Professional Evaluation and Growth Plan

Jordan C Hanson, PhD

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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. 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 both explain why I chose to become a professor, and share my vision for teaching 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 outstanding faculty, and I fell in love with physics. The beauty of physics is found in its theoretical simplicity, and the surge of excitement as observations spark to life. After receiving my Bachelor of Science degree, I joined the community of 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.* At UCI 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 there I first witnessed 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. 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 receiving my doctorate, I solo-taught an introductory physics course during one of my post-doctoral fellowships, learning 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 *enlighten* our students.

1.2 General Reflection and Future Directions

Any general reflection for academics at Whittier must begin and end with the 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 took a course from a professor in another department for the shear joy of learning, but also to learn methods from an experienced teacher. I've involved students in all facets of my research, including software and algorithm development, firmware development, building hardware, and digital storytelling. Two of these students won Keck Fellowships while working 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 served 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 yet 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 technical detail was presented too rapidly and too advanced. 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 helped me with these issues. 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 it is not 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 some students in introductory courses are not prepared to make logical abstractions, requiring a larger number of concrete examples before gaining that ability. I will work diligently 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 growth through 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. Lifting a student learning physics from retention to reflection is beautiful, in that we witness students extending their minds outside *their model* of the world, into *the model* of the world. In general, the teacher and student succeed imperfectly in imparting ideas about *the model* of nature. Thus the process will contain periodic failures. 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 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 a 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 pours work into the semester, and masters new skills in the field. 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 make progress at the learning moments brought forward by mistakes.

A good *professor* is a special kind of teacher, in that he is a teacher that also performs scientific research and

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

serves a college or university. A good professor successfully involves students in his research. One crucial fact 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. While 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 take time to 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

Physics students at Whittier College are first categorized as liberal-arts *non-majors* or *physics majors*. Non-majors encounter physics for two semesters in either *calculus-based* or *algebra-based* courses. We provide such introductory courses because 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 will not take calculus for their degree can still learn to apply some mathematical concepts. 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, and public lectures to children, families, and astronomical societies. Experiencing people's curiosity is necessary to become a great professor. I've continued this practice as Whittier professor, for example, by giving a lecture at Los Nietos Middle School. All people seek an understanding of nature. Moreover, people have a need to know *that the answers exist*, even if we do not all fully grasp them. 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, exposing them to astroparticle physics research [2].

2. **Improvement of Analysis Skill**. The scientific method relies on analysis. We as physicists best serve Whittier non-majors when we are developing their problem-solving. The Whittier College physics faculty have several tools for problem-solving development. *Peer Instruction* is becoming a standard method in American colleges [1], 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 [2]. A third tool is PhET (Physics Education Technology) [3], in which students compare analysis results to computer simulations built in conjunction with physics education research. 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 diverse activities, such as group problem solving, verification with computer simulations, and verification via experimentation. One interesting emergent property is that students from different groups verify solutions with each other on the boards in real time, speeding learning. Finally, we incorporate a healthy mix of *traditional* lecture methods to provide concrete examples for our students encountering content for the first time [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 special units centered on these practical applications, including human nerve systems (in PHYS135B) and human metabolism (PHYS180). I also use the final group projects 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 quantify ideas is vital for conducting fact-based discussions. I included a brief unit on climate change and the solar system

[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.

[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.

in PHYS135B and PHYS180, analytical problem solving and simulations. One additional tool for the non-majors is the inclusion of presentations in which the student summarizes a scientific journal article in 5-10 minutes. The brevity requirement causes the students to focus on important details 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 created is Computer Logic and Digital Circuit Design (COSC330/PHYS306). 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 (see section on Scholarship 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 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]

[5] See supplemental materials for examples of student presentations and writing.

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).

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 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

[6]See supplemental material for example syllabi.
[7]See supplemental material for details.

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 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

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

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

PI Modules - 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.

JITT Modules - 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.
- JITT-module questions are drawn from a database, and tailored to common misconceptions.
- Students' anonymous responses are included in the lecture itself, and the class gets a chance to analyze them.

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.

[10] The effect of adding this specific phrase has been studied and shown to benefit the utility of table discussions.
[11] see `https://phet.colorado.edu`

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*.

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 areas that need improvement. Questions 14-16 and 19 read as follows: “This course improved my understanding of the material,” “This course increased my interest in the subject matter,” “Overall, I would recommend this course to others,” and “The professor was able to explain complicated ideas,” respectively. For *algebra-based physics*, there are no pre-requisite courses, but students are required to solve problems involving algebraic equations, graphical analysis, and concepts like vectors and vector fields. It is not surprising that students struggle if they’re encountering these concepts for the first time. I have been trained to teach much faster than the students who disapproved expected.

In the students’ written responses, the most common remark was that the pace of the course was too fast, and that they desired more traditional lecture time with explicit examples given. Some students remarked that the portions of the lecture on the projector (e.g. PI-modules, JITT-modules) were not as helpful as the traditional style with examples. In Fall 2017, Professor Serkan Zorba and I both taught PHYS135A, and in Spring 2018 we both taught PHYS135B, meaning that some students had to switch professors. Students who switched were newly stressed by the increased pace, in addition to the students I had from the Fall. Some students even met with me in office hourse to brainstorm ways in which we could move more slowly, but still cover the necessary book chapters. These meetings were helpful, and I learned that the difference in my expectation of student physics preparation and their actual preparedness was wide. Now that I fully understand the problem, which is more pronounced for 135B, I can begin to solve it.

PHYS135B introduces the concept of vector *fields*, necessary for understanding electromagnetic fields. This new concept further added difficulty for students encountering vectors for the first time[12]. The research-based methods

[12] A single vector describes, for example, the velocity of a single leaf blown in a direction by the wind. A vector field, on the other hand, describes the wind velocity at all points in space.

such as PI-modules rely on groups of students teaching each other. If a whole group is struggling, they don't gain the benefit of the one student who understands the problem to show them how to solve it. Thus, the average scores on questions 14, 16 and 19 showed slight decreases (less than one standard deviation). Responses to Question 11, "This course was academically challenging" showed a slight increase, which is evidence that the students found the second semester more difficult than the first. I assess this further in the Appendix. Figure A.1 of the Appendix shows that when I score high, there is broad consensus among the students that I am performing well. However, when the *average* scores are lower, there is less consenses (a larger variance in the data).

I did not encounter many written responses in which students expressed strong feelings about question 15, "This course increased my interest in the subject matter." Most students taking PHYS135A/B are fulfilling a requirement for their major (a two-thirds majority are KNS majors), and typically do not express a strong desire to take the course[13]. Nevertheless, I have attempted to add content that appeals to KNS majors. For example, when we reach concepts in PHYS135A pertaining to biomechanics, such as torque, I give specific example problems and final project assignments that relate in some way to torque in the human body. Another example pertains to PHYS135B, which addresses electric current. When we reach the topic of current, the class solves problems specific to the electrical currents in the human nervous system[14]. For more information on KNS-relevant material in PHYS135A/B, see Sec. 2.4.

In *calculus-based physics*, the story was different. There are many areas in which the courses and my teaching scored well. **I am especially proud of the fact that Q25 ("Overall, I would recommend this professor to others") jumped in 2018 relative to 2017 for the calculus-based courses. In fact, my teaching scores improved in every single category in calculus-based physics in going from Fall 2017 to Spring 2018.** Further, students in both sections believed that the courses were rigorous and challenging, while still giving me increasing marks in all categories. Some students appreciated the PI modules, PhET simulations, and JITT exercises. This is reflected in responses to question 12 on the standard evaluation ("This course offered useful learning tools"), which is a key data point. I focus on this data point because I am being asked by my department to teach in an activities based style with modules like PI-modules, different from the traditional lecture. 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 through conceptual understanding. However, upon reflecting on the students' constructive comments, it seems that these modules benefit some students but not all.

A vital teaching method emerged in PHYS180, which the students call "board problems" in their written responses to evaluations. It started with an interesting compromise between my desire to move forward in the book faster, and the students' desire to go slowly and have me do examples. Notice that in the PHYS180 written responses, the students still express quite often a desire for worked examples in class. In light of all the research-based teaching methods that encourage students to learn through interactions with each other, I decided to have them *work example problems for each other.* I began by giving an example problem to the class. The problem would be difficult, and I would either design it myself, or draw it from the current chapter. Students would then work the problem in groups of 3-4 on the whiteboards, next to other groups. The class responded positively to this method, and it is reflected in their written responses. Some even state explicitly that my teaching improved! The board-problem method works for two reasons: it allows struggling students to see how harder problems are approached by peers, and struggling groups see other groups' strategies and therefore learn from the whole class.

In addition to the inclusion of board-problems, I have reflected on my student evaluations and have decided on **three concrete improvements** to my introductory courses. In consultation with my department chair, and in studying past PEGP documents in my department, the first improvement will be an increase in traditional lecture content. 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. My colleagues in my department have reassured me that it is necessary to give inexperienced students an explicit starting point. Thus, going forward in my introductory courses, *a significant fraction of class-time will be spent on concrete*

[13]Question 9: "I had a strong desire to take this course." PHYS135A/B students reported 3.24 ± 1.64 and 3.00 ± 1.71, respectively.
[14]In the supplemental materials I include a student's final presentation on the electrical nerve activity of a bicep under torque.

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*.

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*.

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 relief when I began assigning them board-problems, precisely because it allowed them to slow down, and check their work with each other and other groups. Thus, the addition of board-problems solved both the problem of pace and example problems at once. 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.* One minor adjustment to this technique is that the courses are getting larger enrollments, and we may run out of whiteboard space. My planned response to this is to sketch the problem myself, and then allow student groups to design specific examples meant to be exchanged among the groups. So far this has worked in my Fall 2018 PHYS135A sections when it's not feasible to do board-problems.

The third change I'd like to make is to include more applications of calculus in the *calculus-based* introductory sequences. In my view, more applications of calculus should be included in PHYS150/PHYS180. From the feedback from my department, I need to include more laboratory activities in PHYS180. 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 with and without calculus. The inclusion of more lab activities is mandatory (and now possible because I'm fully trained on all the equipment). Thus including calculus concepts in the labs will require little extra effort. Finally, homework problems involving calculus will be selected from the book's less-difficult category, easing the transition from math to physics contexts.

In consultation with my department, I have been focusing on question 17 ("The professor used class time effectively and demonstrated preparation for class."). My colleagues believe that many numbers will rise in correlation with question 17. Struggling students who desired traditional lectures with examples and worksheets likely felt class was not organized because they were unaccustomed to research-based modules like PI or PhET. Of

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).

course I prepared for my courses; I have built an interactive, open-source GB-scale database of lecture content [15]. Going forward, I can use the discussion period during PI modules to focus on helping struggling students one-on-one with a mini-lecture at their table. The group board problems also afford me the chance to do this. Finally, providing more traditional lecture content should help the situation. For further analysis of the data in Tab. 2.2-2.5, see Appendix A.

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[16]. 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 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 [17]. 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

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

[16] 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.

[17] See supplemental material for examples of assignments.

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*.

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 [18]. 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 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. 2.1). 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.

[18]Karnaugh maps are a way of speeding through boolean algebraic derivations efficiently.

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*.

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 [4] which assumed we would have the parts. Upon hearing that the parts would be delayed, I was forced to revert to an alternative textbook a colleague provided me [5]. 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.*

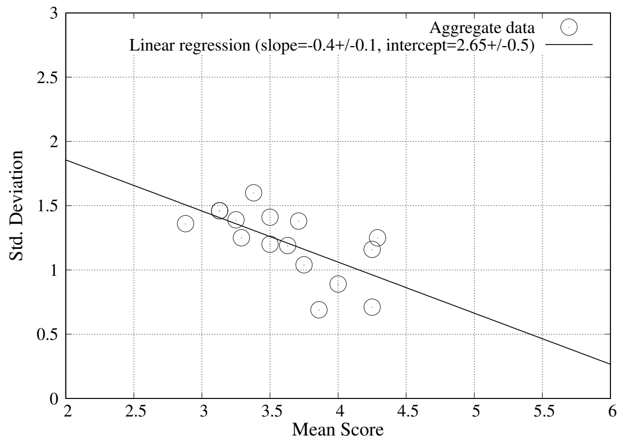

Figure 2.1: Aggregate standard deviations versus mean scores for questions 10-25 for advanced courses taught in Spring 2018.

2.4 Proposed Future Courses

Digital Signal Processing (COSC390) - This special topics in computer science and mathematics is meant to serve primarily 3-2 engineering students, math/computer science majors, and physics/computer science majors. However it will be open to all students interested in learning more about handling digital data scientifically. This course is a brand new course I'm developing, to be taught for the first time this coming January term, 2019.

I will present a broad overview of the subject of digital signal processing (DSP). We will begin with a review of relevant statistics, complex numbers, and types of noise in digital systems. Next the concept of a linear DSP system and the corresponding mathematical techniques will be introduced. From there, a broad overview of the topic of digital filters and data processing will be given, proceeding to DSP applications to scientific data analysis. Among the application topics are audio systems and data compression, electrical circuits, digital imaging, and applied neural networks. Time permitting, advanced topics in DSP with complex numbers will be covered, including the Fourier and Laplace transforms with their digital counterparts, the FFT and z-transforms.

There are several advantages to this course that add value for Whittier science and engineering students. This course is a natural continuation of my COSC330/PHYS306 course, Computer Logic and Digital Circuit Design. Students who have taken both should be able to grasp going all the way from transistor logic to processed digital data. The course also will focus on cleaning and managing data, and performing data analysis on time-series. These skills are relevant to a broad range of science courses, in addition to computer science and physics. Finally, the coding language (octave)[19] and textbook [6] for this course will be open source, and therefore free for students.

The History of Science in Latin America - This is a history of science course I have discussed with professors in my department, and in the Mathematics Department, that I believe would be widely subscribed by the students for several reasons. Given that a) the ethnic composition of Southern California is changing, and b) Latinos are historically under-represented in physics, it might be helpful for all of our students to become familiar with the scientific achievements of pre-Columbian peoples. I do see this as part of the broader effor by the college to be more diligent in the areas of equity and inclusion, but the main focus would be on the history of science. One mathematics professor suggested reviewing the decoding of the Mayan language and scripts. Another suggested covering the astronomical accuracies of the Mayan calendar. I would center the course on two ideas. First is the idea that those people who make good scientific progress are the ones who have the most accurate data, regardless of where they are on the globe. For example, civilizations in Latin America, saw different celestial objects in the sky than those in Europe, and likely had more knowledge of them before European astronomers explored the Southern Hemisphere. Another example are pre-Columbian Latin American calendars. These were precise and functional, based on astronomical data, and worked within certain limitations as European medieval calendars.

The second idea would be that language matters in science - often terminology in physics is confined to the

[19] See `https://www.gnu.org/software/octave`.

English language, however I am curious what words native peoples used to desribe certain physics effects, and how they later translated them into Spanish. As a start, I decided to take introductory spanish courses with Prof. Doreen O'Conner-Gómez, who was kind enough to let me audit one of her courses. I would like to eventually cover original writings and letters from Spanish colonials who had the first glimpse of the scientific knowledge of native Latin Americans. My hypothesis is that pre-Columbian peoples had significant knowledge of physics and astronomy, but that it didn't necessarily appear so to Europeans who did not speak the same language, or quantify scientific effects in the same way. By understanding both the original (or perhaps translated) colonial writings, and physical and astronomical effects which are timeless, I would attempt to show that there was some common understanding of the natural world.

Physics of the Five Senses - This is a course I proposed as a liberal education breadth course, which would expose non-STEM majors to the physics and kinesiology of the human senses. Many kinesiology majors take my introductory physics courses to fulfill graduation requirements, and often express an interest in physiological measurements[20]. Why not base an entire course around making physiological measurements, and open it to non-STEM majors who could take it alongside STEM majors? The course would be fun, and activity-based, centering on KNS and physics labs meant to establish that our five senses are not that different from other sensors based on electrical signals, optics, and thermodynamics.

[20] See supplemental material for a final project example on muscle activation

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. I deliberately chose to work with my competitors to better understand others' ideas, and to form a line of communication between two groups. In my publications and projects these past few years I have tried to build connections, in the hope of designing a combined version of both projects. Such a design will be capable of making record-breaking observations of UHE neutrinos [7]. 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

[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.

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.

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 (QFT) that governs all sub-atomic particles. Beginning with formative discoveries in 1911, the main sub-field at the juncture between astrophysics and particle physics has been 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 QFT 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.*

To aid readers outside the field of physics, below is a list of relevant definitions used in this chapter.

- *Quantum field theory (QFT)* ... Application of quantum mechanics to sub-atomic particles, describing fundamental interactions of matter and light.
- *Cosmic ray* ... A high-energy proton or other atomic nucleus moving near the speed of light in deep space.
- *Neutrino* ... A sub-atomic particle emitted in various nuclear and high-energy quantum interactions.
- *Cherenkov radiation* ... UV light emitted when high-energy charged particles move through ice near the speed of light (or other material with an *index of refraction.*
- *Index of refraction* ... A number n that quantifies the speed of light in a material: $v = c/n$, where v is the speed, and c is the speed of light in a vaccuum.
- *Askaryan effect* ... This effect occurs when a high-energy particle interacts in a material with an index of refraction, depositing energy in the form of many charged particles. The charged particles undergo the Cherenkov effect, but radiate together as a group, leading to a radio pulse.
- *The Standard Model* ... A QFT model that explains all known sub-atomic phenomena with striking precision, up to a certain energy. The model predicts quantum effects that explain the behavior of atoms, molecules, chemistry, etc. Although the model is powerful, neutrinos have properties not predicted by it.
- *ARIANNA* ... Acronymn for Antarctic Ross Ice Shelf Antenna Neutrino Array.
- *ARA* ... Acronymn for Askaryan Radio Array.

Owing to its remote location and isolation, the excellent optical and radio transparency of ice, and the presence of extensive scientific support at research bases, **Antarctica** now supports many astroparticle physics projects. Within the last five years, the IceCube experiment, sensitive to Cherenkov radiation resulting from neutrino interactions in ice, has reported on the first observation of extraterrestrial neutrinos at world-record energies [8]. In-ice detection of RF radiation is a more efficient strategy at neutrino energies 1000 times higher than those observed at IceCube. This strategy arrises from the combination of the Askaryan effect [9, 10, 11] and the observation that RF pulses propagate for kilometers in ice [12, 13]. The Askaryan effect occurs when a UHE particle interacts in solid matter and radiates an RF pulse. Pioneering efforts to capture UHE neutrinos originating from beyond the solar system via the Askaryan effect have been undertaken in Antarctica [14, 15, 16, 17]. Two of these are ARA and ARIANNA. My research focuses on combining the best of these two designs, and achieving world-record breaking UHE neutrino observations.

The detection of neutrinos from beyond the solar system at the highest cosmic-ray energies would be a watershed moment in physics for three reasons. It would aid in the discovery of the source or sources of cosmic rays, which after 100 years remains unknown. Second, it would represent an interaction with matter that is almost certainly from other galaxies, given that neutrinos propagate through deep space for distances much larger than the Milky Way. The long distance propagation stems from the fact that neutrinos interact with matter rarely, and because inter-galactic space is filled with very little matter. Finally, it would allow us to perform fundamental tests of the QFT that forms the Standard Model, which is the global physics model describing all of nature (sub-atomic physics, atomic physics, chemistry, etc.), except gravity.

3.2.1 Recent Peer-Reviewed Publications, with Brief Descriptions

Below is a selection of seven *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 author who officially submits the work for publication and corresponds with the journal editor. We also have a policy of strict alphabetical author listing, in order to recognize the contributions of all team members, even if they did not contribute to a particular paper. This style often runs counter to the expectations of researchers in other fields accustomed to reading the "first author" as the main contributor. I have averaged one peer-reviewed journal article for which I was the corresponding author per year since I graduated from UCI in 2013.

The purpose of the list is two-fold. First, I must demonstrate that I am committed to research excellence and that my research reaches out from Whittier College to the world of astroparticle physics. *The paper listed in bold face I count towards satisfaction of my departmental tenure guidelines.* Second, I provide the list as evidence that I have begun to involve Whittier undergraduates in my research program.

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. The data was collected over many years, but I performed all of my work for this paper while at Whittier College. These observations and their significance to ARA and ARIANNA are described below.*
   - *I am a corresponding author on this paper, and I wrote one-third of this work. My contributions include collecting a large fraction of the data, and 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 Spring 2018 on this research.*
   - ***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 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. I published the paper during my first semester 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).

Category	Requirement	Promotion level
Teaching	Teach full course load	Associate Professor
Teaching	Contribute to major and liberal arts curriculum	Associate Professor
Advising	Encouraged to mentor at least one student	Associate Professor
Service	Encouraged to participate on major committees	Associate Professor
Scholarship	Three *peer-reviewed products*	Associate Professor
All	Differ to FPC, Candidate chooses Boyer categories	Full Professor

Table 3.1: Summary of Physics and Astronomy Department guidelines for receiving tenure. For receiving tenure at the Associate level, the department defines *peer-reviewed products* as: (a) three scientific journal articles in the research area of the candidate, or (b) two such articles and one external grant for which the the candidate is a major contributor. With department approval, the following alternate paths are accepted: (c) one scientific journal article in the research area of the candidate and two journal articles on pedagogy and physics-education topics, plus one grant as in (b), or (d) two scientific journal articles in the research area of the candidate and two journal articles on pedagogy and physics-education topics. The scientific articles should fall under the *scholarship of discovery*, using the Boyer categorization.

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).

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

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).

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

The Department of Physics and Astronomy at Whittier College has clearly defined requirements for granting tenure and promotions. In Tab. 3.1, the departmental criteria for faculty seeking tenure are summarized [6]. I have already begun publishing scientific research as a Whittier College, with one peer-reviewed scientific journal article in my first year as a faculty member. In the next section I outline my plans for grant applications, and future research.

3.3 The Future of UHE Neutrino Science

Recently I helped facilitate merger discussions between ARA and ARIANNA. National Science Foundation (NSF) program officers have committed support for a brand new neutrino detector in Antarctica if ARA/ARIANNA merge. The NSF solicitation is entitled “Windows on the Universe: The Era of Mutli-Messenger Astrophysics”[7], 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/ARIANNA[8] collaboration will require a small army of undergraduate researchers. For more detail about this proposal, see Table 3.2. The funding scale for our Antarctic neutrino detector is approximately 20 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 future goals of the science created by the detector are summarized below.

[6] The departmental guidelines are included in the supporting materials.
[7] See the website `https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=505593`.
[8] We are still in the process of choosing a new name.

Proposal Funding Level	US Institutions	Technical Areas	Whittier Undergraduates
$20 million	Whittier College UC Irvine California Polytechnic (SLO) Lawrence Berkeley Lab Univ. of Chicago Univ. of Kansas University of Wisconsin Ohio State University University of Delaware Otterbein University	RF Hardware/calibration RF Firmware Ice property measurement Software development Deployment and logistics	John-Paul Gòmez-Reed (RF Firmware) Cassady Smith (Software development) Nicholas Clarizio (Hardware calibration)

Table 3.2: Overview of the upcoming ARA/ARIANNA proposal. The overall budget for the proposal will be approximately 20 million USD. There are currently 10 US institutions, and Whittier College is the only Title V HSI. If successful, a portion of the grant will go to Whittier College, with myself as a co-PI. The work required will be in five technical areas. My student Cassady Smith is helping to develop software that simulates the UHE neutrino interactions in ice. John-Paul Gòmez-Reed is assisting in developing firmware for the station electronics. Finally, Nihcolas Clarizio is building a drone to assist with deployed hardware calibration.

- ***Determine the origin of cosmic rays, which remains unknown after 100 years.*** Cosmic rays likely originate in other galaxies, but the initial directions are modified because cosmic rays are charged. When charged particles pass through magnetic fields, like those created by our sun and our galaxy, the initial trajectory is lost. The chargeless UHE neutrinos will point back to the source of cosmic rays, and the properties of the *energy spectrum* of the UHE neutrinos will also contain clues.

- ***Probe QFT at unreachable energies on Earth.*** The laws of physics governing fundamental particles unify and change at ever higher energies. One example is to measure the probability that UHE neutrinos interact quantum mechanically in ice, and check for any deviation from standard QFT. Another example is to measure the relative abundance of the three different quantum flavors of cosmic neutrinos [18] [19].

- ***Investigate correlations between UHE neutrino sources with other UHE astrophysical sites.*** Two recent examples are given: *blazars* [20]. This development would be serendipitous for Whittier College, given that Dr. Glenn Piner studies blazars [21] and I study UHE neutrinos. Thus, there is potential for interdepartmental collaboration.

3.3.1 Conferences, Workshops and Colloquia

I have summarized all my research lectures given in my first year as a Whittier Professor in Tab. 3.3, and I have included the undergraduates who helped me with the research. The purpose of this listing is two-fold: to demonstrate that I have already begun to expose my research students to the broader field of astroparticle physics, and to demonstrate that I am both an active member of the scientific and Whittier communities.[9]

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 [22].**

[9] Student feedback on the Whittier College colloquium is provided in the supplemental material.

Event	Date/Location	Undergraduates Involved
RF Prop. Coding Workshops	Oct. 2017 at UC Irvine	Accompanied by C. Smith
Invited Colloquium	April 19th, 2018 at Cal Poly San Luis Obispo	Research aided by C. Smith
Department Colloquium	May 4th, 2018 at Whittier College	Research aided by C. Smith
UHE eng. meeting	July 11th, 2018 at UC Irvine	Accompanied by Keck Fellows
UHE eng. meeting	August 29-31, 2018 at UC Irvine	Research aided by J.P. Gómez-Reed
Merger meeting	September 12-15, 2018 at Ohio State University	Research aided by Keck Fellows
Public lecture	September 26th, 2018 at Los Nietos Middle School	Research aided by Keck Fellows

Table 3.3: Cassady Smith (C. Smith) began performing software development and research with me in Fall 2017, and I took her to meet my colleagues at UC Irvine in Fall 2017. Also in Fall 2017, I was introduced to John-Paul (J.P.) Gómez-Reed, who began developing firmware in my lab. I was invited to Cal Poly San Luis Obispo to give a colloquium by Dr. Stephanie Wissel. I gave a similar colloquium at the end of Spring 2018. I helped J.P. and Cassady win Keck Summer Research Fellowships, and they both accompanied me to UC Irvine for ARIANNA engineering collaboration. A second such meeting took place at UCI in late August, beginning the merger discussions. Finally, I attended the merger meeting between ARA and ARIANNA researchers at Ohio State, where I presented my Keck Fellows' research alongside my own.

On a publication with 19 authors, with data collected from multiple Antarctic sites over a decade, I wrote the first third of this publication. I collected the entire set of index of refraction data, which yields a different speed of light at a given ice depth. I showed that if we account theoretically for density perturbations in the ice, classical horizontal RF propagation is still possible under certain conditions. 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 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 on the topic of RF propagation in ice. One paper detailed observations of a solar flare with ARA [23], and the other quantified RF propagation measurements at the South Pole with ARA [24].

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 laboratory the Science and Learning Center. I am grateful to Dean Darrin Good for the startup grant that made this effort possible. With this facility, I teach my students *firmware programming*. Software code is written in languages like C++ and compiled to be executed by a CPU. Firmware code is written in languages like Verilog and VHDL, which is translated into a physical circuit on a field-programmable gate array (FPGA). FPGA designs are reprogrammable microcircuits that can perform arbitrary digital tasks at high speeds ($\approx$ GHz clock frequencies). In addition to the curricular implications for my new course, Computer Logic and Digital Circuit Design (COSC330/PHYS306), this lab supports my research with ARA/ARIANNA in several ways, summarized in Tab. 3.4.

The sensitivity of ARA/ARIANNA to UHE neutrinos increases with the number of RF antenna channels deployed. Each has an RF *threshold* and *trigger*. The incident RF pulse must have a voltage larger than the threshold for that channel to record data (to trigger). The lower the threshold, the higher the chances that channel has of observing a UHE neutrino signal[10]. Naively lowering thresholds comes at the price of triggering on thermal noise and man-made signals [25] [26]. The projects in Tab. 3.4 are all geared towards lowering the threshold while avoiding triggering on unwanted signals. These operations are deemed mandatory by the ARA/ARIANNA collaboration. My student, J.P. Gómez-Reed, has competed major research milestones in the digital trigger throttle project as a Keck Fellow in my lab.

Firmware development is also crucial to the education of our STEM curriculum. *I am the first professor at*

[10]There are many more UHE neutrino signals that produce relatively small signals, versus large ones, compared to the thermal environment around the antenna.

Project	Scientific purpose	Participants
Digital trigger throttle	Automated measurement of RF trigger rate in ARA/ARIANNA. Enables detector mass-production via automation of threshold tuning.	J.C. Hanson J.P. Gòmez-Reed
Digital phased-array	Enables lowering RF threshold for recording increasing number of UHE neutrino signals.	J.C. Hanson
Majority logic-upgrades	Enables use of multiple majorities of different RF antenna types to detect UHE neutrinos	J.C. Hanson J.P. Gòmez-Reed
Digital RF chirp trigger	Allows us to lower thresholds, taking advantage of radio antenna properties	J.C. Hanson

Table 3.4: FPGA-based projects in our RF lab. Each of the projects above contributes to the ARA/ARIANNA *trigger* (see text for details). The purpose of the digital trigger throttle is to automate RF channel calibration, necessary for a detector built from thousands of channels. The purpose of the phased array project is to more efficiently use information from all channels in real time. The third project explores using different antenna subsets for efficient triggers. The final project takes advantage of the *chirping* property of the RF antennas used in ARIANNA, allowing for lower thresholds for the trigger. My Keck Fellow J.P. Gòmez-Reed made excellent progress with the first and third projects during Summer 2018.

Grant Name	Time	Amount	Purpose
Start-up grant	Sept. 2017	\$30,000	Creation of RF lab, new curriculum
Faculty Development Grant	Nov. 2017	\$1500	Attendance of AAPT Conf
Send, Learn, Return Grant	Nov. 2017	\$500	Air-travel to AAPT (above).
DigLibArts Grant	Dec. 2017	\$2000.0	Development of The Primer
Cotrell Scholars Program	Third year at Whittier	\$100,000	Antarctic deployments
NSF CAREER Grant	Third year at Whittier	\$100,000-\$500,000	Completing RF design lab

Table 3.5: A summary of funding for research projects already received, and (below double line) future planned grant applications. Projects above the double line help build toward successful applications below the double line. Internal Whittier College grants (Faculty Development and Send, Learn, Return) helped fund attendance to the American Association of Physics Teachers Conference for New Professors. The DigLibArts grant has helped begin The Primer project. I plan on attempting each of the two grants below the double line within the next two years. For the NSF CAREER grant, my sub-field of UHE neutrinos has had a nice track record, with three awards in the last decade.

Whittier College to teach it, and soon it will become a core component of the computer science curriculum through my new upper division course (COSC330/PHYS306). I am gradually increasing the firmware component of COSC330. Our STEM students will be better prepared for research work, or to gradaute from USC through the 3-2 program if they have encountered firmware development, as it is increasingly becoming standard undergraduate engineering curriculum. for those students considerin careers in science, those who can write firmware applications are of singular importance to collaborations like my own. I'm grateful to Dean Good for providing me start-up resources so I can begin this tradition at Whittier College.

3.6 Funding Received, and Future Plans

In Tab. 3.5, I outline the grants I have already received[11], and plan to submit. The purpose of this listing is to demonstrate my drive to build an externally funded NSF-based research program. I have the advantage of being at Whittier College, for which the NSF gives special grant-writing status to detail how our research has "broader impacts" for the surrounding community. Projects such as The Primer, and participation in the Artemis program I've carefully chosen to demonstrate to the NSF my willingness to make an impact on the community. Thus far, I have received internal grants from Whittier College. However, these contributions to my startup funding as a professor help me seed projects that ultimately benefit the college, in that I can use the progress to build towards larger proposals.

[11] The AAPT conference described in the table is listed here: `http://www.aapt.org/Conferences/newfaculty/nfw.cfm`

Equipment	Cost	Purpose
Mixed Domain Oscilloscope (200 MHz bandwidth)	$6300.00	Multi-purpose RF component analysis and testing
Xilinx Spartan-6 Embedded Kit	$830.00	Development platform for Spartan-6 FPGA
ASUS Desktop PC	$800.00	Workstation for Xilinx firmware development software
ASUS 1080p PC Monitor	$120.00	Screen for PC workstation
Logitech Mouse/Keyboard combo	$20.00	For PC workstation
LogicWorks Software	$70.00	Educational simulation software for digital circuits
Total	$8140.00	RF Lab with FPGA design and testing capability

Table 3.6: The startup grant awarded to me upon joining the Whittier community has been put to excellent use. The FPGA-based projects are made possible by the mixed-domain oscilloscope (meaning digital and analogue signals) and the Xilinx hardware and software. As mentioned above, these projects are important for creating UHE neutrino detectors build with Xilinx firmware. The MDO bandwidth is restricted to 200 MHz, but *upgradable* to 1GHz if it becomes necessary scientifically. I felt it was an economical first step, as 1GHz units can cost up to $20,000.

When I joined Whittier College, I was awarded a start-up grant of $30,000, and I am grateful for the opportunity to use these resources to expand our STEM abilities at Whittier for educational and research purposes. I am the first professor to teach firmware here, and my students have begun to learn this crucial engineering skill. We have used these resources to create a lab which has made progress for ARA/ARIANNA, and helped to place Whittier College firmly within a new field of research.

3.7 Digtal Storytelling and Physics: The Primer

The moment I learned of the DigLibArts group at Whittier, I had the following thought "I know exactly what I will do." The DigLibArts group introduced me to the Scalar project, which is a digital storytelling tool used to make digital scholarly works. There are currently no STEM Scalar projects, but game-like digital physics education projects have been researched[27]. I can produce an interactive digital physics book with Scalar. The book could then collect student learning data, which could be analyzed with machine-learning techniques. I haved connected with Whittier Scholars Program (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. The choice is in reference to a tool called "The Primer" in a novel entitled "The Diamond Age," by Neal Stephenson. A young female character named Nell becomes a world-class engineer when The Primer falls into her hands. I began collaborating with reknowned game designer and graphic artist *Eric Torres*[12], but he had to withdraw for family reasons. 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[13], which will enable us to properly classify student learning data.

[12] https://ericimagines.com.
[13] http://scikit-learn.org/stable/

Chapter 4

Service

When professors usually discuss service to Whittier College, it revolves around work done on comittees. Service on committees is the manifestation of the idea that a university should be self-governed by the faculty. Partnering with the administration, Whittier College faculty have a responsibility to shephard the institution forward into the future. I take this responsibility seriously, and although I was not assigned a commitee during my first year as an assistant professor, I have volunteered to serve Whittier College in five ways.

First, I served as a faculty advisor to a student organization. In recognition of my service, the students gave me The Outstanding Organization Advisor Award for a student organization. Second, I volunteered to serve on a Faculty Search Committee in the Department of Mathematics, which led to the selection of Dr. David Claveau. Third, I've helped to both recruit new physics majors and to serve current physics majors by attending campus recruitment events and serving the Society of Physics Students. Fourth, I continue my usual program of giving public lectures, which is meant to serve Whittier College by increasing our recognition in the surrounding Los Angeles community. Finally, I've joined the Enrollment and Student Affairs Committee (ESAC), with a focus on analyzing admissions data. Below I outline a project I've recently undertaken in service to ESAC.

4.1 Service to Student Organizations - CRU

As a convert to the Christian faith, and a member of the Catholic Church, I believe that my purpose in life is to glorify and love the Lord by obeying The Golden Rule - "Love your neighbor as yourself," from The Gospel of Matthew (7:12 and 22:36-40). Whitter College has a student organization called Campus Crusade, which is colloquially known as CRU. CRU is actually a national organization that provides Christian ministry to college students. The Whittier chapter of CRU usually has 10-20 members each year, and meets weekly to read the Bible, sing, and have fellowship by building a community. Each year, CRU also creates Bible study groups, traditionally partitioned into the Men's Bible Study and the Women's Bible Study.

I can relate to the experience of CRU members. I have kept my faith through the adventure of graduating from college, graduate school, and finally becoming a professor. In addition to the necessary examination of the Christian faith that naturally occurs in a liberal arts college, the college experience in America can at times pull young people away from theology, philosophy, and religious practice. I experienced professors who derided Christianity when I was their student in college. Rather than debating students, I simply accept their invitation to read and analyze scripture in fellowship alongside them. During the weekly Men's Bible Study last year, I joined typically 5-7 students to read the letter of St. Paul to the Romans, in the New Testament.

I can confidently say that we all grew in our spiritual knowledge after finishing Romans, and that I am especially proud of those young men from my Bible study group who graduated in Spring 2018 with the moral support of the group. Some of these students were my physics students, and their friends fellow CRU members continue to take my classes. What I find most important is to empathize with the students, and find ways to serve them in their growth as spiritual people alongside their intellectual growth.

At the end of the Spring 2018 semester, the student organizations held an award ceremony to recognize students and faculty who have gone above and beyond normal service to Whittier College and the surrounding community. The student government recognized me with The Outstanding Organization Advisor Award, for my service to CRU. It was a proud moment in my first year at Whittier College. I am the first professor to win this award in its inaugural year. I will continue to encourage my colleagues to connect with the students in new and inspiring ways, and I look forward to the award ceremony next spring.

4.2 Faculty Search for the Department of Mathematics

I was brought on to the Department of Physics and Astronomy at Whittier College to help add value to our computer science curriculum, in addition to teaching physics courses. The computer science curriculum is currently delivered to the students by a combination of physics and mathematics professors. Since the Department of Mathematics identifies me as a stakeholder in the future computer science curriculum, I was asked to serve on the committee to select a new tenure-track mathematics professor. This new professor is expected to teach not only mathematics, but robotics and other forms of computer science. I participated in many activities as part of this tenure-track search.

I attended faculty search training led by the Dean of the Faculty, Darrin Good. I attended Mathematics Department meetings, and also I attended planning meetings to draft the job listing and interview questions, I helped schedule phone calls with the applicants, and I conducted phone interviews with finalist candidates. Once final candidates were invited to campus, I interviewed them one-on-one in my office. Along with Professor Fritz Smith, I interviewed candidate David Claveau over the phone. I was happy when David was nominated for the position. I look forward to collaborating with David in the field of robotics and drones, which have come up recently in my research.

4.3 Recruitment and Service to the Physics Department

I have directly served my department in two major fashions. The first involves recruitment and mentoring. Along with Professor Seamus Lagan, I have attended recruitment events and mentoring events for physics majors admitted to Whittier College. The first such event was held in the student center in Spring 2018. Professor Lagan and I ran a booth distributing information to admitted incoming freshmen about majoring in 3-2 engineering, and physics. We seek to recruit new physics majors at events like these, and once they arrive on campus, we engage in the mentoring program. Professor Lagan asked me to help him serve as mentor to incoming freshmen taking introductory calculus-based physics. I helped Seamus run an ice-breaker session and an introduction to liberal arts education, as well as attending dinners for the new students and faculty mentors. Finally, I helped current physics majors run the annual Star Party, when we took 30 Whittier undergraduates to the desert of Joshua Tree to observe stars and galaxies.

The second form of service directly tied to physics is my volunteer work with the Artemis program. Professor Serkan Zorba pitched the idea to me, and I have volunteered for the current academic year as an Artemis program sponsor. Physics is infamous for gender disparity, and programs like Artemis seek to balance the disparity by demonstrating to high-school aged female students that careers in physics are for them as well as the male students. I will be connecting my Primer project with Artemis, as I think it nicely dovetails conceptually. It is always a good idea to expose high school students to programming, as many do not have access to programming classes yet in high school but do need that skill in college. I have already received approval of my abstract from Sam Ruiz[1], my Artemis coordinator and liason.

4.4 Public Lectures

Professor Seamus Lagan also connected me with a local high school student, Cole Aedo, who has created STEM Lecture Nights. I have already given a public lecture as part of this program at a local middle school, Los Nietos

[1]For more information, contact Sam Ruiz: sruiz3@whittier.edu

Middle School in Los Nietos, CA. I created an hour-long lecture that provided content on my field of astroparticle physics tailored to the audience of middle school STEM students and their parents. I also answered questions and promoted Whittier College as a place that will provide them with both a good education and an opportunity to do quality scientific research. Giving public lectures is something I've always done, and my C.V. gives other examples of lectures in the past.

4.5 Enrollment and Student Affairs Committee

Finally, I have joined the Enrollment and Student Affairs Committee (ESAC). I have taken minutes and attended meetings, and therein was assigned to a sub-committee examining admissions data. Given that I have a background in analytics and know how to wield machine-learning algorithms, I've embarked on an analytics project seeking to understand recent admissions data and provide insights to the Admissions office. With me on this project are Professors Chuck Hill and Fritz Smith. We are currently collecting the data, which will focus on the last five years of admissions. We seek to derive insights into student outcomes, with the final goal of predicting which students will matriculate to their sophmore year. To achieve this, I proposed to use genetic algorithms to derive a function from the data that takes as inputs data classifiers such as SAT scores, freshman year GPA, and academic quintile classification (AQ1-5). Genetic algorithms have the ability to try vast combinations of linear *and non-linear* combinations of data classifiers until the best combination is found that correctly predicts the outcome. If successful, ESAC would be able to provide the Admissions Office with a formula that will most accurately predict which Whittier admittees would matriculate to sophmore year and beyond.

Chapter 5

Advising and Mentoring

Serving the Whittier students in the role of advisor is one that I take seriously, especially in light of the fact that majoring in physics is a difficult path to choose. Often students who excel at computer programming, mathematics, and science in general do not realize how good of a fit they would be in the physics program because the tangible benefits of majoring in physics are not always obvious. The truth is that majoring in physics opens doors to many technical career paths. Thus, the first task in advising students in physics is to convince them that physics is a good option. The second facet of physics advising is to help physics students to discern the types of physics they should take at the advanced level. Physics courses fall into the *experimental* and *theoretical* groups. Although we require students to take a minimum number of courses from each category (as well as a basic training in advanced mathematics), the advanced technical courses a student will need depends largely on their future research or professional plans. The final facet of advising is to guide the student through a senior research project (officially listed as Senior Seminar in Physics, PHYS499A/B) that exposes them to the year-long research process. Below I make the case that I have participated in each phase of physics advising.

5.1 Recruitment

In Spring 2018 I participated in a weekend recruitment fair to provide newly admitted students information about majoring in physics and astronomy. I also helped Professor Seamus Lagan recruit 3-2 engineering program majors, as there is significant overlap in course load and planning between the 3-2 program and physics/mathematics. I spoke with many students and parents about the tangible benefits of choosing to major in physics, and choosing Whittier College. I emphasized that physics opens many doors, even if the student chooses not to enter academia. Professor Lagan also invited me to help him with the freshmen mentoring program during Fall 2018 orientation, in which we guided new physics students through topics like becoming accustomed to campus and course enrollment. These meetings and ice-breaking activities have been fruitful; several students have now approached me to discuss my research and how they might participate.

5.2 Advisees

I have helped to recruit at least two physics majors. Cassady Smith has switched to physics and is now in her sophomore year. It seemed that she was considering majoring in physics, and after taking my calculus-based physics course and writing an extra-credit essay on the Advanced LIGO project (the Nobel Prize for the discovery of gravity waves), she decided to double major in French and Physics. I also convinced her to take my COSC330 (Computer Logic and Digital Circuit Design). Cassady is not my formal advisee yet, but worked with me as a Keck Fellow over Summer 2018 and is still actively doing research with me. Nicholas Clarizio has completed a business major and is attempting to double major. Nicholas Clarizio is now my formal physics advisee, and I am guiding him through the second and third facets of physics advising: advanced course selection and choosnig a senior project. Currently, I am having him do research for credit for me (listed as PHYS396) in anticipation of a larger project for a senior seminar. Nicholas and I are building an RC drone together, for Antarctic operations. My hope is that as he prepares for graduation next year, this research will blossum into a year-long project that will help him to graduate as my first official physics advisee.

5.3 Mentoring

With Cassady Smith and John-Paul Gómez-Reed, my two Keck Fellows, I do a great deal of *informal advising*, that is, mentoring. I attempt to mentor them in the area of professional growth by aiding them in project design and application to research programs beyond Whittier College. This is also true to a lesser extent of a student named Nicholas Haarlammert, who took calculus-based physics from me with Cassady. I wrote letters of recommendation to several physics research experiences for undergraduates (REUs) for Cassady and Nicholas Haarlammert, including for the University of Michigan and Caltech[1]. Cassady wound up doing the Keck Fellowship here at Whittier, as physics internships are competitive and usually go to juniors and seniors with more experience. I see mentoring as an extension of advising, in that we must advise students about how to proceeed with their physics degree after college, in addition to getting them to graduation day. I have introduced both Cassady Smith and John-Paul Gómez-Reed to my research colleagues at UC Irvine, in the hopes that they might look into going to graduate school there. Both studets would make excellent PhD candidates.

[1] These letters of recommendation are included in the supplemental material.

Chapter 6

Conclusion

In my first year as an assistant professor at Whittier College, I have had many acheivements. I have taught courses in introductory physics that have prepared many students for the hard work of becoming physicists and engineers, and I have done my best to convince struggling students to believe in their ability to perform mathematical and scientific calculations. Large introductory physics courses are objectively difficult to teach, given the wide range of preparation and confidence in mathematics and problem-solving skills of our students. I take this responsibility seriously, and I enjoy the struggle, failure, and final success of the process of enlightening our students. It is my hope that the reflections in this document communicate a sincere and authentic desire to teach well, and I encourage other professors to contact me with any questions or helpful advice on that front. My contact information is listed below. I would also point out that I have created brand new physics and computer science courses at Whittier, and included never-before-taught content, like firmware development and digital signal processing.

I am proud of the research I've accomplished this year, and how I've been able to involve undergraduates in the research process. I've brought a new field of physics research to Whittier College, astroparticle physics, and I've involved a diverse set of undergraduates in my firmware and software activities. I've given colloquia representing Whittier College at other universities, and my students have won fellowships. We have exciting and promising plans going forward, on a diverse set of projects that will educate students *in all phases of science.* Finally, I have demonstrated connections to a broader scientific community that is moving ahead with plans to construct a large new scientific instrument at the South Pole, and this will represent new opportunities for Whittier undergraduates.

I have put in the effort to serve Whittier College and be a helpful advisor to undergraduates, in a number of ways. I look forward to learning more about how the school operates, and helping to nurture this institution. I have helped hire other profesors, and aided students in running an organization. I have served my department by doing the tasks the senior professors ask me to do regarding recruitment and mentoring. I've joined the ESAC committee and I've embarked on a suitable and useful research project regarding admissions data. Finally, I've taken on the role of advising physics majors, with the goal of graduating my first majors by the end of next year.

I look forward to growth as a teacher and a scholar, and I'd like to thank the Faculty Personel Committee for taking the time to evaluate this report. Please contact me with any questions. Thank you for your consideration and support.

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

7.1 Teaching

1. Student Evaluation Summaries and Individual Evaluations ... *All courses taught from Fall 2017-Spring 2018.*
2. American Association of Physics Teachers (AAPT) Workshop for New Professors program. I attended this workshop for new professors on research-based teaching methods in physics education in Fall 2017.
3. Sample midterm, Computer Logic and Digital Circuit Design
4. Sample midterm and study-guide, Algebra-based Physics I (PHYS135A)
5. Sample midterm and study-guide, Algebra-based Physics II (PHYS135B)
6. Sample midterm and study-guide, Calculus-based Physics I (PHYS150)
7. Sample midterm and study-guide, Calculus-based Physics II (PHYS180)
8. Sample syllabi ... *One syllabus included for each course taught between Fall 2017-Fall 2018*
9. Sample GitHub webpages and databases for teaching materials ... *All courses Fall 2017-Fall 2018.* I use these databases to store every lecture, PI module, and laboratory activity I've given as a professor. These databases provide a complete record of my teaching for future use and modification. Additionally, the databases can be branched into different versions suitable for classes of different skill levels and content focuses.
10. Example Final Assignment (PHYS135A) ... *Final Essay on Venus Transits by Elmer van Butselaar.* This was a final assignment in PHYS135A, practicing written and oral communication in science. The student explains how the distance between the Earth and the Sun was first measured.
11. Example Final Assignment (PHYS135B) ... *Final Pres. on Muscle Activation Voltages by Brandon Mai.* This was a final assignment in PHYS135B, practicing written and oral communication in science. The student explains human muscles are activated by voltages from the nervous system, and measurements were performed and reported on bicep muscle voltages.
12. Example Final Assignment (PHYS150) ... *Final Essay on Gravity Waves from LIGO by Nick Clarizio.* This was a final assignment in PHYS150, practicing written and oral communication in science. The student explains the significance of the experiment that won the 2017 Nobel Prize in physics.
13. Example Final Assignment (PHYS180) ... *Final Essay on Energy Conservation by Brandon Choi.* This was a final assignment in PHYS180, practicing written and oral communication in science. The student explains the origins of the law of energy conservation.
14. Example PhET Assignment (PHYS135B/PHYS180) ... *Modeling DC circuits.* This is an example of a PhET exercise incorporated into the curriculum, in which students use a computer simulation to model a real circuit, verifying their calculations.

7.2 Research

1. *Curriculum Vitae*

2. *Department of Physics and Astronomy Department guidelines on tenure and promotion*

3. Physics Colloquium slides ... *Whittier College.* This is a copy of the hour-long lecture I gave to students and faculty at Whittier College at the end of Spring 2019.

4. Physics Colloquium slides ... *California Polytechnic San Luis Obispo.* This is a copy of the hour-long lecture I gave to students and faculty at California Polytechnic University, San Luis Obispo campus. Meetings with faculty there were key in advancing the calculations and ideas in the lecture, and the Whittier Colloquium directly benefitted.

5. Colloquium Feedback from Students ... *Maya Eylon and Nick Clarizio.* Two of my students provided feedback from the Whittier colloquium, and indicated that the lecture benefitted them in several ways.

6. Samples of Recent Scholarship ... *Two scientific peer-reviewed journal articles (primary author).* The paper published in the Journal of Cosmology and Astroparticle Physics I claim as my first official publication as a Whittier professor, in satisfaction of the tenure and promotion guidelines of my department.

7. Write-up for DigLibArts on The Primer ... *Created for Prof. Andrea Rehn, DigLibArts.* Professor Andrea Rehn required me to create a short deliverable for the Primer project, to be shown to other DigLibArts faculty and students.

7.3 Service

1. Award for Outstanding Organization Advisor ... *For service to CRU.* I am the first Whittier College professor to win this award, for service to a student organization.

2. Photo of Lecture at Los Nietos Middle School ... *STEM Lecture Nights Outreach Program.* I gave a public lecture explaining the role of Whittier College in physics research to middle school students and parents. A local high-school student named Cole Aedo helped me to organize the event, and the principle Shannon Brann-Zelaya is standing to the left of me in the photo.

7.4 Advising and Mentoring

1. Sample letter of recommendation for Cassady Smith.

2. Sample letter of recommendation for Nicholas Haarlammert.

Appendix A

Further Analysis

What follows is a short numerical analysis of student evaluation data from Tab. 2.2-2.8. The *mean scores* for questions 10-15 are plotted on the x-axis of Fig. A.1 (left) for introductory courses I taught in Fall 2017, and on the x-axis of Fig. A.1 (right) for Spring 2018. The *mean* is synonymous with the average of the data. The *standard deviation* measures how much the data varies within the data set, around the mean. We can find the *fractional error* of a measured mean by dividing the standard deviation by the mean. For example, a score with a mean of 4.0 and a standard deviation of 2.0 has a fractional error of 2.0/4.0 or 50%. If a measurement has large fractional error, there is less consensus and more variation. Similarly, if the data show a low fractional error, there is consensus toward the mean.

In general, when the scores are lower in a particular category, there are larger standard deviations. When I score high, my students are in closer alignment with each other. One way of showing this numerically is Fig. A.1. For both Fall and Spring courses, the standard deviation for the scores is inversely correlated with the mean scores. The fractional error is typically $\approx 50\%$ for low scores. This is large when compared to the 10% when the scores are high. A subset of students must have been marking low scores, while the rest were marking high scores (this the only way to obtain a such standard deviations). A linear regression, or trend line, has been matched to the data in Fig. A.1, and shows that that the standard deviation is inversely correlated with mean score. This is further evidence that there is more consensus when the scores are higher, and vice versa when they are lower.

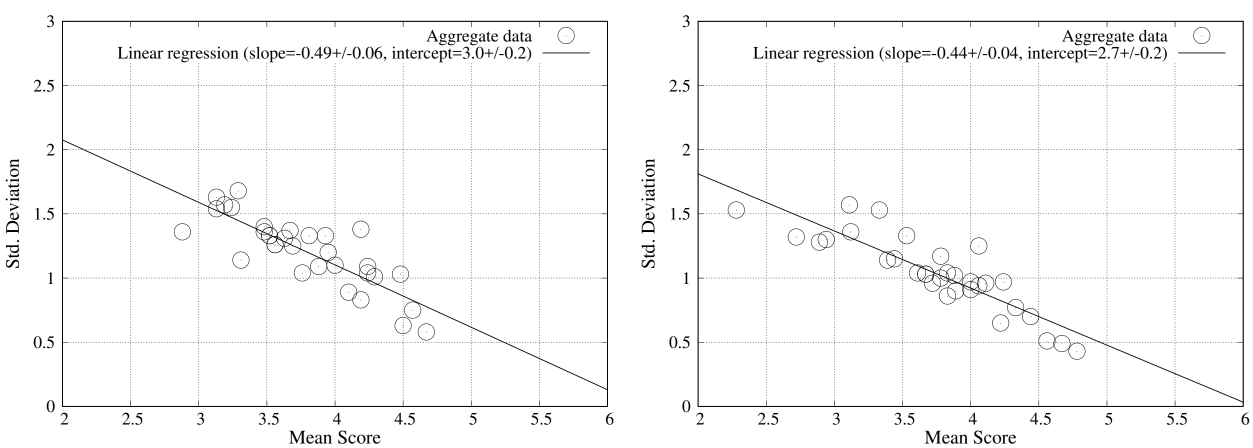

Figure A.1: (Left) Aggregate standard deviations versus mean scores for questions 10-25 for introductory courses taught in Fall 2017. (Right) Same, for introductory courses taught in Spring 2018.

My hypothesis is that the individual students causing the large standard deviations and lower means are the ones who are struggling with the material. *By locating the struggling students and providing one-on-one discussion time with them, I hope to push the data points further into the lower right corners of Fig. A.1.* This would indicate more student satisfaction, and more consensus. The students needing attention are more likely to rate the course and professor more favorably if their needs are met. I outline three concrete steps to achieve this in Sec. 2.2.1.

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