Professional Evaluation and Growth Plan

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Chapter 1

Introduction

1.1 Background

My name is Jordan Hanson, and I am formally submitting my first Professional Evaluation and Growth Plan (PEGP). As required by Whittier College, and in accordance with the regulations in the Whittier College Faculty handbook, the material herein pertains to my first complete academic year as a tenure-track Assistant Professor of Physics and Astronomy. Being new to the Whittier College community, I have included this professional introduction for those readers to whom I have not yet been introduced. I look forward to meeting and working with my colleagues in other departments over the years, and I hope that this brief introduction will explain why I chose to become a professor. Accordingly, I share my vision for teaching physics and scholarship in the area of *astroparticle physics* at Whittier College.

My professors and colleagues in the professional-track physics program at Yale University inspired me to excel beyond what I thought was possible for myself. I was introduced to the world of academic scholarship by faculty who had known they would enter this world from from a young age. I fell in love with physics for the beauty of its theoretical simplicity, and the surge of excitement as observations spark to life through hard laboratory work. After receiving my Bachelor of Science degree, I landed at UC Irvine, the home of the Nobel Laureate who made the first observation of a sub-atomic particle called a neutrino. UC Irvine excels in the study of extrasolar, high-energy sub-atomic particles: *astroparticle physics.* I was introduced to Professors Steve Barwick and Stuart Kleinfelder. Dr. Barwick is a professor of physics in the Department of Physics and Astronomy, and Dr. Kleinfelder is a professor of physics in the Department of Electrical Engineering. Together we embarked on a journey to produce world record-breaking observations of high-energy neutrinos from beyond the solar system.

UC Irvine served as a training ground for my ability to teach, and I began to understand why teachers love to witness the flash of light in a student's eyes. I taught as an assistant under Dr. Barwick, serving students in sections associated with introductory physics courses comprised of several hundred students. During the early semesters in my graduate career, I was teaching physics sections of twenty students each for five continuous hours, three days per week. After concluding my teaching duties, I focused on research for several years. Upon completing my dissertation and receiving my doctorate, I solo-taught an introductory physics course during one of my post-doctoral fellowships. During that summer I learned the difference between *teaching* a course and *creating* a course. I enjoy creating new courses, and I have already created and taught new courses for students at Whittier. Above all else, I hope my work at Whittier will serve to *enlighten* our students.

1.2 General Reflection and Future Directions

Any general reflection for academics at Whittier must begin and end with our students. Over the past year and a half, I have chosen to become an *active participant in this community* and to push beyond what is required of me as a young professor. I have taught introductory physics courses to students who have no prior experience in physics, and created a new advanced computer science course. I've attended conferences to improve and expand my teaching methods, taking advantage of the broad research in physics education. I decided to take a class from a professor in another department for the shear joy of learning, but also to learn methods from an experienced teacher. I've involved a group of students in all facets of my research, including software and algorithm development, firmware development, and digital storytelling. Two of these students won Keck Fellowships and have engaged in summer physics research in my laboratory. We are preparing to become part of a collaboration of researchers who plan to build a world-class astroparticle detector at the South Pole. Additionally, I've become a mentor and advisor to a student organization, and helped serve the Math Department in a tenure-track faculty search. Each action I've taken during these past months has been geared towards serving our students thoughtfully and rigorously, to provide them with a quality education and research environment.

Despite these accomplishments, I am not satisfied with some aspects of my teaching. I was surprised to find that in my introductory courses, a group of students felt that the level of mathematical and technical detail was too advanced, and that the pace of the courses was too rapid. A group of students has been vocal in their assessment of these issues, and I take them seriously. Some of my students in an introductory course actively worked with me in office hours to find common ground. It is my hope that in the coming years, I will be able to implement a pace and difficulty level suitable for the academic environment at Whittier that *does the most good, for the largest number of students.* Although I do not feel it would be right to omit core physics principles from introductory courses, I will rely on the past experiences of my department to find a solution. My hypothesis is that many of my students in introductory courses are not prepared to make logical abstractions of physical systems, and require a larger number of concrete examples and demonstrations before gaining that ability. I will work diligently during the coming academic year to boost the abstract problem-solving ability of my students through leading by example.

Chapter 2

Teaching

2.1 Teaching Philosophy

The heart of the intelligent acquires knowledge, and the ear of the wise seeks knowledge. - Proverbs 18:15

I guess you could call it a "failure," but I prefer the term "learning experience." - Astronaut Mark Watney in *The Martian* by Andy Weir

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Teaching is about beautiful failure. Learning takes place between at least two people where at least one lacks knowledge. A lack of knowledge is an advent to *enlightenment* and is therefore beautiful. Regardless of the teaching methods chosen for a given teacher and student, the student should leave the encounter *enlightened*, with increased knowledge of the truth. The success of the encounter is measured by the varying degree to which the student can retain, apply, understand, and reflect upon the knowledge. I believe that lifting a student learning physics from retention to reflection is beautiful, in that I witnesses a student extending their mind outside *their model* of the world, into *the model* of the world. In general, both the teacher and student succeed imperfectly in imparting ideas about *the model* of nature, and therefore the process will contain periodic failures. Further, the physics model itself may be an imperfect description of true nature. Growing through these "failures" is a hallmark of learning modern physics, a subject built upon increasingly accurate approximations to the truth.

Teaching physics begins with defining the concept of a "system" about which we can make measurements. All physics students must begin at this common place. With well-defined concepts of distance, mass, displacement, and time, the entire subject of *classical physics* may be undertaken. Students who are non-majors usually experience exclusively classical physics. Physics majors grow through the inaccuracies of classical physics to *modern physics*, which includes relativity and quantum mechanics [1]. Mastering these subjects represents maturity made possible through diligent and patient teaching. Teachers capable of bringing students to the advanced level and enlightening beginners are not molded upon the completion of graduate school. Physics teaching requires experiences shaped by failures and successes enlightening students studying classical and modern physics.

A good teacher loves growth. Each semester at the beginning of my introductory courses, I give a speech about learning to embrace failure entitled "It's OK to Be Wrong." The introductory student fears being wrong, losing points, and receiving a low grade. Counter-intuitively, those students who embrace their mistakes and learn from them turn out to be the strongest students. Converting failure to growth has two components. First, there is no substitute for *hard work and sacrifice*. A good teacher leads by example, pouring effort into the semester until the job is done. A good teacher works to master new skills by attending teaching conferences in his field, consulting students through mid-semester feedback mechanisms, analyzing student evaluations. A good teacher also works to become nimble, switching from method to method, until the suitable vehicle properly engages the student. Second, a good teacher *creates a proper learning space*. In my classrooms, no student is penalized for being wrong, with the single exception of taking exams. By creating a space in which it is ok to be wrong, we take

[1] Students satisfying liberal arts requirements via specialty courses do experience non-classical physics qualitatively.

advantage of the learning moments brought forward by mistakes, and make real progress.

A good *professor* is a special kind of teacher, in that he is a teacher that also performs scientific research and serves a college or university. A good professor successfully involves undergraduate students in his research. One crucial fact about myself that I learned during the past two semesters is that I love the *instructive* act of research just as much as I love the *investigative* act. Even when I am conducting research with my students, I should still be instructing them, and I've found that I love it. The instructive act of research lies in *pausing to reflect* upon what our actions in the laboratory imply. Whether a procedure succeeds or fails my laboratory, the student and I must take time away from the procedure to step back and understand *why* we observed the result. I hope to grow as much in the area of research instruction as I will grow in classroom instruction, and to produce students who will become quality researchers.

Instruction of Students in Introductory Courses

The first categorization of physics student at Whittier College is whether they are a liberal-arts *non-major* or *physics major*. Non-majors encounter physics for two semesters in either a *calculus-based* or *algebra-based* environment. We categorize students in this fashion because classical physics at the standard undergraduate introductory level is built upon single-variable calculus, with some multi-variable or vector calculus introduced in the second semester. Students who will not take calculus for their degree can still learn to apply core mathematical concepts like vectors and instantaneous quantities and apply them to physics. Thus, *non-major* students usually take the *algebra-based* version of mechanics, and *physics majors* and students who have chosen another technical degree take the *calculus based* version of mechanics.

Three focuses are relevant for teaching non-majors algebra-based physics:

1. **Curiosity**. I regularly give colloquia at universities, seminars in physics departments, public lectures to children in libraries and adults in astronomical societies. I believe that experiencing people's curiosity is necessary to become a great professor. I've continued this practice as Whittier professor by giving a lecture at Los Nietos Middle School. All people seek an understanding of nature. Further, people have a need to know *that the answers exist*, even if we do not yet fully grasp them as a society. I believe good teaching for non-majors should therefore *convince them that physics is interesting* by enticing their curiosity. I have built into the algebra-based curriculum specific learning activities designed to entice student curiosity. Presenting science articles to the class and presentations on home-built circuit projects are two examples. I regularly give colloquia at Whittier and incentivize my students to participate, thereby exposing them to astroparticle physics research [2].

2. **Improvement of Analysis Skill**. The scientific method is not possible without the skill of analysis. We as physicists best serve Whittier non-majors when we are developing their ability to apply physical theory via problem-solving. The Whittier College physics faculty have several important tools for developing introductory student problem solving. *Peer Instruction* is becoming a standard method in many American colleges [14], which is laser-focused on analyzing concepts in small groups. *Just in Time Teaching* is an auxiliary method designed to modify class time, focusing on exactly the problem solving strategies the students find challenging [10]. A third analytical tool is PhET (Physics Education Technology) [15], in which students compare analysis results to computer simulations built in conjunction with physics education research. At Whittier we employ an integrated lecture/laboratory format, which is facilitated by the design of the Science and Learning Center. The integrated techniques allow the instructor to provide versatility in problem solving practice, such as group problem solving, checking answers against computer simulations, and verification of analysis results via direct experimentation. One interesting emergent property is that students from different lab groups verify techniques and solutions with each other, providing encouragement. Finally, we incorporate *traditional* lecture methods to provide the concrete examples of analysis with which we begin new material for our students [3].

3. **Applications to Society**. Whittier College non-majors gain potential in technically oriented careers if they can qualitatively explain phenomenon using physics. In recent years, our standard open-source textbooks have included material relevant to popular majors (e.g medicine and KNS). I have incorporated

[2] See supporting materials for notes from students on my spring colloquium.

[3] Traditional lecture methods refer to a broad class of instruction methods, but generally refer to the professors performing example calculations on the chalkboard while students take notes and learn through repetition.

special units centered on these practical applications, including human nerve systems (in PHYS135B) and human metabolism (PHYS180). I also use the final group project rubric to allow non-majors who've chosen pre-medicine or KNS as their major to go further in their study of the intersection of physics and the human body. I proposed a new course entitled *Physics of the Five Senses*, designed to be connecteed with KNS courses. I plan to reintroduce this course in the near future when appropriate [4]. Being able to quantitatively understand science is vital for conducting fact-based discussions and economic participation. I included a brief unit on climate change and the solar system in PHYS135B and PHYS180, analytical problem solving and simulations. One additional tool for the non-majors is the inclusion of a individual presentation in which the student summarizes a scientific journal article in 5-10 minutes. The brevity requirement causes the students to focus on important details, decide whether they support the hypothesis, and on identification of the societal implications.

Instruction of Students in Advanced Courses

Physics majors are the second category of students we typically encounter. I broaden my discussion to *Mathematics and Computer Science majors* due to the specific circumstances under which I was hired. The Departments of Mathematics and Physics at Whittier College seek to build a separate Major in Computer Science. Currently, our college allows students interested in computer science to combine computer science with physics or math, or enter the 3-2 program in which they obtain two degrees in five years from Whittier College and The University of Southern California. The advanced course I have taught is Computer Logic and Digital Circuit Design (COSC330/PHYS306), a brand new course at Whittier College I've created. Those who participated were physics majors, mathematics majors, and Whittier Scholars Program majors, all having some connection to computer science. This course is under rapid development in parallel with developments in my research laboratory, as I will explain below.

Three focuses are relevant for teaching physics, mathematics, and computer science majors at the advanced level, in addition to those above for non-majors and introductory courses:

1. **Mental Discipline**. Advanced physics, math and computer science courses require discipline. When tackling a hard physics problem involving both advanced math and the cleverness to set up the problem correctly, there is no substitute for grit. The professor has a roll in calling it forth. Showing advanced students that *consistency beats intensity* is vital, and that value can be communicated in two ways. The first is delivering a rigorous curriculum. Problem sets and exams should be difficult, requiring time and reflection. For example, in COSC330, homeworks were assigned in two-week increments, with both mathematical repetition (to facilitate learning binary) and open-ended design questions (like designing a device that adds two binary numbers). Second, the content delivery should be efficient, demonstrating to the students that the professor is invested in them and carries expertise in the material. Advanced classes in large universities sometimes leave the student with a blunt delivery that merely entices the student to teach themselves in the library. The right path leaves the student *motivated* to fill in gaps in their understanding, with the professor happily rising to the challenge of elevating students' understanding outside of class. For example, in COSC330 my students and I happily debugged digital circuits in simulation software together in office hours, before building them for class presentation.

2. **Strength in all Phases of Science**. Good curriculum in these advanced topics must include the following *phases* of scientific activity: theoretical problem solving, numerical modeling or simulation, experimental design and execution, and data analysis. We may think of these phases as the activity that move the student through the scientific method. In COSC330, an example of the incorporation of all four phases occurs in teaching the students to work with binary numbers and code. First, the mathematics for conversion from decimal to binary is introduced along with addition and subtraction techniques, and we work example problems. Second, we model addition and subtraction via 8-bit adders in a computer simulation. Third, we actually build the adders, and fourth, we demonstrate that they work by analyzing the outputs. When students gain experience in all four phases, they more firmly grasp the concept. Students are also more likely to have a breakthrough in understanding a concept if they encounter it in multiple phases.

3. **Communication**. Two skills that should never go overlooked in technical fields are oral and written communication. Presentations, papers, lab reports, and summarizing peer-reviewed articles for the class are

[4] The KNS department declined to allow personel for pairing or team-teaching. Subsequently, the number of new students requiring introductory courses increased, and we modified my schedule by dropping my proposed course and adding an introductory one.

Semester	Course	Credits	Students	Curriculum feature
Fall 2017	PHYS135A-01	4.0	24	None
Fall 2017	PHYS150-01	4.0	17	COM1
Spring 2018	PHYS135B-01	4.0	18	None
Spring 2018	PHYS180-02	5.0	19	COM1
Spring 2018	COSC330/PHYS306	3.0	6	Advanced course
–	Total	20.0	–	–

Table 2.1: This table is a summary of the courses I have taught since Fall 2017. The introductory courses carry the course numbers 135A, 135B, 150, and 180. The advanced course, PHYS306, is cross-listed as a computer science course (COSC330).

several examples of rubrics that I use in advanced courses to hone communication skills. From personal experience, work in technical subjects would often proceed more quickly if not for the inability of group members to express themselves clearly. When dealing with abstract concepts in engineering discussions, clear communication prevents the introduction of design flaws and the introduction of bugs in software. No matter which advanced class I am teaching, my students will write at least one report, or give one presentation. I often allow students to write for extra credit, going beyond the scope of the course in the subject matter. Any practice in technical writing Whittier majors receive now will benefit them down the line as they proceed to graduate school or private sector engineering careers. [5]

Department-Level Goals

I have identified three focuses each for instruction of non-majors and majors. In addition, the Department of Physics and Astronomy has eight well-defined goals as part of our 5-year assessment cycle. In the coming course descriptions, these goals and my three focuses will be referenced. The departmental goals are:

1. 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).
2. Create research experiences for physics majors that will engage and inspire them in their discovery of physics.
3. Build a departmental community that is supportive and welcoming and that encourages students in their studies of physics.
4. Keep the physics curriculum current so that students gain the skills necessary for success in todays scientific environment.
5. Teach students how to teach themselves. Give them the intellectual tools necessary for independent thinking and learning.
6. Train students to think "scientifically" i.e. critically, rigorously, quantitatively, and objectively, so that they can analyze problems and generate solutions.
7. Train students to effectively communicate scientific ideas to others.
8. Advise students about various career paths and help them along these paths.

2.2 Introductory Course Descriptions

Algebra-based physics (135A/B). Algebra-based physics, PHYS135 A/B, is a two-semester integrated lecture/laboratory sequence that covers algebra-based kinematics, mechanics, and electromagnetism [6]. Algebra-based physics is a core requirement for many technical majors other than physics, such as kinesiology and chemistry. I have taught one section of PHYS135A and one section of PHYS135B, for a total of 42 students. I am

[5] See supplemental materials for examples of student presentations and writing.
[6] See supplemental material for example syllabi.

currently teaching two sections of PHYS135A with a total of 50 students. In addition to traditional lecture-based methods, I employ research-based physics teaching methods, and use the latest version of the OpenStax open-source textbooks, **satisfying departmental goals 1, 4, and 6**. These methods are *Peer Instruction (PI)*, *Just in Time Teaching (JITT)*, and *Physics Education Technology (PhET)*. I attended the American Association of Physics Teachers (AAPT) Workshop to learn how to implement these practices [7]. (See description of module types in the next section).

To reach the first learning focus I identify for non-majors, **basic curiosity**, I use the three research-based methods plus a few other techniques. For example, laboratory activities centered on constructing DC circuits and matching them to PhET simulations are meant to arouse basic curiosity about how electronics work. Second, integrating laboratory and lecture activities is meant to satisfy curiosity by providing laboratory confirmation of results derived on the board only moments ago. Finally, group projects prompt students to design and test their own projects [8].

To reach the second of the three learning focuses, **improvement of analysis skill**, I utilize the peer instruction method (PI modules), which has been shown to yield higher learning gains than traditional lectures concerning theoretical physics concepts. I strive to enhance problem solving ability through repeated conceptual exercises meant to show the students that textbook problems can be translated into equations that produce answers. After introduction of new material in the traditional sense, I provide repeated PI-modules that prompt students to examine misconceptions and use decuctive reasoning. Sometimes I will provide a film clip or popular science article to propose a system for examination, and the class explores facets of the system with PI modules. For example, the text provides a model of a nerve fiber transmitting an electrical signal, or a link to a TED video explaining solar wind. After watching the clip or examining the diagram, I post a series of PI questions on the real-world topic that the class works through together. In other cases where I can physically build the system in question, we perform laboratory style measurements meant to prove efficacy of a formula we derived in the lecture portion. The students gain analysis experience via the process of understanding statistical and systematic measurement errors.

To reach my focus of **applications to society**, I begin with the prompts to applications in the OpenStax texts, creating units that are relevant for the majors in my class. Examples have included nerve signals, forces in the body, and kinesiological measurements made in group projects. The JITT modules demonstrate if the students have done the reading I assign, and whether they comprehend how the physics we are learning applies to society. For extra credit, I sometimes assign term-papers asking students to explain the physics in a chapter of a science fiction novel or film. More often I assign students needing extra credit a paper on the history of science. Some brilliant examples have emerged regarding the first measurements of the distance between the Earth and the Sun.

Calculus-based physics (150/180). Calculus-based physics, PHYS150/PHYS180, is a two-semester sequence that covers calculus-based kinematics, mechanics, thermodynamics, and electromagnetism [9]. As with algebra-based courses, I aim to satisfy **departmental goals 1, 4, and 6**. I have taught one section of PHYS150 and one section of PHYS180, for a total of 36 students. As in the algebra-based classes, I implement *Peer Instruction (PI)*, *Just in Time Teaching (JITT)*, and *Physics Education Technology (PhET)*, and use OpenStax textbooks. The key difference between calculus and algebra-based physics methods is the increased use of PhET simulations to visualize calculus concepts. Because PHYS150 and PHYS180 require tools from single and multi-variable calculus, students taking those courses concurrently require PhET simulations to help visualize mathematical concepts. Examples include operations with scalar and vector fields in electromagnetism, single-variable integrals and derivatives in kinematics, and line integral calculation of work and energy.

To reach the first learning focus I identify for non-majors, **basic curiosity**, I use the three research-based methods plus a few other techniques. For example, PhET simulations allow us to visualize the electric field generated by a specific charge distribution. I can combine the field visualization with a PI module that asks the students conceptual questions about the field, including what geometric symmetry is being displayed and why. Symmetry is a hugely important topic within physics, but some students might not see it straight from the equations or diagrams. Group projects in calculus-based physics have generally been more sophisticated. For example, students used the 3D printer to build a Sterling engine as a study of thermodynamics. Another group

[7] See supplemental material for details.
[8] Examples of student work provided in supplemental material.
[9] See supplemental material for example syllabi.

studied 2D kinematics with air-pressure rockets on the football field. A side benefit of these presentations is that the students practice good *oral communication.*

To reach the second of the three learning focuses, **improvement of analysis skill**, I utilize the peer instruction method (PI modules), in conjunction with a procedure I learned on the fly during my first semester. I require the students to **leave their tables, and solve the technical or numerical problem together on the whiteboards** that cover the walls of my classrooms. Students are able to see each other's approach, and validate it against their own group's method. Upon returning to the tables, the groups feel more prepared and eager to solve the PI module problems that follow. The students report in their evaluations that adding this step greatly benefitted their learning, and that they felt more comfortable with the material afterwards. I wish I had known to do this from the beginning of the semester, and it will be incorporated into all future classes that I teach. The students also gain analysis experience via the process of understanding statistical and systematic measurement errors. Relative to the algebra-based activities, the calculus-based activities require a more complete understanding of error propagation and quantitification.

To reach my focus of **applications to society**, I begin with the prompts to applications in the OpenStax texts, creating units that are relevant for the majors in my class. Examples have included nerve signals, solar wind, and global warming. The JITT modules demonstrate if the students have done the reading I assign, and whether they comprehend how the physics we are learning applies to society. For extra credit, I sometimes assign term-papers asking students to explain the history of science for a particular topic. The Nobel Prize in Physics last year was for the discovery of gravitational waves, and several students chose to write about Advanced LIGO, the experiment that recorded the famous signals. Group presentations on topics of their choice at the end of the course offer a chance to practice oral communication skills. Finally, I required in PHYS180 each student to briefly summarize a scientific journal article for the class, in an attempt to further practice oral communication of science.

Descriptions of each Module Type

<u>PI Modules</u> - Implementation of an active learning strategy involving group problem solving.

- PI-based modules contain conceptual, multiple-choice questions for the class about a physical system.
- Students respond individually with an electronic device, and the distribution of answers for choices A-D is shown on the class screen (answer E indicates the student is lost).
- One of two actions is taken next:
    1. If the fraction of correct answers to the conceptual question is larger than 0.7, the class proceeds.
    2. If the fraction is less than 0.7, the professor initiates table discussion.
- Table discussions take place between 2-4 students at the same table. The professor tells the students to *attempt to convince each other they are right, and that just because they gave the same answer does not indicate correctness*[10].
- A second poll of the class is taken, to measure the increased fraction of correct answers, or *gain.* If more than one person selects E after the second round, the material is covered again.

<u>JITT Modules</u> - Modification of lecture time based on student reading the day before class.

- JITT activities grew out of reading quizzes in a traditionally structured course. Through Moodle, students are sent 3-4 questions the day before class based on the assigned reading.
- JITT questions are conceptual, and if a large portion of students are answering correctly, the material is covered more lightly. Questions that trigger many incorrect responses becomes the focus of class time.
- PI-module questions are drawn from a database, tailored to the misconceptions.
- Students' anonymous responses are included in the lecture itself, and the class gets a chance to analyze correct and incorrect responses.

[10] The effect of adding this specific phrase has been studied and shown to benefit the utility of table discussions.

Question	135A N	135A Mean	135A Std. dev.	135B N	135B Mean	135B Std. dev.
10	21	3.76	1.04	18	3.72	0.96
11	21	4.57	0.75	18	4.78	0.43
12	21	4.29	1.01	18	3.78	1.00
13	21	3.52	1.33	18	3.33	1.53
14	21	3.48	1.36	18	2.72	1.32
15	21	3.29	1.68	18	2.28	1.53
16	21	3.19	1.57	18	2.94	1.30

Table 2.2: Summary of questions 10-16 on the student evaluation form, for PHYS135A/B taught in Fall 2017 and Spring 2018. These questions pertain to the *course*.

Question	135A N	135A Mean	135A Std. dev.	135B N	135B Mean	135B Std. dev.
17	21	4.24	1.04	18	3.67	1.03
18	21	3.52	1.33	18	3.11	1.57
19	21	3.48	1.40	18	2.89	1.29
20	21	4.24	1.09	18	4.06	1.25
21	21	4.48	1.03	18	3.78	1.17
22	21	4.10	0.89	18	3.88	1.02
23	21	3.95	1.20	18	3.53	1.33
24	21	4.67	0.58	18	4.24	0.97
25	21	3.24	1.55	18	3.12	1.36

Table 2.3: Summary of questions 17-25 on the student evaluation form, for PHYS135A/B taught in Fall 2017 and Spring 2018. These questions pertain to the *professor*.

PhET Modules - Simulation activities integrated into the textbook and laboratory/PI modules.

- The OpenStax textbooks for PHYS135 and PHYS150/PHYS180 have built-in HTML links to JAVA-based simulations called PhET simulations[11].
- PhET simulations are incorporated into laboratory activities, in which simulated results of a system are compared to measurements of identical systems.
- Systems that cannot be constructed in the lab are studied via PhET activities as well.
- PhET simulations often augment special curricular activities pertaining to other majors, like the human body. For example, in PHYS135B we used a PhET simulation to understand the behavior of human nerve signals.

2.2.1 Analysis of Student Evaluations

Tables 2.2 and 2.3 show the results of the *algebra-based* introductory physics courses taught in the 2017-2018 academic year. Tables 2.4 and 2.5 show the results of the *calculus-based* introductory physics courses taught in the 2017-2018 academic year. The results show an interesting correlation that reveals a potential strategy for continual improvement of my teaching in these courses.

First, there are obvious areas that need improvement. Questions 14-16 and 19 for 135B for example correspond to student understanding of the material, interest in the material, recommending the course to others, and my ability to explain complicated ideas, respectively. This particular algebra-based course is meant to cover electricity and magnetism. We introduce students without a technical background to abstract ideas like electromagnetic fields and how they connect to applications like DC circuits. Skills necessary to complete the work in this course include solving algebraic equations and systems of equations, analyzing graphs of functions, and correctly measuring properties of circuits and magnets. It is no surprise that students struggle with the material upon encountering it for the first time. I have been trained to teach much faster and more intensely than the students who disapproved of the course desired.

[11] see `https://phet.colorado.edu`

Question	150 N	150 Mean	150 Std. dev.	180 N	180 Mean	180 Std. dev.
10	16	4.19	0.83	18	4.00	0.91
11	16	4.19	1.38	18	4.67	0.49
12	16	3.63	1.31	18	4.06	0.94
13	16	4.00	1.10	18	4.00	0.97
14	16	3.93	1.33	18	3.89	0.90
15	16	3.56	1.26	18	3.67	1.03
16	16	3.56	1.26	18	3.83	0.86

Table 2.4: Summary of questions 10-16 on the student evaluation form, for PHYS150 taught in Fall 2017, and PHYS1809 taught in Spring 2018. These questions pertain to the *course.*

On the other hand, there are many areas in which the courses and my teaching scored well. **I am especially proud of the fact that Q25 jumped in 2018 relative to 2017 for the calculus-based courses.** Further, students in both sections believed that the courses were rigorous and challenging. Some students appreciated the PI modules, PhET simulations, and JITT exercises. This is reflected in responses to question 12 on the standard evaluation, which is a key data point. The reason I focus on this data point is that I am being asked by my department to teach in an activities based style, far different from the traditional lecture format. The purpose of the activities and group exercises is to satisfy the focus on **improvement of analysis skill**. The PI, JITT, and PhET modules are constructed to improve analysis skill. However, upon reflecting on the students' constructive comments, it seems that these modules benefit some students but not all.

In the students' remarks, many shared with me that these courses were the very first physics courses they have taken, or that they have anxieties with mathematics. In consultation with my department chair, and in studying past PEGP documents in my department, it appears that an increase in traditional lecture style is necessary. The reason is that if every single concept and number in physics is confusing to a first-time student, then merely updating the teaching style with researched-based modules will not help that student. The traditional lecture style offers the benefit that students see many example problems done in explicit detail, such that they can copy and repeat the technique. I was taught to never expect this as an undergraduate student, because it is wrong. My colleagues in my department have reassured me that it is not only not wrong, but necessary to give inexperienced students an explicit starting point. Thus, this will be the first major change to my introductory teaching this coming semester: *fifty percent of class-time will be spent on concrete examples in the traditional style.*

The second major change I will be making to my introductory course teaching style is to slow the pace. In reading students' remarks, this is the second most common desire on their part. I was taught at the undergraduate and graduate levels at high speed, with intense focus on both content and mathematical detail. Of course I must make adjustments for the environment at Whittier College, and not merely teach to myself. I must *teach to the middle*, as one of my colleagues recommended. The students felt major relief when I began assigning them a problem to work on the whiteboards in groups precisely because it allowed them to slow the class down, and check their work with each other. Thus, that move solved both problems at once: the problem of pace and the problem of adding more traditional lecture content. The students got a chance to lecture to each other momentarily. In the upcoming semester, *I will include the group-board technique in the normal course plan.*

Third, I'd like to include calculus in the *calculus-based* versions of our introductory sequences. Currently, our department does not include enough calculus-based content in PHYS150 and PHYS180. However, I am congizant of the risks in adding content to these courses, in which we are already pushing the majority of students to their limits. From the feedback from my department, I need to include more laboratory/measurement activities. Thus, I propose solving both problems simultaneously. When I teach *calculus-based* introductory courses in the future, I will use the laboratory activities as a venue for demonstrating the difference between results obtained from calculus (derivatives and integrals) and the average results one obtains without calculus. It is my hope that the students will learn to use some calculus tools, even if the majority cannot deploy calculus in some challenging homework problems. The inclusion of more lab activities is already required of me, now that I am trained on all of our equipment, so this idea will require no additional effort above what I'm already scheduled to do.

Finally, I will put more focus on struggling students through organization of class time (in response to Q17). My

Question	150 N	150 Mean	150 Std. dev.	180 N	180 Mean	180 Std. dev.
17	16	3.31	1.14	18	3.44	1.15
18	16	2.88	1.36	18	3.39	1.14
19	16	3.13	1.54	18	3.83	1.04
20	16	3.69	1.25	18	4.22	0.65
21	16	3.88	1.09	18	4.11	0.96
22	16	3.81	1.33	18	4.44	0.70
23	16	3.67	1.37	18	4.33	0.77
24	16	4.50	0.63	18	4.56	0.51
25	16	3.13	1.63	18	3.61	1.04

Table 2.5: Summary of questions 17-25 on the student evaluation form, for PHYS150 taught in Fall 2017, and PHYS180 taught in Spring 2018. These questions pertain to the *professor*.

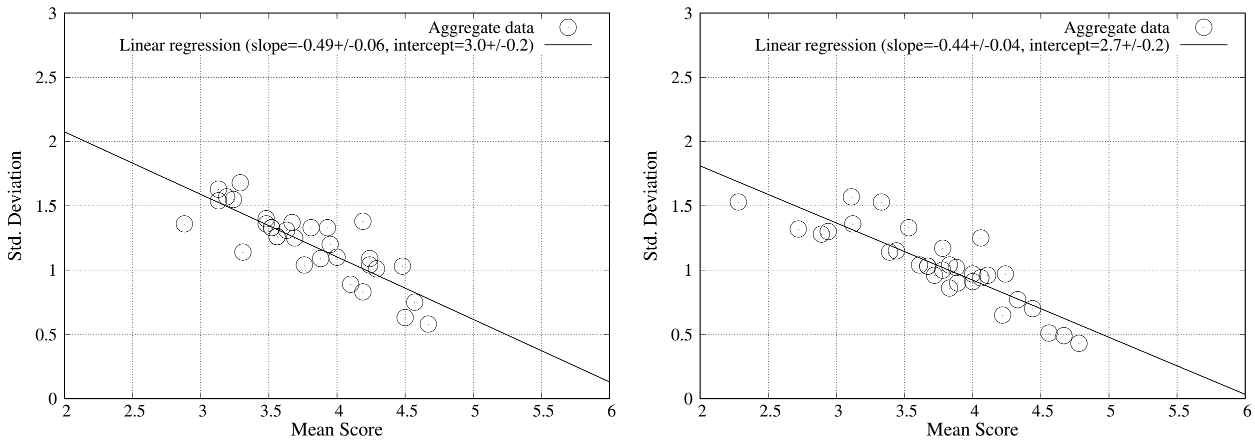

Figure 2.1: (Left) Aggregate standard deviations versus mean scores for questions 10-25 for introductory courses taught in Fall 2017. (Right) Same, for introductory courses taught in Spring 2018.

department colleagues feel that many numbers will rise in correlation with Q17. It is my hypothesis that students that felt class was not organized properly felt so because it was not organized to *help them.* Of course I prepared for my courses; I have built an interactive, open-source GB-scale database of lecture content [12]. However, when I identify the students who are struggling, I can use the discussion time during PI modules and other activities to focus on helping them one-on-one, while letting the more advanced students help others. In general, when I score low in a particular category, there is large variance in student opinion. When I score high, my students are in closer alignment with each other. One way of showing this numerically is Fig. 2.1 below. For both Fall and Spring courses, the standard deviation for all my scores is inversely correlated with the mean scores. In fact the fractional error is typically $\approx 50\%$ for low scores, compared to 10% when I score well. *By locating the struggling students and focusing one-on-one discussion time with them, I hope to draw the data points down and to the right in Fig. 2.1.*

2.3 Advanced Course Descriptions

Computer Logic and Digital Circuit Design. My premier advanced course was ambitious, and has a well-defined direction for continual improvement. Digital design is as broad a topic as any undergraduate would encounter. To cover it adequately at Whittier College, I had to make hard choices about where to spend class-time. 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. Naturally multi-disciplinary, digital design has many sub-topics within it[13]. COSC330/PHYS306 is a 300-level integrated computer science course that satisfies core requirements in the following majors: ICS/Math, ICS/Physics, ICS/Economics, 3-2 Engineering/Math, and the scientific

[12] see my account on Github.com: `https://github.com/918particle/AlgebraBasedMechanics1`.

[13] See supplemental material for a course syllabus. Although listed as COSC330, this course is also cross-listed as PHYS306, so I felt our departmental goals should apply.

Semester	Course	Credits	Students	Curriculum feature
Fall 2017	PHYS135A-01	4.0	24	None
Fall 2017	PHYS150-01	4.0	17	COM1
Spring 2018	PHYS135B-01	4.0	18	None
Spring 2018	PHYS180-02	5.0	19	COM1
Spring 2018	COSC330/PHYS306	3.0	6	Advanced course
–	Total	20.0	–	–

Table 2.6: This table is a summary of the courses I have taught since Fall 2017. The introductory courses carry the course numbers 135A, 135B, 150, and 180. The advanced course, PHYS306, is cross-listed as a computer science course (COSC330).

computing minor. Such a broad course that serves a wide variety of students should touch on at least the following sub-topics:

1. Binary mathematics and non-decimal base systems
2. Boolean algebra and logic
3. Implementing boolean algebra with transistors
4. Digital clock signals and digital component specifications
5. Digital components built from clocks and transistors
6. Complex digital systems (microprocessors, microcontrollers)

Additionally, any good digital design course at a liberal arts college must evenly cover the following phases of the field: *mathematics, computer programming, hardware design and function, and computer modelling.* I attempted to design a course syllabus that incorporated **all phases** of the field.

My first advanced course learning focus is **mental discipline**, and I attempted to reach that goal in three ways. First, the homework assignments were difficult, and assigned in two-week increments, with both mathematical repetition (to facilitate learning to speak with binary and boolean algebra) and open-ended design questions [14]. Second, I chose to combine a traditional lecture component with electronic slides that meshed with my work on the whiteboard, as I've observed with professors of foreign language at Whittier College. Teaching binary to newcomers felt like teaching a new programming or spoken language. Solving problems individually and in pairs helped those struggling during the introduction of Boolean algebra. A language course requires a student *verbally communicate* repeatedly with others to improve grammar and comprehension, so I required my students to practice the same mental discipline. Finally, I assigned design problems in the homework and group projects. The students' project designs had to achieve an agreed-upon task, via a project proposal. Next, they had to be modelled with software, built, tested, and presented to the group. The group projects were designed also as additional oral and written communication practice.

My second advanced course learning focus is **strength in all phases of science**. By design, this course incorporated multiple sub-topics and four phases (as listed above): *mathematics, computer programming, hardware design and function, and computer modelling.* The first month of the course required me to focus on binary math and boolean algebra, finishing with the topic of Karnaugh maps [15]. Unfortunately, although I ordered the digital components for this course over a month in advance, the purchase orders were not followed and we did not received the parts until about 1 month into the course. This disrupted my curriculum, but the parts are reusable so it cannot happen again. While waiting for components, we focused on simulating the circuits implied by our algebraic derivations with a software package called LogicWorks. LogicWorks gave the students the benefit of seeing how their designs would behave over time, once activated. It also allowed student to locate rare cases for which the algorithm implied by their design would fail. When the hardware arrived, we built everything from super-heterodyne AM transistor radios, to circuits that could add two 8-bit binary numbers. The students

[14] See supplemental material for examples of assignments.
[15] Karnaugh maps are a way of speeding through boolean algebraic derivations efficiently.

Question	COSC330 N	COSC330 Mean	COSC330 Std. dev.
10	8	3.13	1.46
11	8	3.71	1.38
12	8	3.75	1.04
13	8	3.25	1.39
14	8	3.63	1.19
15	8	3.86	0.69
16	8	3.29	1.25

Table 2.7: Summary of questions 10-16 on the student evaluation form, for COSC330/PHYS306, taught in Spring 2018. These questions pertain to the *course*.

Question	COSC330 N	COSC330 Mean	COSC330 Std. dev.
17	8	3.38	1.60
18	8	3.50	1.20
19	8	3.13	1.46
20	8	4.25	0.71
21	8	3.50	1.41
22	8	4.00	0.89
23	8	4.25	1.16
24	8	4.29	1.25
25	8	2.88	1.36

Table 2.8: Summary of questions 17-25 on the student evaluation form, for COSC330/PHYS306, taught in Spring 2018. These questions pertain to the *professor*.

enjoyed the tinkering aspect of the course in the lab, but I would have wanted the lab and lecture activities to be more integrated.

My third advanced learning focus is **communication**. I had groups of two and three submit project proposals to me for approval. The project proposal rubric is graded on *attention to detail*, and the students responded with diagrams, sketches, and text explaining their design. Once everyone was on the same page, I required them to simulate the design in LogicWorks, checking it for flaws, and to show me progress. The students used office hours to ask for help "de-bugging" their designs, which is jargon for trouble-shooting. I recall spending a few hours with each group during the semester thinking about their design logic in an attempt to locate algorithm flaws. In these moments I admired the growth in the students' mathematical communication. The final presentations were good, and would have been excellent had I provided more specific guiderails for the presentation content. What we experienced was two main presentation components: the demonstration and the explanation with data. In the future, I will formalize the requirement of both, and provide a structured schedule for the components of the assignment.

2.3.1 Analysis of Student Evaluations

Tables 2.7 and 2.8 show the results of my advanced computer science and physics course. The results show a similar correlation as the introductory courses (see Fig. 2.2). For the lower scores, the fractional error is about 50%, whereas the higher scores have fractional error of about 20%. The correlation is not as strong as the introductory courses, because the sample size is smaller. These numbers do inform the analysis of my teaching of digital design, however the students' remarks in the evaluations provide more detail.

Some students remarked that the course did not seem adequately structured or prepared. This was in large part caused by the disruption of not having the equipment I needed. Although I did order the textbooks and digital components long before the first day of class, the company shipping the parts refused to accept our department check, wanting a credit card. I had chosen a standard electronics textbook and lab companion book written by professors at MIT[16] which assumed we would have the parts. Upon hearing that the parts would be delayed, I

[16] *The Art of Electronics, 3rd Ed.*, Horowitz and Hill. Cambridge University Press (2017).

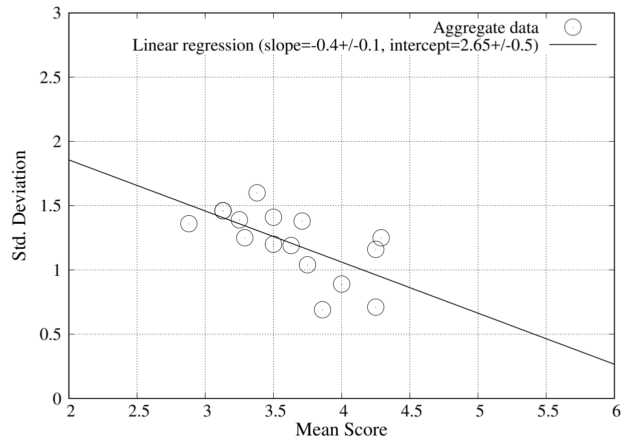

Figure 2.2: Aggregate standard deviations versus mean scores for questions 10-25 for advanced courses taught in Spring 2018.

was forced to revert to an alternative textbook a colleague provided me[17]. This text was excellent for demonstrations of binary math and boolean algebra, but was lighter on hardware. The students were unhappy that the textbooks they bought would not be used until later in the course.

We now have the reusable digital components stored in the physics labs, so we will be able to integrate the lab and lecture activities and use free instructor desk copies of the MIT text I obtained. Also, this will allow me to do what I originally planned, which was to organize the course by *sub-topic* rather than simply doing all the mathematics first. This should raise the students' assessment of categories like course preparation and effective use of class time. Finally, having experienced once how long it takes students to assemble circuits, I can better plan future class times. Students remarked that the super heterodyne AM radio took too long to assemble, for example. In the future, those projects could be partially completed by me first, before allowing the students to finish them.

Some students remarked that they felt underprepared for the course material. I did notice that I had two Whittier Scholar Program majors (F. Capraro, and A. Dodds), and while one felt the course was easy and appeared comfortable with the material, the other did not. Nevertheless, I was pleased to have those students and would like to encourage WSP enrollment in the future. The others were either 3-2 engineering or mathematics majors, and some felt that they did not remember enough physics to understand some sub-topics (resistors, capacitors, and transistors, for example). I had a tough decision regarding the pre-requisites for the course, which are normally introductory-level physics and computer science courses. My department and I felt that in the course's inaugural year that I should be able to waive the pre-requisites on a case-by-case basis in order to gain more students. I promoted COSC330 in my PHYS150 and PHYS180 courses, and students who felt they could handle it approached me personally and asked to take it. It turned out to be the mathematics seniors who did not remember enough physics and struggled with circuit-based topics. In the future, I plan to review circuit analysis in more detail, before adding digital elements.

Note: this does not have to live in the final version. *Finally, I must admit that I need more experience and training in classroom management. One of my students demonstrated behavioral problems. These included the following: persistent tardiness, sending inappropriate or disrespectful emails, not doing a fair share of group work, and complaining strongly about grades. This student even wrote on a midterm exam that the midterm was not fair, rather than spending time working the problem. The student remarked that even the student evaluation form was flawed. Finally, the student challenged my grading and submitted a grade appeal, all the while sending me aggressive emails over summer 2018. For the future, I'd like to work on my ability to handle difficult students and inspire them to be positive, and to focus on the work.*

[17] *Digital Fundamentals, 8th Ed.*, Floyd. Pearson Education (2003).

2.4 Proposed Future Courses

Some text.

Chapter 3

Scholarship

3.1 Professional Background

I began my professional career as a physicist when I entered graduate school in 2007 at the University of California at Irvine. UC Irvine was the home of Frederick Reines, the Nobel Laureate who discovered the neutrino along with Clyde Cowan. UC Irvine has a long tradition of neutrino and particle physics research, participating in the Nobel-winning Super-Kamiokande experiment[1], and the Nobel-winning ATLAS and CMS collaborations at the Large Hadron Collider at CERN[2]. My PhD advisor was Dr. Steve Barwick, who helped to found the Antarctic Ross Ice Shelf Antenna Neutrino Array (ARIANNA) project (see below), an experiment searching for ultra high-energy (UHE) neutrinos from outside the solar system. I became an expert in analysis of pulsed radio-frequency (RF) data, RF antenna and circuit design, digital signal processing, and the corresponding software development.

After I received my doctorate, I was hired as a post-doctoral fellow at the University of Kansas, where I continued to work on ARIANNA and other RF-based projects. Finally, in an attempt to bridge the divide between two competing groups within my sub-field of *astroparticle physics*, I applied for and received a fellowship from the Center for Cosmology and Astroparticle Physics (CCAPP) at Ohio State University. CCAPP is the home of the Askaryan Radio Array (ARA), a competing project to ARIANNA. One major theme of my publications and projects these past few years has been to build connections between these two groups, in the hope of building a final version of both projects capable of making record-breaking observations of UHE neutrinos. I have published in all phases of my sub-field: theoretical calculations, computer simulations, hardware design and deployment, and data analysis[3].

3.1.1 History of Undergraduate Involvement and Public Engagement

As a graduate student and post-doctoral fellow, I worked closely with undergraduates to help them understand and participate in the research. At the University of Kansas, I worked on the QuarkNet program with my advisor Dr. Dave Besson [4]. The QuarkNet program recruits promising young high-school STEM students to work in a university physics lab over a summer. I volunteered to aid Dr. Besson with two young women who were making measurements of RF surface waves across materials with a variety of speeds of light. The students and I were attempting to show that RF surface waves could exist in Antartica, which is relevant to the research I describe below. As a post-doctoral fellow at CCAPP, I volunteered with my advisor Dr. Amy Connolly on the ASPIRE program, which she created to inspire female high school students to explore careers in STEM. The program was one week each summer, plus time to recruit the students at local schools. We gave them projects involving coding, both for computers and Arduino circuit boards [5] Also at Ohio State, I gave public lectures to the Columbus Astronomical Society, which is a tradition I am continuing in the Whittier Community by giving lectures at local middle schools. My first such lecture is this semester at Los Nietos Middle School. It is my hope that this history of community engagement aligns with the goals and ideals of Whittier College.

[1] See `http://www-sk.icrr.u-tokyo.ac.jp/sk/index-e.html`
[2] See `https://home.cern/`
[3] My C.V. has been included in the supplemental material.
[4] https://quarknet.org/
[5] Arduino is an ubiquitous open-source microcontroller company that supplies DIY boards for prototype designs.

3.2 Astroparticle Physics

Astroparticle physics is simply the combination of *astrophysics* and *particle physics*. The study of astrophysics may be further subdivided into observational astronomy, which is the study of the origin and phenomenology of celestial objects, and the physics of celestial objects themselves. The former is based on observations from telescopes sentitive to various parts of the electromagnetic spectrum, and the latter involves topics like special relativity, general relativity and cosmology. Particle physics involves the study of atoms and photons, electrons and nuclei, and the quantum field theory that governs all sub-atomic particles. For the last 100 years, the main sub-field at the juncture between astrophysics and particle physics was the study of *cosmic rays*. Cosmic rays are UHE nuclei, photons, electrons, and neutrinos that arrive at Earth from deep space. Particle physics data suggests that the fundamental forces in nature unify under one quantum field theory as the particle energy increases, and the particle speed approaches the speed of light. Before humans could accelerate sub-atomic particles to such energies, we studied them exclusively in the form of cosmic rays. The Nobel prize-winning discoveries of cosmic radiation, antimatter, the cloud chamber, the muon (a heavier version of an electron), quantum neutrino oscillations and solar neutrinos, and gravitational waves have all come from a sub-field that evolved from cosmic-ray physics into what we now call *astroparticle physics*, or *multi-messenger astronomy*.

Owing to its remote location and isolation, the excellent transparency of ice at wavelengths ranging from optical through radio, and the presence of extensive scientific support at research bases, **Antarctica** now supports multiple astronomy and astrophysics-oriented projects. Within the last five years, the IceCube experiment, sensitive to optical and near-optical Cherenkov radiation resulting from neutrino interactions in ice, has reported on the first observation of extraterrestrial neutrinos at world-record energies [1]. At higher energies than IceCube, in-ice detection of longer-wavelength (radio) radiation is likely a more sensitive detection strategy, owing to the Askaryan effect [3, 4, 5], combined with the observation that RF pulses propagate for kilometers in cold polar ice [6, 7]. The Askaryan effect occurs when a UHE particle interacts in solid matter, creates a cascade of new particles, and radiates RF pulses. Several pioneering efforts to capture UHE neutrinos from outside our solar system via the Askaryan effect have been undertaken in Antarctica [2, 8, 11, 13]. Two of these are the Askaryan Radio Array (ARA) and the Antarctic Ross Ice Shelf Antenna Neutrino Array (ARIANNA). My research focuses on combining the best of the two detectors, merging them into one, and achieving world-record breaking UHE neutrino observations a factor of 1000 times more energetic than those of IceCube.

3.2.1 Recent Peer-Reviewed Publications, with Brief Descriptions

Below is a selection of xxx *recent* peer-reviewed publications in this field, in reverse chronological order. I indicate in the list the papers for which I was the *corresponding author* with an asterisk (*). In the fields of particle and astrophysics, the corresponding author is the one responsible for the paper. We have a policy of alphabetical author listing, in order to recognize the contributions of all team members, which often runs counter to the expectations of researchers in other fields used to reading the "first author" as the main contributor. Recently, I have averaged one peer-reviewed journal article for which I was the corresponding author per year for the last three years.

1. J.C. Hanson et al. "Observation of classically forbidden electromagnetic wave propagation and implications for neutrino detection." Journal of Cosmology and Astroparticle Physics. **(2018)** (2018).

    - *In my first publication as a Whittier College Assistant professor, we reported the first measurements of horizontal RF propagation in Antarctic Ice. These observations and their significance to ARA and ARIANNA are described below.*
    - *For technical reasons, I could not be the corresponding author. However, I wrote one-third of this work, including break-through theoretical calculations that led to a better understanding of the data.*
    - *For the past few years, we have not been holding physics colloquia at Whittier College. I renewed that tradition by giving a colloquium at the end of the spring semester, 2018.*
    - *My student Cassady Smith was involved with this research, and I helped her to obtain a 2018 Keck summer research fellowship to work on this with me.*

2. *J.C. Hanson and A. Connolly. "Complex Analysis of Askaryan Radiation: A Fully Analytic Treatment including the LPM effect and Cascade Form Factor." Astroparticle Physics. **(91)** pp. 75-89 (2017).

- *I derived the first complex analytical theory of the Askaryan effect (described below) to include crucial formulations of the LPM effect and the shape of the UHE particle cascade created by a neutrino in ice.*
- *Complex analytical calculations facilitate high-speed computational simulations of ARA/ARIANNA neutrino detection.*
- *Prior calculations neglected the LPM effect, which occurs at energies relevant to ARA/ARIANNA.*
- *I'm grateful to my advisor Amy Connolly for editing the paper, so I gave her authorship credit. We were finishing the paper as I arrive at Whittier College.*

3. The ARIANNA Collaboration. "Radio detection of air showers with the ARIANNA experiment on the Ross Ice Shelf", Astroparticle Physics **(90)** pp. 50-68 (2017).

   - *This is the world's only detection of UHE cosmic rays based exclusively on RF signals from air-showers. Air-showers are the high-energy cascades left by cosmic rays in the Earth's atmosphere.*
   - *Other experiments rely on high-energy muon signals and record the RF signals as a by-product.*
   - *RF detection of cosmic rays is orders of magnitude cheaper than other methods.*
   - *I was involved in the data analysis of this paper. By measuring the time-domain "response" of the ARIANNA systems (one of my papers below), I was able to discern which RF signals in the data were cosmic rays. I provided these insights to others who finished the analysis with simulations.*

4. The TARA Collaboration. "First Upper Limits on the Radar Cross Section of Cosmic-Ray Induced Extensive Air Showers", Astroparticle Physics **(87)** pp. 1-17 (2017).

   - *In this project, we attempted to measure the radar cross-section of UHE cosmic ray cascades in the Earth's atmosphere. A radar cross-section quantifies how much RF energy is reflected by an object illuminated by radar.*
   - *These cascades are several kilometers long, but it turns out that they are so thin that we could only set an upper limit on the radar cross-section.*

5. *J.C. Hanson et al. "Time-Domain Response of the ARIANNA Detector." Astroparticle Physics **(62)** pp. 139-151 (2015).

   - *This paper provided key details to suppor the conclusions of other major recent publications, including the radio detection of air showers and the first-search for cosmogenic neutrinos with ARIANNA.*
   - *These measurements, the first of their kind, were taken at the University of Kansas.*

6. *J.C. Hanson et al. "Radio-frequency Attenuation Length, Basal Reflectivity, Depth, and Polarization Measurements from Moore's Bay in the Ross Ice-Shelf." Journal of Glaciology **(61)** 227, pp. 438-446(9).

   - *Similar to the above paper, this paper provided key details about the ice to the first-search paper below.*
   - *The ice properties affect the sensitivity of our projects to UHE neutrinos.*

7. The ARIANNA Collaboration. "A First Search for Cosmogenic Neutrinos with the ARIANNA Hexagonal Radio Array." Astroparticle Physics **(70)** pp. 12-36 (2015).

   - *This work published the first upper limits on the UHE neutrino flux from outside the Milky Way by ARIANNA. This paper was the culmination of years of planning, construction, and analysis.*
   - *I helped to deploy the hardware used to collect the data analyzed for this paper.*
   - *Given our current projects, this paper shows that ARA/ARIANNA will be the most sensitive detector in history to UHE neutrinos if built on a mass scale.*

3.3 Antartic Ice as a Particle Detection Medium, and the Future of UHE Neutrino Science

Recently, I have facilitated merger discussions between the ARA and ARIANNA collaborations. Program officers from the National Science Foundation (NSF) have indicated that if the ARA and ARIANNA were to merge, they would strongly support a brand new neutrino detector in Antarctica. The NSF solicitation is entitled "Windows on the Universe: The Era of Mutli-Messenger Astrophysics"[6], and is due December 4th, 2018. The NSF liason is Vladimir Papitashvili (vpapita@nsf.gov) from the NSF Office of Polar Programs (OPP). Five years after receiving my PhD, I am proud to state that we are on the verge of major detector construction, due to workshops I helped to organize at both UC Irvine and Ohio State this year. The timing of this merger is especially impactful for Whittier College undergraduates, for soon the joint ARA and ARIANNA[7] collaboration will require a small army of undergraduate researchers. Whittier is ideally located near UC Irvine, a founding institution and the center for RF hardware and firmware development.

The funding scale for our Antarctic neutrino detector is approximately 15 million USD, with software, firmware, and hardware developed by multiple independent physics and engineering teams at different colleges and universities. A multi-institution collaboration is required to complete this scale of project. This is a standard field-wide in astroparticle physics, as these major science facilities cannot be supported by a single university or national lab. The detector will be comprised of ≈ 100 detector modules, all independently observing ≈ 1 km^3 of ice. Antarctic deployments require coordination and planning best acheived by a collaboration rather than a small group of individuals. In addition to working on the detectors and data analysis, I also participate in RF measurements of polar ice properties, to better understand how the UHE neutrino signals would propagate ≈ 1 km to our detector modules. These ice properties include how much energy is lost by the RF pulse in the ice, and how the trajectory of the radio wave is curved due to the changing density of ice versus depth. I was one of the first researchers in the world to quantify the energy loss of RF pulses for the ice of ARIANNA [12].

3.3.1 Conferences and Workshops

3.4 RF Pulse Propagation in Ice

Given that my sub-field is one collaboration, we publish papers as a collaboration. In my first publication as a Whittier College professor we reported on the first-ever observations of horizontally propagating RF pulses in polar ice. Normally, RF pulses travel along curved paths in ice because the speed of light is correlated with density, which changes with depth. Because the RF pulses are inherently wave-like, *classical* electromagnetic theory states that the RF pulses should swerve downward, because the top of the wave in faster ice outpaces the bottom in the slower ice. This "shadowing effect" is similar to the physics of a mirage, and removes some ice volume from which neutrinos can geometrically originate while still being detectable. **In stark contradiction with *classical* propagation theory, we have observed RF pulses traveling in horizontal paths with no apparent curvature, in multiple venues around Antarctica [9]**. On a publication with 19 authors, I wrote the first third of this work. I showed that if we account for density perturbations in the ice, classical horizontal RF propagation is possible. I have also shown that internal reflection layers (independently observed via radar and field samples) could also lead to horizontally propagation. *If true, the existence of horizontal RF propagation could increase the probability of UHE neutrino detection* with ARA and ARIANNA, for the simple reason that a larger volume of ice per detector module becomes a potential UHE neutrino target. I am considered a secondary author on these works. I already have one physics major, Cassady Smith, working with me on simulations that quantify these effects. With me as advisor, Cassady received a Keck Summer Research Fellowship for Summer 2018. I was a secondary author on two other peer-reviewed works this year: one paper quantified RF propagation measurements at the South Pole with ARA, and the other detailed observations of a solar flare with ARA.

3.5 RF Circuit Fabrication and Testing Laboratory

Given that I am striving for quality research in *all phases* of my sub-field, I have built an RF circuit fabrication and testing station in my laboratory in the Science and Learning Center. I have begun to teach myself *firmware programming*, which is a wholly different discipline than *software programming.* Software code is written in languages like C++ and compiled into assembly and then binary to be executed by a CPU. Firmware code is written in languages like Verilog and is compiled directly to binary, which is translated into a physical circuit on a field-programmable gate array (FPGA). The combination of firmware code and FPGAs leads to reprogrammable microcircuits that perform repeated digital tasks at $\approx$ GHz clock frequencies. This discipline is relevant to my research in that the ARIANNA and ARA detector modules make heavy use of FPGAs in their sub-systems to

[6] See the website `https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=505593`.

[7] Given that physics professors are not known for their ability to compromise, we are still in the process of choosing a new name.

filter and process RF pulse data. My students and I have already begun to modify and update the ARIANNA firmware on an actual ARIANNA module on-loan from UC Irvine. This has given my students hands-on experience with firmware development. The firmware upgrades we are developing are a vital part of the detector expansion currently underway in the merge of ARA and ARIANNA. We plan on contracting with the collaboration to bring funding to Whittier College as a developer for ARIANNA modules in the coming year. I already have one 3-2 engineering major, John-Paul Gómez-Reed, working with me on ARIANNA firmware development. With me as advisor, John-Paul received a Keck Summer Research Fellowship for Summer 2018.

3.6 Digtal Storytelling and Physics: The Primer

I remember exactly what I thought, the moment I learned of the DigLibArts group at Whittier: "I know exactly what I will do with these capabilities." The DigLibArts group introduced me to the Scalar project, which is a digital storytelling tool used to make digital textbooks and other scholarly materials in humanities areas. I realized that a) there are currently no STEM Scalar projects, b) Scalar could be used to produce a digital physics text that collects learning pattern data, and c) the data could be analyzed with machine-learning techniques. I haved connected with WSP and digital media majors, Amy Trinh and Brienne Estrada, who have helped design Adobe-based digital characters for this tool. I have received a grant from the DigLibArts group to aid in developing this project. We have named this project The Primer, after 19th Century finishing-school texts meant to educate young ladies. The choice is in reference to a subversive digital education tool called "The Primer" in a novel entitled "The Diamond Age," by Neal Stephenson, in which a young girl named Nell becomes a world-class engineer when the primer falls into her hands. I had originally contracted with reknowned game designer and graphic artist *Eric Torres*[8] to help us with the designs, but he has had to withdraw for family reasons. Although losing Eric was a setback, it was a wonderful experience for Amy, Brienne, and Cassady to Skype with him and hear his ideas.

The Primer project has also been an excellent opportunity for Cassady Smith to learn about machine learning via the scikit-learn python module[9]. Cassady Smith has been working on python code that will gather data on how students proceed through the physics problems, and will analyze the outcomes via machine-learning algorithms. Machine-learning algorithms evolve themselves based on training data, and solve a fixed type of problem more efficiently than human beings when provided with appropriate features. A feature is a data classifier, such as the probability students answer a particular question correctly. I plan to continue The Primer project through recruitment of Whittier Scholars Program students, who have the ideal mixed skillset for such a project. Once the basic code is written and paired with the artwork of Amy Trinh and Brienne Estrada, I will begin sharing it with high-schoolers from the Artemis Program, who will share the Primer with their friends and use it to collect data on how people learn science. The Artemis program is a program sponsored by the Whittier College Center for Engagement with Communities (CEC) that seeks to empower young women in STEM. I have volunteered this year to be an Artemis professor coordinator. This project will combine game-like python code editing with data collection and analysis, similar to a physics education research project I encountered at Ohio State as a post-doctoral fellow [16].

[8] `https://ericimagines.com.`

[9] http://scikit-learn.org/stable/

Chapter 4

Service

Hello, here is some text without a meaning. This...

Chapter 5

Advising and Mentoring

Hello, here is some text without a meaning. This...

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