual variety of their chosen area. *Sometimes the interests of the student align with my research, and sometimes they do not. I advise them nonetheless, and do my best to meet the student where they are to guide them forward.*

There have been times a student has drifted towards another professor (John Paul, for example, worked with Prof. Fred Park for a while because he was interested in learning more about machine learning). Sometimes I develop shared interests with a student, and we develop a project idea together that is related to my research experience but not perfectly aligned. Finally, and rarely, a student knows that my research is what they want to do, and they are eager to get started (Raymond Hartig, for example, plans to attend graduate school for physics). In the supporting material, I have included two letters from two of my advisees regarding projects we developed together from start to finish as a team. The first is from Raymond Hartig regarding our novel mathematical physics model

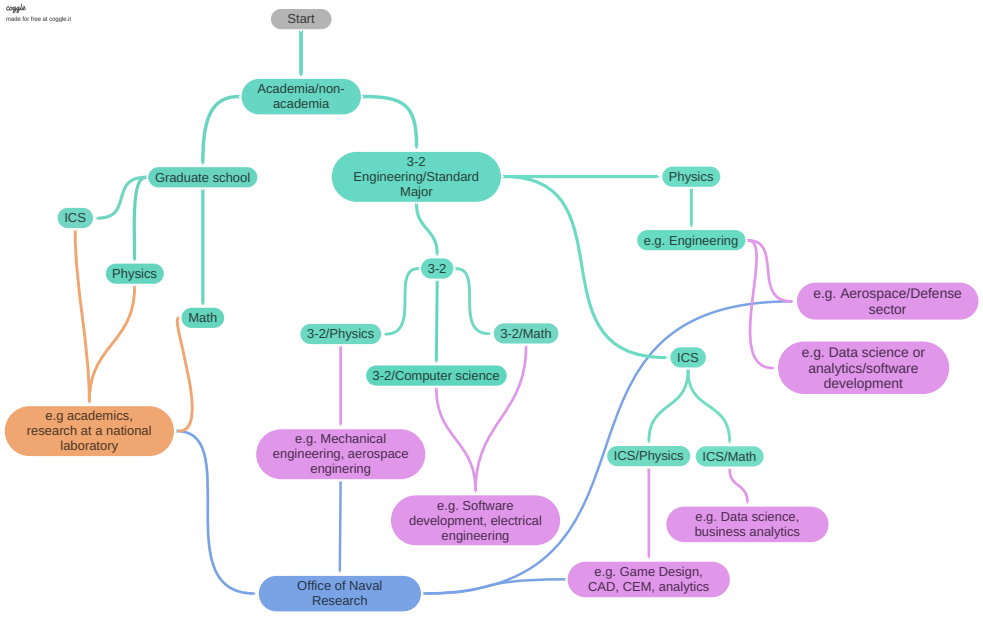


Figure 5.1: A decision-tree that orders my thinking around the advising of my STEM students.

of Askaryan radiation. I know that Raymond wants to double-major in math and physics and then apply to graduate school, so I have been coaching him for that process. The second note is from Nicolas Bakken-French, who graduate from the Whittier Scholars Program after creating a holistic study of glaciology with me that included travel around the world.

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

In reflecting on my advising practices with my STEM students, I realize that there is an implicit decision-tree that lives in my mind (see Fig. 5.1). I use this decision-tree to guide students in LinkedIn profile creation, resumé-writing, and writing letters of recommendation[1]. *It is important to note that Fig. 5.1 does not represent any sort of hierarchy, but merely the order in which I proceed with the students.* Reflecting on my conversations with the students reveals that the discernment process simply follows this pattern. Practical concerns about potential salary, proximity to family, and technical ability all factor into the path of the student through the process described by Fig. 5.1.

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

Discernment means the ability to understand oneself, while seeking honest guidance to make one more spiritually and mentally sound. Advising STEM majors sometimes requires me to provide them a form of "professional candor" that the FPC is tasked with providing me. If we do not identify where we need to grow, then we are either not hearing the guidance given by peers, or not adequately reflecting on our situation. This was the case when one of my first year students, Wyatt, shared with me that he wanted to study physics. He shared with me that he was not keen on taking calculus, and did not find his computer science course exciting. This was a clue to me that he was not on the right track. Normally, a physics student would sink his or her teeth into these courses. After a period of discernment in Spring 2021, we found that Wyatt was not interested in physics because of the *scientific experimentation* portion of it. He was interested in physics because he liked understanding and playing with the way the world fits together in his mind. Given his interest in manga and anime, I recommended he talk to his family about digital art and design. I also noted that Whittier College offers courses in world building and graphical design.

[1] Examples of letters of recommendation for a variety of students are included in the supporting materials.

Sometimes students arrive in my office already having discerned that they want to make a career in science. At the first decision point, we have *academia or non-academia.* This decision is usually the first decision, because the course list our department requires for the academic track in physics contains more theoretical physics and math courses. Usually, if the student wants to attend graduate school, they have discerned that as well. The real task in that case is to discern which area of academia they wish to explore. Since we now require COSC120, Computer Science I, for physics majors, students can experience computer science before deciding between ICS or PHYS as a major track. Although I have taught and mentored students who were straight mathematics majors, none of them were my advisees. During the middle of the junior year, we begin the graduate school search and application-building process. If there is an academic connection to my CEM/ONR research, we can explore potential connections in their senior projects if the student desires.

On the other side of the decision point, there is the private or public-sector path. In Fig. 5.1, the rest of the decision tree branches into the different topics and example career selections. Common private sector career selections involve CAD design for engineering firms and software development for gaming companies. The decision regarding 3-2 program versus ICS needs to be made during the first or second semester in order to plan the student's courses. Once I see a committment to the 3-2 program, I help the student plan their courses for every semester. Though the 3-2 majors do not complete a senior project, I involve them in my CEM/ONR research if possible during the summers. This is so they can gain the experience necessary to secure valuable internships and projects at their next institution (usually USC).

If the student wants to be at Whittier for four years, but not major in physics, the choice is usually ICS/Physics or ICS/Math. A growing career selection for this area is data science, and we are now offering two new courses in data science at Whittier College. One trick I have added to my LinkedIn advising lately is the geographical job search. Because there are so many firms in Southern California that specialize in data science, the student and I generate some search terms and then run a geographical search within LinkedIn for matches. We narrow the field by eliminating the organizations that are located too far from the family of the student[2]. The narrowed list of firms provides the students with example jobs they can peruse for skill requirements. Finally, we think about ways in which final projects and course selections connect to the skill requirements. This was especially important for Matthew Buchanan Garza, one of my advisees, who wants to enter the world of software design for gaming. Knowing that algorithm development is highly important for software development and gaming roles, we prioritized the corresponding course in his schedule.

5.3 Advising and Mentoring Whittier Scholars Program Majors

I have had a wonderful time recruiting students for the Whittier Scholars Program. There are two moments that stand out for me. The first happened when I accompanied Nicolas Bakken-French to his final meeting with Profs. Rehn and Kjellberg, where his planned scholarship was approved. After the meeting, we were walking back to my office and Nick was electrified. As we parted ways, he gave me a big hug and thanked me for helping him gain this opportunity to graduate with a custom major in Environmental Analysis and Glaciology. We had argued that there is a useful connection between understanding the *science* of glaciers and glacial melt, the cultural impact of glaciers on communities, and the environmental science and policy decisions that affect glaciers.

The second moment that stands out is when I was meeting with my first-year advisee Andrea Wainwright to talk about course selection. She knew that she wanted to continue with French, but I was also hearing remarks like "Well, I'm also interested in art history, but I just love the renaissance, and oh, there's history as well ..." At some point, I interjected: "You know we have a special program that allows you to design your own major, right?" Her eyes widened. "Oh, that sounds awesome, I think that is for me!" For some students who simply love learning and want to know everything, and for whom one major is not enough, I know to direct them to WSP101: The Individual, Identity, and Community. One near-term goal I have is to serve on the Whittier Scholars Advisory board, so that when students take that first step, I can help them form their educational plans in detail.

[2]The search radius depends on the student, but most envision Southern California, unless they are from a different state. I have not yet advised an international student. When that situation arises we will have broader conversations about where the student wants to live and work.

5.3.1 Organization of Field Deployments

In many ways, my student, Nicolas Bakken-French, was an exceptional case. Nicolas simply walked into my office with confidence, and said "I heard you do research in Antarctica. Is there a way I can help?" Nick must have been an early sophomore, and already I could tell he had a fire in his belly, also called the *Nansen spirit* in my INTD255 course about Antarctic science and exploration. Fridtjof Nansen was the first human to cross Greenland, and held the record for furthest North latitude before the North Pole was finally reached by his protegé Roald Amundsen. Exploring Antarctica is not that different from operating in Nordic climates, and it turns out Nick had already been doing that for several years when visiting the Norwegian half of his family.

I knew right away that I should attempt to secure him a spot on the next ARIANNA expedition. We had the idea that by sending him with our recently built drone (thanks to Nick Clarizio, Physics and Business '19), that he could use it to take aerial photos of glaciers feeding into the Ross Ice Shelf. After consultation with my ARIANNA colleagues at UC Irvine, they agreed to add him to the roster. There are two stages to obtaining the green light for a trip to McMurdo. First, one must pass medical checks, which are extensive the first time. Nick finished the process, which includes multiple medical appointments for blood and cardiovascular tests. The second stage is to acquire travel documents and airline tickets. My UCI colleages were going to support Nicks' air travel. I met with VP Andrew Wallis (International Programs) to create a plan for keeping Nick enrolled as a student while he was away. Most Antarctic expeditions take place between November and February, when the sun is out all day. We coordinated with the instructors of Nick's courses to ensure the content he would miss could be completed remotely[3]. One of his instructors was me, since Nick took INTD255 (the Antarctica course).

Then the ARIANNA budget was cut. No expedition was to take place that year out to Moore's Bay to finish data collection from the detector. The pandemic subsequently wiped out the next season, and we were dead in the water. Those that work in polar research know that events like these are not abnormal. We encounter plenty of similar stories in my INTD255 course, where expeditions are put on hold if finances or logistics are not yet in order. I worked with Michelle Ponce, who was heading the career office at the time. We reorganized Nick's internship credits so that he could help with a physics project at UCI developing a heating element that can melt slots into glacial surface snow. The slots are ncessary to insert instrumentation uniformly as glacial probes. After Nick returned from UCI, we set out a roadmap of programs to which he could apply to gain nordic exploration and scientific experience. Our educational plan was approved by WSP, and it merged climate science, the cultural impacts of glaciers, and the science of glaciology. Nick went on to travel to Iceland, the National Outdoor Leadership School, and the Juneau Ice Field of Alaska.

The idea began to come together as a photo-journalistic experience. Nick was to learn the scientific trade from the experts running the programs at the sites, and bring back photos with a dual purpose. The photos were to provide a geological record of glacial retreat, and also evoke a sense of *aliveness* from an artistic perspective. In *The Secret Lives of Glaciers,* by Prof. Jackson (National Geographic Society Explorer and TED Fellow), the author writes about experiencing a glacier as if it is alive. Glaciers breath, move, sweat, and make sounds. They influence agriculture and fisheries. Human cultures near glaciers have always ascribed some degree of life to glaciers. The holistic view of glaciology and culture was an idea Nick encountered in Iceland, and he applies it to glaciers and cultures in Latin America, Alaska, Wyoming, and Iceland in his thesis.

5.4 The Finished Product

My role in helping Nick to finish his degree was two-fold. First, I had to guide him through the process of counting credits, and ensuring that Prof. Rehn, myself, and Nick were all on the same page. I viewed this as a team effort, and since Nick was denied the chance to go to Antarctica, I made sure that every little credit he took online and in the field counted towards his WSP major. Second, it was my job to make sure the final thesis was polished in both the scientific and writing senses. Regarding the first round of polishing, I made sure that Nick applied my INTD100 techniques to his thesis. Scientific graphics are used when appropriate, to enhance and clarify the logic and flow of ideas. The captions are edited to include real units, which are explained in the text. Concise sentences are used to explain the logical chain of ideas that surround glaciological claims.

One example is found in the section that explains how we infer global average temperature over 800,000 years from Antarctic ice cores. The specifics of the measurement involve analyzing radioactive isotope ratios in air bubbles trapped within the ice at varying core depth. The radioactive isotope analysis is mapped onto years in

[3] Just a few months later, we *all* had to create fully remote content.

the past by using layering and ice physics. We wanted the language for the thesis to reach a broad audience, so we practiced generalizing statements filled with scientific jargon while keeping the logic intact. Overall, we think the thesis is accessible to readers with diverse training and engagement with glaciology and climate science.

The thesis begins by explaining the way in which Greenlandic and Antarctic glaciers and ice shelves will influence global climate in the next 50-100 years. We move into more detailed case studies of the effect of glaciers on agriculture in Wyoming, fisheries in Alaska, native cultures in Latin America and Iceland, and biodiversity in California. One strategic choice we made was to focus the detailed analysis on Iceland. Though Nick learned a great deal on all of his expeditions, and in my INTD255 course, Iceland provided the holistic picture in one location. We were able to communicate the message without expanding the length of the entire document. We included cultural persectives on glaciers in Southeastern Iceland, near the Vatnajökull ice cap. The icecap is the largest in Europe, and it feeds many glaciers that dominate the fertile landscape near the ocean. The people farm the land between the ice cap and the ocean, and glaciers can retreat or advance to change the landscape. The older generation views the current recession of glaciers as just part of the natural cycle, whereas others can see that the shift will eventually become permanent. Some even have taken advantage of the situation to form "last chance" tourism companies, bringing in eco-tourists eager to glimpse the mighty glaciers before they disappear.

My second role as Nick's advisor for the thesis was to help Nick polish the writing. Unfortunately, this took place during Sring 2021, when I was teaching INTD290 and two physics courses, all for the first time in the module system and online. I was stretched very thin, and I think we could have done a better job polishing the grammar and eliminating redundant sentences. Normally, when I help to write a paper, I have a regular process for outlining, building, and polishing. There was less time for this than I would have liked. Nick was due to go to Alaska for the summer to explore the Juneau ice fields, and I was also preparing for the ONR research along with my 3-2 engineering student. The shining jewel of the dissertation, however, are Nick's photographs. We include them in the end, and I hope their truth and beauty make up for a few awkward sentences. I introduced WeVideo to Nick so that he could weave them into a digital storytelling piece for the WSP senior presentation. Nick has told me recently that these photos and the rest of the work will someday be added to a book underway with his colleagues from Iceland. If there is time, I'd like to circle back to Moore's Bay, Antarctica once the pandemic subsides.[4]

[4]With Nick's permission, I have shared some of the photos in the supporting materials.

Chapter 6

Conclusion

Jordan C. Hanson, PhD
Assistant Professor, Department of Physics and Astronomy
Science and Learning Center, 212
Whittier College
562.907.5130
jhanson2@whittier.edu

Chapter 7

Supporting Materials

Bibliography

[1] I. Kravchenko, S. Hussain, D. Seckel, D. Besson, E. Fensholt, J. Ralston, J. Taylor, K. Ratzlaff, and R. Young, "Updated results from the RICE experiment and future prospects for ultra-high energy neutrino detection at the south pole," *Phys. Rev. D*, vol. 85, p. 062004, Mar 2012.

[2] P. W. Gorham et al, "Constraints on the ultrahigh-energy cosmic neutrino flux from the fourth flight of ANITA," *Phys. Rev. D*, vol. 99, p. 122001, Jun 2019.

[3] Ahlers, M, et al, "Astro2020 science white paper: Astrophysics uniquely enabled by observations of high-energy cosmic neutrinos," *Bull. Am. Astron. Soc.*, vol. 51, no. 185, 2019.

[4] Ahlers, M, et al, "Astro2020 science white paper: Fundamental physics with high-energy cosmic neutrinos," *Bull. Am. Astron. Soc.*, vol. 51, no. 185, 2019.

[5] A. Connolly, R. S. Thorne, and D. Waters, "Calculation of high energy neutrino-nucleon cross sections and uncertainties using the Martin-Stirling-Thorne-Watt parton distribution functions and implications for future experiments," *Phys. Rev. D*, vol. 83, p. 113009, Jun 2011.

[6] G. Askaryan, "Excess negative charge of an electron-photon shower and its coherent radio emission," *Soviet Physics JETP*, vol. 14, no. 441, 1962.

[7] G. Askaryan, "Coherent radioemission from cosmic showers in the air and dense media," *Soviet Physics JETP*, vol. 21, no. 658, 1965.

[8] D. Saltzberg, P. Gorham, D. Walz, C. Field, R. Iverson, A. Odian, G. Resch, P. Schoessow, and D. Williams, "Observation of the Askaryan Effect: Coherent Microwave Cherenkov Emission from Charge Asymmetry in High-Energy Particle Cascades," *Phys. Rev. Lett.*, vol. 86, pp. 2802–2805, Mar 2001.

[9] P. W. Gorham, S. W. Barwick, J. J. Beatty, D. Z. Besson, W. R. Binns, C. Chen, P. Chen, J. M. Clem, A. Connolly, P. F. Dowkontt, M. A. DuVernois, R. C. Field, D. Goldstein, A. Goodhue, C. Hast, C. L. Hebert, S. Hoover, M. H. Israel, J. Kowalski, J. G. Learned, K. M. Liewer, J. T. Link, E. Lusczek, S. Matsuno, B. Mercurio, C. Miki, P. Miočinović, J. Nam, C. J. Naudet, J. Ng, R. Nichol, K. Palladino, K. Reil, A. Romero-Wolf, M. Rosen, L. Ruckman, D. Saltzberg, D. Seckel, G. S. Varner, D. Walz, and F. Wu, "Observations of the Askaryan Effect in Ice," *Phys. Rev. Lett.*, vol. 99, p. 171101, Oct 2007.

[10] J. Alvarez-Muñiz, P. M. Hansen, A. Romero-Wolf, and E. Zas, "Askaryan radiation from neutrino-induced showers in ice," *Phys. Rev. D*, vol. 101, p. 083005, Apr 2020.

[11] M. G. Aartsen et al, "First Observation of PeV-Energy Neutrinos with IceCube," *Phys. Rev. Lett.*, vol. 111, p. 021103, Jul 2013.

[12] M. G. Aartsen et al, "A Combined Maximum-Likelihood Analysis of the High-Energy Astrophysical Neutrino Flux Measured with IceCube," *The Astrophysical Journal*, vol. 809, p. 98, aug 2015.

[13] E. Waxman and J. Bahcall, "High energy neutrinos from astrophysical sources: An upper bound," *Phys. Rev. D*, vol. 59, p. 023002, Dec 1998.

[14] M. G. Aartsen et al, "Differential limit on the extremely-high-energy cosmic neutrino flux in the presence of astrophysical background from nine years of IceCube data," *Phys. Rev. D*, vol. 98, p. 062003, Sep 2018.

[15] J. C. Hanson and A. L. Connolly, "Complex analysis of Askaryan radiation: A fully analytic treatment including the LPM effect and Cascade Form Factor," *Astroparticle Physics*, vol. 91, pp. 75–89, 2017.

[16] J. C. Hanson, S. W. Barwick, E. C. Berg, D. Z. Besson, T. J. Duffin, S. R. Klein, S. A. Kleinfelder, C. Reed, M. Roumi, T. Stezelberger, J. Tatar, J. A. Walker, and L. Zou, "Radar absorption, basal reflection, thickness and polarization measurements from the Ross Ice Shelf, Antarctica," *Journal of Glaciology*, vol. 61, no. 227, pp. 438–446, 2015.

[17] J. Avva, J. Kovac, C. Miki, D. Saltzberg, and A. Vieregg, "An in situ measurement of the radio-frequency attenuation in ice at Summit Station, Greenland," *Journal of Glaciology*, 2014.

[18] S. Barwick, D. Besson, P. Gorham, and D. Saltzberg, "South polar in situ radio-frequency ice attenuation," *Journal of Glaciology*, vol. 51, no. 173, p. 231238, 2005.

[19] S. Barwick, E. Berg, D. Besson, T. Duffin, J. Hanson, S. Klein, S. Kleinfelder, K. Ratzlaff, C. Reed, M. Roumi, T. Stezelberger, J. Tatar, J. Walker, R. Young, and L. Zou, "Design and Performance of the ARIANNA HRA-3 Neutrino Detector Systems," *IEEE Transactions on Nuclear Science*, vol. 62, no. 5, pp. 2202–2215, 2015.

[20] S. A. Kleinfelder, E. Chiem, and T. Prakash, "The SST Multi-G-Sample/s Switched Capacitor Array Waveform Recorder with Flexible Trigger and Picosecond-Level Timing Accuracy," *arXiv*, 2015.

[21] A. Anker, S. W. Barwick, H. Bernhoff, D. Z. Besson, N. Bingefors, D. Garca-Fernndez, G. Gaswint, C. Glaser, A. Hallgren, J. C. Hanson, S. R. Klein, S. A. Kleinfelder, R. Lahmann, U. Latif, J. Nam, A. Novikov, A. Nelles, M. P. Paul, C. Persichilli, I. Plaisier, T. Prakash, S. R. Shively, J. Tatar, E. Unger, S. H. Wang, C. Welling, and S. Zierke, "Neutrino vertex reconstruction with in-ice radio detectors using surface reflections and implications for the neutrino energy resolution," *arXiv*, vol. 2019, no. 11, pp. 030–030, 2019.

[22] Anker, A, et al, "Probing the angular and polarization reconstruction of the ARIANNA detector at the South Pole," *Journal of Instrumentation*, vol. 15, no. 09, pp. P09039–P09039, 2020.

[23] J. C. Hanson, "Ross Ice Shelf Thickness, Radio-frequency Attenuation and Reflectivity: Implications for the ARIANNA UHE Neutrino Detector," *32nd International Cosmic Ray Conference*, 2011.

[24] L. Gerhardt, S. Klein, T. Stezelberger, S. Barwick, K. Dookayka, J. Hanson, and R. Nichol, "A prototype station for ARIANNA: A detector for cosmic neutrinos," *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 624, no. 1, pp. 85–91, 2010.

[25] S. Barwick, E. Berg, D. Besson, G. Binder, W. Binns, D. Boersma, R. Bose, D. Braun, J. Buckley, V. Bugaev, S. Buitink, K. Dookayka, P. Dowkontt, T. Duffin, S. Euler, L. Gerhardt, L. Gustafsson, A. Hallgren, J. Hanson, M. Israel, J. Kiryluk, S. Klein, S. Kleinfelder, H. Niederhausen, M. Olevitch, C. Persichelli, K. Ratzlaff, B. Rauch, C. Reed, M. Roumi, A. Samanta, G. Simburger, T. Stezelberger, J. Tatar, U. Uggerhoj, J. Walker, G. Yodh, and R. Young, "A first search for cosmogenic neutrinos with the ARIANNA Hexagonal Radio Array," *Astroparticle Physics*, vol. 70, pp. 12–26, 2015.

[26] S. Barwick, D. Besson, A. Burgman, E. Chiem, A. Hallgren, J. Hanson, S. Klein, S. Kleinfelder, A. Nelles, C. Persichilli, S. Phillips, T. Prakash, C. Reed, S. Shively, J. Tatar, E. Unger, J. Walker, and G. Yodh, "Radio detection of air showers with the ARIANNA experiment on the Ross Ice Shelf," *Astroparticle Physics*, vol. 90, pp. 50–68, 2017.

[27] A. Anker, S. W. Barwick, H. Bernhoff, D. Z. Besson, N. Bingefors, D. Garca-Fernndez, G. Gaswint, C. Glaser, A. Hallgren, J. C. Hanson, S. R. Klein, S. A. Kleinfelder, R. Lahmann, U. Latif, J. Nam, A. Novikov, A. Nelles, M. P. Paul, C. Persichilli, I. Plaisier, T. Prakash, S. R. Shively, J. Tatar, E. Unger, S. H. Wang, and C. Welling, "A search for cosmogenic neutrinos with the ARIANNA test bed using 4.5 years of data," *Journal of Cosmology and Astroparticle Physics*, 2019.

[28] S. Barwick, E. Berg, D. Besson, T. Duffin, J. Hanson, S. Klein, S. Kleinfelder, M. Piasecki, K. Ratzlaff, C. Reed, M. Roumi, T. Stezelberger, J. Tatar, J. Walker, R. Young, and L. Zou, "Time-domain response of the ARIANNA detector," *Astroparticle Physics*, vol. 62, pp. 139–151, 2015.

[29] S. W. Barwick, E. C. Berg, D. Z. Besson, G. Gaswint, C. Glaser, A. Hallgren, J. C. Hanson, S. R. Klein, S. Kleinfelder, L. Kpke, I. Kravchenko, R. Lahmann, U. Latif, J. Nam, A. Nelles, C. Persichilli, P. Sandstrom, J. Tatar, and E. Unger, "Observation of classically 'forbidden' electromagnetic wave propagation and implications for neutrino detection.," *Journal of Cosmology and Astroparticle Physics*, vol. 2018, no. 07, pp. 055–055, 2018.

[30] C. Glaser, D. Garca-Fernndez, A. Nelles, J. Alvarez-Muiz, S. W. Barwick, D. Z. Besson, B. A. Clark, A. Connolly, C. Deaconu, K. D. d. Vries, J. C. Hanson, B. Hokanson-Fasig, R. Lahmann, U. Latif, S. A. Kleinfelder, C. Persichilli, Y. Pan, C. Pfendner, I. Plaisier, D. Seckel, J. Torres, S. Toscano, N. v. Eijndhoven, A. Vieregg, C. Welling, T. Winchen, and S. A. Wissel, "NuRadioMC: simulating the radio emission of neutrinos from interaction to detector," *The European Physical Journal C*, vol. 80, no. 2, p. 77, 2020.

[31] C. Glaser, A. Nelles, I. Plaisier, C. Welling, S. W. Barwick, D. Garca-Fernndez, G. Gaswint, R. Lahmann, and C. Persichilli, "NuRadioReco: a reconstruction framework for radio neutrino detectors," *The European Physical Journal C*, vol. 79, no. 6, p. 464, 2019.

[32] J. C. Hanson and J. P. Gómez-Reed, "A 100 MHz Frequency-Counter Deployed in FPGA for RF Neutrino Research in Antarctica," in *Proceedings of the Southern California Conference for Undergraduate Research*, sccur.org, 2018.

[33] J. C. Hanson and J. P. Gómez-Reed, "Communications between an onboard fpga and microcontroller system for antarctic neutrino research," in *Proceedings of the Southern California Conference for Undergraduate Research*, sccur.org, 2019.

[34] J. C. Hanson and R. Hartig, "Complex Analysis of Askaryan Radiation: A Fully Analytic Model in the Time-Domain," *arXiv*, 2021.

[35] A. F. Oskooi, D. Roundy, M. Ibanescu, P. Bermel, J. Joannopoulos, and S. G. Johnson, "Meep: A flexible free-software package for electromagnetic simulations by the FDTD method," *Computer Physics Communications*, vol. 181, no. 3, pp. 687–702, 2010.

[36] Anne Marie Porter and Rachel Ivie, "Women in Physics and Astronomy, 2019." `https://www.aip.org/statistics/reports/women-physics-and-astronomy-2019`, 2019.

[37] William Moebs, Samuel J. Ling, and Jeff Sanny et al., "University Physics vols. 1-3." `https://openstax.org/subjects/science`, 2016.

[38] William Moebs, Samuel J. Ling, and Jeff Sanny et al., "College Physics." `https://openstax.org/subjects/science`, 2016.

[39] Harvey Mudd College, "Digital Electronics and Computer Engineering (ENGR085 HM." `http://catalog.hmc.edu/`, 2021.

[40] Rio Hondo Community College, "Music - Advanced Sound Design." `https://pathways.riohondo.edu/program/music-advanced-sound-design-coa/`, 2019.

[41] E. Mazur, *Peer Instruction: A User's Manual*. Pearson Education, 2013.

[42] "American Association of Physics Teachers Workshops for New Faculty." `https://aapt.org/Conferences/newfaculty/nfw.cfm`. See especially Fall 2018 pres by McDermott et al.

[43] "PhysPort: Supporting Physics Teaching with Research Based Resources." `https://www.physport.org/methods/method.cfm?G=Peer_Instruction`. Example of teaching material repository for PI module questions.

[44] U. of Colorado, "Physics Education Technology." `https://phet.colorado.edu/`, 2018.

[45] Gregor Novak, Andrew Gavrin, Wolfgang Christian, and Evelyn Patterson, *Just-In-Time Teaching: Blending Active Learning with Web Technology*. Addison-Wesley, 1999.

[46] William Deresiewicz, "Solitude and Leadership." The American Scholar (online), 2010.

[47] E. Boyer, D. Moser, T. Ream, J. Braxton, *Scholarship Reconsidered: Priorities of the Professoriate*. Jossey-Bass (Expanded Edition), 2015.

[48] L. Miramonti, "Latest results and future prospects of the pierre auger observatory," *Journal of Physics: Conference Series*, vol. 1766, no. 1, p. 012002, 2021.

[49] K. Greisen, "End to the cosmic-ray spectrum?," *Phys. Rev. Lett.*, vol. 16, pp. 748–750, Apr 1966.

[50] G. T. Zatsepin and V. A. Kuz'min, "Upper Limit of the Spectrum of Cosmic Rays," *Soviet Journal of Experimental and Theoretical Physics Letters*, vol. 4, p. 78, Aug. 1966.

[51] M. G. Aartsen, M. Ackermann, J. Adams, J. A. Aguilar, M. Ahlers, M. Ahrens, C. Alispach, K. Andeen, T. Anderson, I. Ansseau, G. Anton, C. Argelles, J. Auffenberg, S. Axani, H. Bagherpour, X. Bai, A. B. V, A. Barbano, I. Bartos, S. W. Barwick, B. Bastian, V. Baum, S. Baur, R. Bay, J. J. Beatty, K. H. Becker, J. B. Tjus, S. BenZvi, D. Berley, E. Bernardini, D. Z. Besson, G. Binder, D. Bindig, E. Blaufuss, S. Blot, C. Bohm, S. Bser, O. Botner, J. Bttcher, E. Bourbeau, J. Bourbeau, F. Bradascio, J. Braun, S. Bron, J. Brostean-Kaiser, A. Burgman, J. Buscher, R. S. Busse, T. Carver, C. Chen, E. Cheung, D. Chirkin, S. Choi, B. A. Clark, K. Clark, L. Classen, A. Coleman, G. H. Collin, J. M. Conrad, P. Coppin, K. R. Corley, P. Correa, S. Countryman, D. F. Cowen, R. Cross, P. Dave, C. D. Clercq, J. J. DeLaunay, H. Dembinski, K. Deoskar, S. D. Ridder, P. Desiati, K. D. d. Vries, G. d. Wasseige, M. d. With, T. DeYoung, S. Dharani, A. Diaz, J. C. Daz-Vlez, H. Dujmovic, M. Dunkman, E. Dvorak, B. Eberhardt, T. Ehrhardt, P. Eller, R. Engel, P. A. Evenson, S. Fahey, A. R. Fazely, J. Felde, K. Filimonov, C. Finley, D. Fox, A. Franckowiak, E. Friedman, A. Fritz, T. K. Gaisser, J. Gallagher, E. Ganster, S. Garrappa, L. Gerhardt, K. Ghorbani, T. Glauch, T. Glsenkamp, A. Goldschmidt, J. G. Gonzalez, D. Grant, T. Grgoire, Z. Griffith, S. Griswold, M. Gnder, M. Gndz, C. Haack, A. Hallgren, R. Halliday, L. Halve, F. Halzen, K. Hanson, A. Haungs, S. Hauser, D. Hebecker, D. Heereman, P. Heix, K. Helbing, R. Hellauer, F. Henningsen, S. Hickford, J. Hignight, G. C. Hill, K. D. Hoffman, R. Hoffmann, T. Hoinka, B. Hokanson-Fasig, K. Hoshina, F. Huang, M. Huber, T. Huber, K. Hultqvist, M. Hnnefeld, R. Hussain, S. In, N. Iovine, A. Ishihara, M. Jansson, G. S. Japaridze, M. Jeong, K. Jero, B. J. P. Jones, F. Jonske, R. Joppe, D. Kang, W. Kang, A. Kappes, D. Kappesser, T. Karg, M. Karl, A. Karle, U. Katz, M. Kauer, A. Keivani, M. Kellermann, J. L. Kelley, A. Kheirandish, J. Kim, T. Kintscher, J. Kiryluk, T. Kittler, S. R. Klein, R. Koirala, H. Kolanoski, L. Kpke, C. Kopper, S. Kopper, D. J. Koskinen, P. Koundal, M. Kowalski, K. Krings, G. Krckl, N. Kulacz, N. Kurahashi, A. Kyriacou, J. L. Lanfranchi, M. J. Larson, F. Lauber, J. P. Lazar, K. Leonard, A. Leszczynska, Y. Li, Q. R. Liu, E. Lohfink, C. J. L. Mariscal, L. Lu, F. Lucarelli, A. Ludwig, J. Lnemann, W. Luszczak, Y. Lyu, W. Y. Ma, J. Madsen, G. Maggi, K. B. M. Mahn, Y. Makino, P. Mallik, K. Mallot, S. Mancina, I. C. Mari, S. Marka, Z. Marka, R. Maruyama, K. Mase, R. Maunu, F. McNally, K. Meagher, M. Medici, A. Medina, M. Meier, S. Meighen-Berger, G. Merino, J. Merz, T. Meures, J. Micallef, D. Mockler, G. Moment, T. Montaruli, R. W. Moore, R. Morse, M. Moulai, P. Muth, R. Nagai, U. Naumann, G. Neer, L. V. Nguyen, H. Niederhausen, M. U. Nisa, S. C. Nowicki, D. R. Nygren, A. O. Pollmann, M. Oehler, A. Olivas, A. O'Murchadha, E. O'Sullivan, T. Palczewski, H. Pandya, D. V. Pankova, N. Park, P. Peiffer, C. P. d. l. Heros, S. Philippen, D. Pieloth, S. Pieper, E. Pinat, A. Pizzuto, M. Plum, Y. Popovych, A. Porcelli, P. B. Price, G. T. Przybylski, C. Raab, A. Raissi, M. Rameez, L. Rauch, K. Rawlins, I. C. Rea, A. Rehman, R. Reimann, B. Relethford, M. Renschler, G. Renzi, E. Resconi, W. Rhode, M. Richman, S. Robertson, M. Rongen, C. Rott, T. Ruhe, D. Ryckbosch, D. R. Cantu, I. Safa, S. E. S. Herrera, A. Sandrock, J. Sandroos, M. Santander, S. Sarkar, S. Sarkar, K. Satalecka, M. Scharf, M. Schaufel, H. Schieler, P. Schlunder, T. Schmidt, A. Schneider, J. Schneider, F. G. Schrder, L. Schumacher, S. Sclafani, D. Seckel, S. Seunarine, S. Shefali, M. Silva, R. Snihur, J. Soedingrekso, D. Soldin, M. Song, G. M. Spiczak, C. Spiering, J. Stachurska, M. Stamatikos, T. Stanev, R. Stein, J. Stettner, A. Steuer, T. Stezelberger, R. G. Stokstad, A. Ststl, N. L. Strotjohann, T. Strwald, T. Stuttard, G. W. Sullivan, I. Taboada, F. Tenholt, S. Ter-Antonyan, A. Terliuk, S. Tilav, K. Tollefson, L. Tomankova, C. Tnnis, S. Toscano, D. Tosi, A. Trettin, M. Tselengidou, C. F. Tung, A. Turcati, R. Turcotte, C. F. Turley, B. Ty, E. Unger, M. A. U. Elorrieta, M. Usner, J. Vandenbroucke, W. V. Driessche, D. v. Eijk, N. v. Eijndhoven, J. v. Santen, S. Verpoest, D. Veske, M. Vraeghe, C. Walck, A. Wallace, M. Wallraff, N. Wandkowsky, T. B. Watson, C. Weaver, A. Weindl, M. J. Weiss, J. Weldert, C. Wendt, J. Werthebach, B. J. Whelan, N. Whitehorn, K. Wiebe, C. H. Wiebusch, L. Wille, D. R. Williams, L. Wills, M. Wolf, J. Wood, T. R. Wood, K. Woschnagg, G. Wrede, J. Wulff, D. L. Xu, X. W. Xu, Y. Xu, J. P. Yanez, G. Yodh, S. Yoshida, T. Yuan, and M. Zcklein, "IceCube Search for Neutrinos Coincident with Compact Binary Mergers from LIGO-Virgos First Gravitational-wave Transient Catalog," *The Astrophysical Journal*, vol. 898, no. 1, p. L10, 2020.

[52] F. W. Stecker, "Ultrahigh energy photons, electrons, and neutrinos, the microwave background, and the universal cosmic-ray hypothesis," *Astrophysics and Space Science*, vol. 20, no. 1, pp. 47–57, 1973.

[53] V. Beresinsky and G. Zatsepin, "Cosmic rays at ultra high energies (neutrino?)," *Physics Letters B*, vol. 28, no. 6, pp. 423–424, 1969.

[54] M. Stockham, J. Macy, and D. Besson, "Radio frequency ice dielectric permittivity measurements using CReSIS data," *Radio Science*, vol. 51, no. 3, pp. 194–212, 2016.

[55] P. Allison, J. Auffenberg, R. Bard, J. Beatty, D. Besson, S. Bser, C. Chen, P. Chen, A. Connolly, and J. Davies, "Design and initial performance of the Askaryan Radio Array prototype EeV neutrino detector at the South Pole," *Astroparticle Physics*, vol. 35, no. 7, pp. 457–477, 2012.

[56] J. Hanson, *The Performance and Initial Results of the ARIANNA Prototype*. PhD thesis, University of California at Irvine, 2013.

[57] J. Ralston, "Radio surf in polar ice: A new method of ultrahigh energy neutrino detection," *Physical Review D*, vol. 71, no. 1, 2005.

[58] J. C. Hanson, "Broadband rf phased array design with meep: Comparisons to array theory in two and three dimensions," *Electronics*, vol. 10, no. 4, 2021.

[59] P. Allison, J. Alvarez-Muñiz, J. J. Beatty, D. Z. Besson, P. Chen, Y. Chen, J. M. Clem, A. Connolly, L. Cremonesi, C. Deaconu, P. W. Gorham, K. Hughes, M. Israel, T. C. Liu, C. Miki, J. Nam, R. J. Nichol, K. Nishimura, A. Novikov, A. Nozdrina, E. Oberla, S. Prohira, R. Prechelt, B. F. Rauch, Q. Abarr, J. M. Roberts, A. Romero-Wolf, J. W. Russell, D. Seckel, J. Shiao, D. Smith, D. Southall, G. S. Varner, A. G. Vieregg, S. A. Wissel, E. Zas, and A. Zeolla, "The Payload for Ultrahigh Energy Observations (PUEO): A White Paper," *arXiv*, 2020.

[60] P. W. Gorham et al, "Antarctic surface reflectivity measurements from the anita-3 and hical-1 experiments," *Journal of Astronomical Instrumentation*, vol. 06, no. 02, p. 1740002, 2017.

[61] E. Zas, F. Halzen, and T. Stanev, "Electromagnetic pulses from high-energy showers: Implications for neutrino detection," *Physical Review D*, vol. 45, no. 1, p. 362, 1992.

[62] R. V. Buniy and J. P. Ralston, "Radio detection of high energy particles: Coherence versus multiple scales," *Physical Review D*, vol. 65, no. 1, 2001.

[63] J. Aguilar, P. Allison, J. Beatty, H. Bernhoff, D. Besson, N. Bingefors, O. Botner, S. Buitink, K. Carter, B. Clark, A. Connolly, P. Dasgupta, S. de Kockere, K. de Vries, C. Deaconu, M. DuVernois, N. Feigl, D. García-Fernández, C. Glaser, A. Hallgren, S. Hallmann, J. Hanson, B. Hendricks, B. Hokanson-Fasig, C. Hornhuber, K. Hughes, A. Karle, J. Kelley, S. Klein, R. Krebs, R. Lahmann, M. Magnuson, T. Meures, Z. Meyers, A. Nelles, A. Novikov, E. Oberla, B. Oeyen, H. Pandya, I. Plaisier, L. Pyras, D. Ryckbosch, O. Scholten, D. Seckel, D. Smith, D. Southall, J. Torres, S. Toscano, D. V. D. Broeck, N. van Eijndhoven, A. Vieregg, C. Welling, S. Wissel, R. Young, and A. Zink, "Design and sensitivity of the radio neutrino observatory in greenland (RNO-g)," *Journal of Instrumentation*, vol. 16, p. P03025, mar 2021.

[64] A. Fedeli, C. Montecucco, and G. L. Gragnani, "Open-Source Software for Electromagnetic Scattering Simulation: The Case of Antenna Design," *Electronics*, vol. 8, no. 12, p. 1506, 2019.

[65] Allen Taflove and Susan C. Hagness, *Computational Electrodynamics: The Finite-Difference Time-Domain Method, 3rd ed.* Boston: Artech House, 2005.

[66] S. Prohira, C. Sbrocco, P. Allison, J. Beatty, D. Besson, A. Connolly, P. Dasgupta, C. Deaconu, K. D. d. Vries, S. D. Kockere, D. Frikken, C. Hast, E. H. Santiago, C. Y. Kuo, U. A. Latif, V. Lukic, T. Meures, K. Mulrey, J. Nam, A. Novikov, A. Nozdrina, J. P. Ralston, R. S. Stanley, J. Torres, S. Toscano, D. V. d. Broeck, N. v. Eijndhoven, and S. Wissel, "Modeling in-ice radio propagation with parabolic equation methods," *arXiv*, 2020.

[67] G. Yang, S. Ye, F. Zhang, Y. Ji, X. Zhang, and G. Fang, "Dual-Polarized Dual-Loop Double-Slot Antipodal Tapered Slot Antenna for Ultra-Wideband Radar Applications," *Electronics*, vol. 10, no. 12, p. 1377, 2021.

[68] F. Pizarro, R. Salazar, E. Rajo-Iglesias, M. Rodriguez, S. Fingerhuth, and G. Hermosilla, "Parametric Study of 3D Additive Printing Parameters Using Conductive Filaments on Microwave Topologies," *IEEE Access*, vol. 7, pp. 106814–106823, 2019.

[69] W. D. Christine Cooper, Shannon Sedgwick, "The changing face of aerospace in southern ca," *LAEDC Inst. for Applied Economics*, 2016.

[70] P. F. Flowers, C. Reyes, S. Ye, M. J. Kim, and B. J. Wiley, "3D printing electronic components and circuits with conductive thermoplastic filament," *Additive Manufacturing*, vol. 18, pp. 156–163, 2017.

[71] O. Yurduseven, P. Flowers, S. Ye, D. L. Marks, J. N. Gollub, T. Fromenteze, B. J. Wiley, and D. R. Smith, "Computational microwave imaging using 3D printed conductive polymer frequencydiverse metasurface antennas," *IET Microwaves, Antennas & Propagation*, vol. 11, no. 14, pp. 1962–1969, 2017.