Professional Evaluation and Growth Plan

Jordan C Hanson, PhD

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0.1 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

Teaching is about growth through failure. Learning takes place between at least two people where at least one seeks knowledge. Seeking 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 nature, into *the model* of nature. 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 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*

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

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]. *Just in Time Teaching* is an auxiliary method designed to modify class time, focusing on 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. 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. 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 applications, including human nerve systems (in PHYS135B) and human metabolism (PHYS180). I use the final group projects to allow non-majors to present on the intersection of physics and their field of study. I proposed a new course entitled *Physics of the Five Senses*, designed to be connected with KNS courses. I plan to reintroduce this course in the near future when appropriate [4]. I included also a brief unit on climate change and the solar system in PHYS135B and PHYS180, based on analysis and simulations. One additional tool for the non-majors is the inclusion of student-led summaries of a scientific journal article in 5-10 minutes. The brevity requirement causes the students to focus on important details, and 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 provide the current computer science curriculum. Our students can choose majors that combine computer science with physics, math, or economics, or join the 3-2 engineering program. The upper-level computer science 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:

[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 did not have the personel for pairing or team-teaching. Subsequently, the number of new students requiring PHYS180 increased, and we had to drop my CON2 plans so I could add a section of PHYS180.

1. **Mental Discipline**. Advanced physics, math and computer science courses require discipline. and there is no substitute for grit. I think the professor has a role in calling forth this value in the students, 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 sums binary numbers). Second, the content delivery should demonstrate expertise, but also show the students that the professor is invested in them. Advanced classes in large universities sometimes leave the students with a blunt delivery that merely entices them to teach themselves. The right path leaves the student *motivated* to fill in gaps in their understanding, with the professor thoughtfully elevating students' understanding outside of class. For example, in COSC330 my students and I happily debugged digital circuits in simulation software together, 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 actions 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]

Department-Level Goals

The Department of Physics and Astronomy has eight goals, developed as part of our 5-year assessment cycle. In the coming course descriptions, these goals 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.

[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 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).

0.2 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 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 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, or on the history of a special scientific discovery. Some brilliant examples have emerged, including the history of the first measurements of the distance between the Earth and the Sun.

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

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 an important topic in physics, but some students might not see it from 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 benefited their learning, and that they felt more comfortable with the material afterwards. 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.

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. The term-papers asking students to explain the history of science for a given topic also serve this teaching focus. 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 that have now broadened society's understanding of general relativity. Group presentations on self-designed science projects at the end of the course offer a chance to practice oral communication skills. Finally, I required in PHYS180 each student to briefly summarize a scientific journal article for the class, in an attempt to further practice oral communication of science.

Descriptions of each Module Type

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

- PI-based modules contain conceptual, multiple-choice questions for the class about a physical system.
- Students respond individually with an electronic device, and the distribution of answers for choices A-D is shown on the class screen (answer E indicates the student is lost).
- One of two actions is taken next:
    1. If the fraction of correct answers to the conceptual question is larger than 0.7, the class proceeds.
    2. If the fraction is less than 0.7, the professor initiates table discussion.

[9] See supplemental material for example syllabi.

Question	First Time	Most Recent Time	Raw change	Standard deviations
10	3.76 ± 0.227	4.46 ± 0.159	0.7 ± 0.277	2.53
11	4.57 ± 0.164	4.42 ± 0.159	-0.15 ± 0.228	-0.657
12	4.29 ± 0.22	4.54 ± 0.159	0.25 ± 0.272	0.919
13	3.52 ± 0.29	4.42 ± 0.19	0.9 ± 0.347	2.6
14	3.48 ± 0.297	4.46 ± 0.169	0.98 ± 0.342	2.87
15	3.29 ± 0.367	4.25 ± 0.21	0.96 ± 0.423	2.27
16	3.19 ± 0.343	4.33 ± 0.188	1.14 ± 0.391	2.92
17	4.24 ± 0.227	4.57 ± 0.149	0.33 ± 0.271	1.22
18	3.52 ± 0.29	4.48 ± 0.174	0.96 ± 0.338	2.84
19	3.48 ± 0.306	4.38 ± 0.167	0.9 ± 0.348	2.58
20	4.24 ± 0.238	4.52 ± 0.174	0.28 ± 0.294	0.951
21	4.48 ± 0.225	4.54 ± 0.169	0.06 ± 0.281	0.213
22	4.1 ± 0.194	4.48 ± 0.202	0.38 ± 0.28	1.36
23	3.95 ± 0.262	4.64 ± 0.135	0.69 ± 0.294	2.34
24	4.67 ± 0.127	4.75 ± 0.108	0.08 ± 0.167	0.48
25	3.24 ± 0.338	4.46 ± 0.169	1.22 ± 0.378	3.22

Table 2: Comparison algebra-based numbers for the first time taught (first column) to the most recent time (second column). The raw change is given in the third column, and the change divided by the standard deviation is given in the fourth column.

- 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.

0.2.1 Analysis of Student Evaluations

Tables 4 and 5 show the results of the *algebra-based* introductory physics courses taught in the 2017-2018 academic year. Tables 6 and 7 show the results of the *calculus-based* introductory physics courses taught in the

[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	First Time	Most Recent Time	Raw change	Standard deviations
10	4.19 ± 0.207	5 ± 0	0.81 ± 0.207	3.9
11	4.19 ± 0.345	5 ± 0	0.81 ± 0.345	2.35
12	3.63 ± 0.327	5 ± 0	1.37 ± 0.327	4.18
13	4 ± 0.275	5 ± 0	1 ± 0.275	3.64
14	3.93 ± 0.333	5 ± 0	1.07 ± 0.333	3.22
15	3.56 ± 0.315	5 ± 0	1.44 ± 0.315	4.57
16	3.56 ± 0.315	5 ± 0	1.44 ± 0.315	4.57
17	3.31 ± 0.285	5 ± 0	1.69 ± 0.285	5.93
18	2.88 ± 0.34	5 ± 0	2.12 ± 0.34	6.24
19	3.13 ± 0.385	5 ± 0	1.87 ± 0.385	4.86
20	3.69 ± 0.312	5 ± 0	1.31 ± 0.312	4.19
21	3.88 ± 0.273	5 ± 0	1.12 ± 0.273	4.11
22	3.81 ± 0.333	4.75 ± 0.251	0.94 ± 0.417	2.26
23	3.67 ± 0.343	5 ± 0	1.33 ± 0.343	3.88
24	4.5 ± 0.157	5 ± 0	0.5 ± 0.157	3.17
25	3.13 ± 0.407	5 ± 0	1.87 ± 0.407	4.59

Table 3: Comparison calculus-based numbers for the first time taught (first column) to the most recent time (second column). The raw change is given in the third column, and the change divided by the standard deviation is given in the fourth column.

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 4: 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 5: 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*.

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 6: 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 7: 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*.

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 prerequisites, 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 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 **??** 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

[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.

[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.

problems specific to the electrical currents in the human nervous system[14]. For more information on KNS-relevant material in PHYS135A/B, see Sec. 0.4.

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 almost every 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.

The success of the "board problems" technique also reflected the fact that some of the issues PHYS150/PHYS180 students shared were similar to those in PHYS135A/B. Some students wrote that the pace was too fast, while others reminded me that this was the first time they had encountered mathematical concepts like vector fields. Students also wrote that class time should be used more effectively, with fewer PhET simulations and more concrete traditional lecturing with examples. Finally, some students wrote that they didn't benefit from the summarization of scientific articles (meant to practice scientific oral communication). A handful of students seemed to express the opposite opinion, that there should be more of that activity. Going forward, I have learned that inclusion of communication activities should be gauged mid-semester, and I will include them if the students are eager and if time permits.
Having reflected extensively on all of the student feedback, I 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 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

[14] In the supplemental materials I include a student's final presentation on the electrical nerve activity of a bicep under torque.

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 coming semesters, *I will include the group-board technique regularly.* One minor adjustment to this technique is that the courses are getting larger enrollments, and we may run out of whiteboard space. My plan is to sketch the problem, and then allow student groups to design specific examples meant to be exchanged with another group. This is working 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 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. 4-7, see Appendix A.

0.3 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[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 modeling.* I attempted to design a course syllabus that incorporated **all phases** of the field.

[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.

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 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 modeled 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 modeling.* 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 halfway through 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 guide-rails 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.

0.3.1 Analysis of Student Evaluations

Tables 8 and 9 show the results of my advanced computer science and physics course. For the lower scores, the fractional error is about 50%, whereas the higher scores have fractional error of about 20%, similar to the introductory courses (see Appendix). The numbers inform the analysis of my teaching of COSC330, and the students' remarks in the evaluations provide more detail.

Some students remarked that the course did not seem adequately structured or prepared. This was in large part caused by the disruption of not having the equipment I needed. Although I did order the textbooks and digital components long before the first day of class, the company shipping the parts refused to accept our department cheque, 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

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

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

Table 8: Summary of questions 10-16 on the student evaluation form, for COSC330/PHYS306, taught in Spring 2018. These questions pertain to the *course*. N refers to the number of students.

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 9: Summary of questions 17-25 on the student evaluation form, for COSC330/PHYS306, taught in Spring 2018. These questions pertain to the *professor*. N refers to the number of students.

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. Further, pre-assembly of some of the digital circuits will facilitate learning by freeing up time to probe how the circuit projects work (taking it apart and reassembling, for example).

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 assembled by me in advance. Some students also wrote that they didn't understand how the transistor radio was related to digital circuits. I included the transistor radio so the students could get a hands-on experience working with transistors, which form the basis for other all other digital components. In the next iteration of the course, partial pre-assembly should leave more time to probe how the circuit works using transistors, rather than spending more time just building the project.

Some students remarked that they felt under-prepared 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. To entice the curiosity of the WSP majors, I included some cross-disciplinary examples during the Boolean algebra phase of the course. Nevertheless, the pace will have to be relaxed if I am to continue to accomodate WSP majors in this type of course. Some 3-2 engineering and mathematics majors felt that they did not remember the physics related to sub-topics like resistors and capacitors well enough to relate those concepts to transistors. I had a tough decision regarding the course prerequisites, 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 waive the prerequisites on a case-by-case basis in order to gain more students. I promoted COSC330 in PHYS150 and PHYS180, and students who felt they could handle it approached me. It turned out to be the mathematics seniors who did not remember the physics and struggled with circuit-based topics, which is taught in PHYS180 (a course they might not have taken). In the future, I plan to review circuit analysis in more detail, before adding digital elements.

0.4 Proposed Future Courses

Here I propose future courses that will serve the broader liberal arts goals of Whittier College. I have already submitted two proposals for two CON2-style courses which linked aspects of physics and my sub-field of *astroparticle* physics with broader cultural and scientific issues. The first was entitled *Physics of the Five Senses* (see below). The second was a entitled *Safe Return Doubtful: History and Current Status of Modern Science in Antarctica*, which incorporated elements of my sub-field of research with elements of history of science and exploration, environmental science, and climate change. The latter course would be a longer-term project, whereas the former would require a simple remix of content I already teach. I have already offered 9.0 credits of COM1 in my first year, because both *calculus-based* introductory courses, PHYS150 and PHYS180, count as COM1. While this is a start, I plan to do more to help further the liberal arts goals of the College, and the courses below are one set of ideas to meet those goals.

Digital Signal Processing (COSC390) - This special topics in computer science and mathematics is meant to serve 3-2 engineering students, math/computer science majors, and physics/computer science majors, while remaining open to all students interested in interacting with digital data. The applications will include audio and image processing, and "analytics" or Big Data analysis, This course is a brand new course, to be taught for the first time this coming January term, 2019. There are several advantages to this course that add value for Whittier science and engineering students. First, this course is a natural continuation of my COSC330/PHYS306, and students taking both should be able to grasp the entire digital-data ecosystem from transistors to data processing. Second, the course will focus on managing large data sets (Big Data), which prepares students for "analytics" applications. These skills are relevant to a broad range of science courses. Finally, the coding language (octave)[19] and textbook [6] for this course will be open source, and therefore free.

The History of Science in Latin America - This is a history of science course that I believe would be widely subscribed 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. [20] I would center the course on two ideas. First is the idea that those people who make scientific progress have the most accurate data, regardless of where they are on the globe. For example, civilizations in Latin America saw different celestial objects 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 based on astronomical data, and worked within certain limitations, just as European calendars.

The second idea would be that language matters in science. I am curious what words pre-Columbian 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 documents from Spanish colonials who had the first glimpse of the scientific knowledge of the indigenous people. My hypothesis is that indigenous peoples had significant knowledge of physics and astronomy, but that it didn't translate simply into the contemporary European framework. By understanding both the original Spanish writings, and physical and astronomical effects, I would attempt to show that there was some common understanding of the natural world. This course would probably become a CON2-type course, but I would be open to pairing it as a CON1 if another professor is willing.

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

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

[20] Math professors have already suggested the decoding of the Mayan language, and the accuracy of the Mayan calendar as example topics.

measurements[21]. 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.

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

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