Professional Evaluation and Growth Plan

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0.1 Teaching Philosophy

> *That people may know wisdom and discipline, may understand intelligent sayings; May receive instruction in wise conduct, in what is right, just and fair; That resourcefulness may be imparted to the inexperienced, knowledge and discretion to the young.* - Proverbs 1:2-5

The following is a reflection on the growth and development of my teaching practices as a professor, and is submitted upon recommendation by the Faculty Personnel Committee (FPC). My first two years as an assistant professor of physics were filled with valuable experiences and memories. I have strived to make important adjustments to my classroom practices, and to follow recommendations given to me by both my department and FPC. In putting these changes in place, I have reflected on my teaching philosophy. Looking back at my first submitted teaching philosophy, I view it as a good place to begin, but something that should always evolve as I grow professionally. In the letter submitted to FPC by my department, and in the feedback letter provided to us by FPC, three general recommendations have emerged.

First, the *pace* of my content delivery should be slowed, in order maximize student success. Second, I must increase the number of *step-by-step example problems* in my physics classes, in order to give students new to the subject and those who are struggling something concrete to grasp before moving forward. Third, I need to include more *traditional lecture content* in my classes, which take the form of an integrated lecture/laboratory format. Traditional lecture content is a term used in physics education research (PER) to refer to the classical teaching style in which a new equation is first introduced or derived on the board, then solved in examples and displayed in graphical form. I have strived diligently to put these changes in place, and it has in fact yielded promising results in my classes as evidenced by my increased student evaluation numbers (see Secs. 0.2.1 and 0.3.2).

Introductory physics courses at Whittier are taught in an integrated lecture/laboratory format. I describe the lecture/laboratory format in Sec. 0.1. I have learned in my first two years that although our department uses this format by default, it does not *preclude* using traditional style. In fact, what works best (we have found) is a healthy mixture of the two. When I attend the classes of my colleagues in the physics department, this mixture is also what I observe. We must begin new concepts traditionally, and then branch into laboratory activities and research-based lecture content when the students are ready. *Researched-based content* is a term in PER that refers physics teaching modules subjected to controlled research, and that have been shown to boost student learning beyond traditional content. I described three such modules in my first PEGP: Peer-instruction (PI) [1], Just-in-Time Teaching (JITT) [2], and Physics Education Technology (PhET) [3]. I reflect in Sec. 0.1 on which modules tend to work best, which do not, and why.

Teaching physics is about growth. Regardless of the physics teaching methods chosen, the student should leave the encounter with an improved understanding of the physics concepts. Success is measured by the varying degree to which the student can retain, understand, and apply the concepts. The goal of the professor is to formulate the concepts of physics into specific equations, testable by experimentation, and to cause the students to to master the equations through problem-solving. The student usually encounters failure, then the ability to solve specific example problems. Finally, the professor leads the students to mastery by showing them that the concepts may be applied *in general* to broad classes of problems. Each stage must be accompanied by careful laboratory experiments to verify the equations.

All physics subjects begin by defining a "system," with measurable properties. We define measurable quantities such as displacement, velocity, acceleration, time duration, mass, and the electric charge of a system. What follows is the subject of *classical physics*: a description of the motions, forces and energies that govern all systems. With the addition of concepts like temperature and heat, *thermodynamics* may be added to classical physics. Students who do not major in physics usually encounter only classical physics and thermodynamics. Physics *majors* progress to *modern physics*, which adds the subjects of relativity and quantum mechanics to the toolkit[1]. Physics professors often distinguish between *physics majors* and *non-majors*, who encounter different types of material. The bulk of PER is done in the context of serving students who are non-majors, and thus the named

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

modules (PI, JITT, and PhET) are usually applied to introductory courses. Upper division courses are usually taught in traditional style.

Analogous to learning physics, learning to become a great physics instructor involves solving the basic problem of imparting simple concepts to the students and building upon their success. The instructor must be able to generalize the teaching modules to lead students to more advanced topics, building the system of classical physics in their minds. At each phase, the instructor must be able to guide laboratory experimentation, while at the same time demonstrating how the physics formulas are derived and used to solve problems. Upon examining my teaching practices, I have found the correct "solution" for our classical and introductory physics courses to be keeping the pace of the modules under control, including more concrete examples, and increasing the proportion of traditional lecture content.

I have built upon modifications made in the introductory courses in my advanced physics and computer science classes. It was rewarding to see positive reviews in my new Digital Signal Processing (COSC390) course, taught in January 2019. Almost every student in that course wrote in their evaluations that the course should be made into a full-semester length course because they liked it so much. I was especially pleased to see the course changes that followed from the FPC and department feedback pay off at the introductory course level in PHYS135A/B and PHYS180. Non-majors regularly report that they do not want to take the algebra-based physics courses (see Sec. 0.2.1), so to hear the students report that these courses increased their interest in physics was worth the all hard work I invested, and a great joy.

Instruction of Students in Introductory Courses

Physics students at Whittier College are categorized as *non-majors* or *physics majors*. Non-majors encounter physics for two semesters in either *calculus-based* or *algebra-based* courses. Classical physics at the undergraduate introductory level is built upon single-variable calculus, with some multi-variable or vector calculus introduced in the second semester. However, students who have not taken calculus can still learn using tools from algebra and trigonometry. Thus, *non-major* students usually take PHYS135A/B, and *physics majors* and related majors take PHYS150/180.

Three focuses are relevant for teaching at the introductory level, especially to non-majors:

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 instructor. I have continued this practice as Whittier professor. I have given lectures at Los Nietos Middle School and colloquia here at Whittier College, and invited speakers from UC Irvine to give colloquia as well. I am scheduled this Spring (2020) to continue with a Family Science Night at Granada Middle School. Good teaching for non-majors should *entice curiosity*, which begins by having an encounter with students where they are in their knowledge, and asking them to think more quantitatively about their physics knowledge. My introductory courses include specific activities designed to boost curiosity. I begin each semester with the students estimating how many candies could fill a jar, and then asking them to think about the problem more quantitatively. Thus, they are drawn into the mathematics after becoming more curious. Other examples including having students present science articles to the class, and give presentations on home-built experiments. Within this teaching focus, I seek to achieve three specific goals:

   - Measurably increase student interest in physics as measured by questions 15 and 18 on the evaluations
   - Teach the students to satisfy curiosity through self-designed experiments and pre-designed lab activities
   - Coach the public speaking skills of the students to empower them to present results to peers

2. **Improvement of Analysis Skill**. The scientific method relies on analytical skill. We as physicists best serve Whittier College introductory students, especially non-majors, when we develop their problem-solving abilities. We apply PER modules in introductory courses to train students in their problem solving. Students also learn by example, and therefore we provide healthy mixtures of traditional lecture content and step-by-step examples of problem solving. This involves calculations as simple as converting between units (i.e. kilograms to pounds) to plotting the trajectory of a particle in a vector field. Within this teaching focus, I seek to achive two specific goals:

- Measurably increase the ability of the students to obtain the correct answer in word problems (questions 12, 19, and 20 on the evalutations)
- Teach the students to measure with precision the correct result in laboratory settings

3. **Applications to Society**. Whittier College students gain potential in technical careers if they can qualitatively explain phenomenon using physics. In recent years, our open-source textbooks [4] [5] have included material relevant to popular majors (e.g medicine and kinesiology). I have incorporated special units centered on these applications, including human muscle motion (in PHYS135A) and nerve systems (in PHYS135B and PHYS180). I help the students design experiments which can relate to their field. One example included KNS majors in 135B who measured bicep muscle voltages for varying amounts of lifted weight. Another tool within this learning focus is the inclusion of student-led summaries of scientific articles, which encourage class discussions about the broader implications for society. Within this teaching focus, I seek to achive two measurable goals:
    - Empower the students to present and discuss articles they find relevant or interesting due to the societal impact (see Supplemental Material)
    - Manage and aid in student-designed experiments that are presented to the class, relevant to society (see Supplemental Material)

Instruction of Students in Advanced Courses

Physics majors are the second category of students we encounter, and I broaden the category to *Mathematics and Computer Science majors*, because I also teach advanced computer science courses. In my time at Whittier College, I have created two upper-division computer science courses that are part of every engineering/computer science curriculum in schools similar to Whittier College, but were not being offered here. The first was PHYS306/COSC330, Computer Logic and Digital Circuit Design, and COSC390, Digital Signal Processing. For sample curricula demonstrating the widespread adoption of these courses in schools like Whittier College, see [6] [7].

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

1. **Mental Discipline**. Advanced physics, math and computer science courses require mental discipline. The professor must foster this value in the students in two ways. First, a good start is a professional curriculum in which students are required to think *analytically* and *creatively*. Second, the professor should demonstrate *expertise* in the field, and the ability to lead students by example. For example, in COSC390 I wrote example code in MATLAB to demonstrate complex concepts, and they in turn took that code and modified it to suit their purposes for individual projects. These ideas may be summarized into two measurable goals:
    - Challenge the students with course content that requires both analytic and creative thinking (questions 11 and 20 from the evaluation)
    - Provide the students with technical expertise and guidance (questions 12 and 19 from the evaluation)
2. **Strength in all Phases of Science**. Advanced course curriculum in physics, math, and computer science must include the following *phases* of scientific activity: abstract problem solving, numerical modeling/prediction, experimental design and execution, and data analysis. I therefore have four specific goals in this area, corresponding to the four areas:
    - Measurably strengthen the abstract problem solving of the students (question 14 from evaluation)
    - Expose students to numerical modeling with computer code
    - Assist the students with the design and execution of technical projects
    - Strengthen the data analysis abilities of the students
3. **Communication**. A critical skill in technical fields is oral and written communication. Whittier College graduates in the fields of physics, mathematics, and computer science should be able to communicate technical ideas to their peers. Clear communication in engineering and scientific research contexts prevents design flaws and misconceptions. I require the students to submit a longer paper and/or presentation in each advanced course, with the goal of improvement of their communication of technical ideas. To this end, I set two concrete goals:

Semester	Course	Credits	Students	Curriculum feature
Fall 2017	PHYS135A-01	4.0	24	Intro
Fall 2017	PHYS150-01	4.0	17	COM1/Intro
Spring 2018	PHYS135B-01	4.0	18	Intro
Spring 2018	PHYS180-02	5.0	19	COM1/Intro
Spring 2018	COSC330/PHYS306	3.0	6	Advanced
Fall 2018	PHYS135A-01	4.0	24	Intro
Fall 2018	PHYS135A-02	4.0	26	Intro
Jan 2019	COSC390	3.0	8	Advanced
Spring 2019	PHYS135B-01	4.0	25	Intro
Spring 2019	PHYS180-02	4.0	9	Intro/COM1
–	Total	39.0	–	–

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. The other advanced course, COSC390, is now listed as an upper division computer science course and counts towards the Integrated Computer Science (ICS) requirements. This table does not include the two times I have taught PHYS396 (Physics Research), which does not count for teaching credit, but is 3.0 credits per student. Physics 396 also goes toward **Departmental goal 2**.

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

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.

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.

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 physics from kinematics and Newton's Laws to electromagnetism without the mathematics of calculus[2]. Algebra-based physics is a core requirement for many

[2]See supplemental material for example syllabi.

technical majors such as kinesiology (KNS) and chemistry (CHEM). Students learn problem solving in a physics context with algebra, trigonometry, and vectors. I employ a mixture of traditional and PER active learning methods to **satisfy departmental goals 1, 4, and 6**. These methods are *Peer Instruction (PI)* and *Physics Education Technology (PhET)*. I no longer use JITT modules, which I experienced to be ineffective for the students (see Sec. 0.2.1). I attended the American Association of Physics Teachers (AAPT) Workshop in 2017 to practice the implementation of these modules [3], and I have since modified them as per department and FPC recommendations. My total teaching credits and number of students for this course is listed in Tab. 1.

The first learning focus I identify for non-majors is **curiosity**, with the measureable goals stated in Sec. 0.1. To help satisfy the goal of increasing their interest in physics, I encourage an activity at the beginning of each class period in which a student presents a news or science journal article pertaining to physics that was published in the previous week. I incentivise the students to volunteer as presenters by offering extra credit, and through the activity I help them to practice oral communication of scientific ideas (**Departmental goal 7**) and help them recover points lost on midterms [4].

A second method I use to increase student curiosity is to require the students to design and complete a physics experiment. The OpenStax textbooks contain many workable suggestions that the students can construct. Each student group must first collectively agree on an idea, and submit a proposal to me in the middle of the semester. I then edit it with the group and ensure they have the equipment they need. After they have begun to collect data, I invite them to office hours to coach them on the presentation of the results [5]. By allowing the students to choose the topic and design, I provide them the opportunity to satisfy their own curiosity. Making this assignment an oral presentation also goes toward **Departmental goal 7**. With the two activities of article/journal presentations, and group-designed physics labs, I touch upon all three goals for the curiosity learning focus. The data in Sec. 0.2.1 show that the students are reporting an increase in their curiosity for physics at an increasing rate over time.

The second introductory course learning focus is **improvement of analysis skill**. PI (Peer Instruction) modules were first developed by Eric Mazur [1], and tend to yield higher learning gains than traditional lecture content. Moreover, it is often helpful to illustrate physics concepts with PheT (Physics Education Technology) simulations, or to perform laboratory activities we cannot consruct (e.g. altering the strength of gravity) [3]. These two activities form the engine by which I seek to improve the analysis skill of introductory students. In alignment physics department and FPC recommendations, I have balanced the use of these two modules with the inclusion of more traditional lecture content in recent semesters. Finally, after reflecting upon the use of JITT modules [2], I have decided to cut them in favor of more example problems. The students express a desire for more concrete, step-by-step examples. Although popular PER methods claim to yield better results than traditional content, we must be receptive to the concerns of the students.

A typical introductory physics class in the lecture/laboratory format begins with 1-2 journal/news article presentations from the students. After a short discussion, we begin with a warm-up example on the white board from the prior class. We then introduce new concepts on the projector screen, followed by several examples worked out in traditional form by me on the whiteboard. Third, I engage the students with a PI module pertaining to the topic at hand. PI modules first pose a problem *conceptually*, with A-D multiple choice answers. Our classrooms are equipped with a system that records student answers anonymously. The students take several minutes to think conceptually *without specific numbers or equations*, and answer on their own. I view the answer distribution, and if fewer than 70% of the class answers correctly, I ask them to discuss at their table how they obtained the answer. The students often learn best from each other, as they explain their reasoning in their own words. I circulate through the classroom at this stage, seeking out the struggling students and helping them. Deliberately focusing on the struggling students helps me to build a relationship of trust with them, and relaxes anxieties they have with word problems.

After 2-3 minutes, I require them to re-submit their answers *as a group* at their table. We observe the distribution of answers (choices A-E) *shift* toward the correct one at the end of PI modules[6]. Further, if the students answer correctly before the group discussion I learn that I can move on without the need for the group discussion. In this way, we only accelerate the pace when most of the students are ready. This leads to the possibility of 1-2 students

[3] See supplemental material for details.
[4] Examples of such articles presented by students are included in the supplemental materials.
[5] Included in the supplemental materials are examples of the students' final presentations.
[6] See supplemental material for example PI modules.

being left behind (if they are not in the super-majority of the A-D answers), so I have added the concept of WAT[7]. Usually WAT corresponds to answer E, and it allows a student who is lost notify me anonymously. If a WAT occurs, I work another example until it disappears. *This strategy ensures inclusivity in my introductory classes*, in that we leave no struggling student behind. For more difficult or extended examples, I have the student groups work the problem together on the whiteboards in the classroom together[8]. The advantage there is that the students can observe how other groups are solving a problem step-by-step.

The second-half of the lecture/laboratory format moves on to the laboratory activity or PheT module. An example of the difference between traditional labs and PhET modules occurs in PHYS135B and PHYS180, which cover electromagnetism. In these courses, we often build DC electric circuits. If the circuit is constructable in our lab, we perform a traditional experiment in which we measure voltages and electric current to verify a principle such as Ohm's Law. If the circuit cannot be easily built in our lab, we simulate it virtually with PhET software. Whenever possible, we first simulate the circuit in PhET, and then construct it to compare theory and experiment in full detail. The PI modules, PheT modules, and traditional lecture content complete my strategy for improving the students' analysis skill, and go towards **Departmental goals 1, 4, and 6**. *The student evaluation data in Sec. 0.2.1 show great progress in a broad range of measures in this category.*

I employ several methods to reach my third introductory course learning focus, **applications to society**. The obvious routes are the applications in the OpenStax texts [4] regarding kinesiology and medicine. I develop special PI modules and example problems around topics such as motion/work/energy in the human body, nerve cells as DC circuit simulation, and lightning/weather. Which modules I deploy depends on the semester. I have reflected on the fact that in more recent semesters I have been much better about learning what interests the students and including content specifically for the students in my class. Another reason why I have dropped the JITT module is that it frees up time before class for me to add material I know particular students will enjoy[9].

Two final methods for my third learning focus are the student-led article discussions, and term-papers. A nice example of the former occured during the past year occurred when I had an environmental science major interested in climate change in PHYS135A/B who would find climate science articles that used concepts from class to present to the group. This type of activity empowers the students to choose topics they value, and believe have an impact on our community. Occasionally I give hints at articles which are of high-impact for the *scientific community*, and this prompt is all most timid students need to take the next step of preparing one for class. For extra-credit I offer term-papers asking students to explain the physics of a recent or past historical discovery. Some brilliant examples have emerged, including the history of the first measurements of the distance between the Earth and the Sun[10]. The preparation of these papers requires the students to use concepts learned during the semester to understand scientific breakthroughs, as well as providing them a venue to practice writing about societal impact of physics (**Departmental goal 7**).

Calculus-based physics (150/180). Calculus-based physics, PHYS150/PHYS180, is a two-semester lecture/laboratory formatted sequence that covers calculus-based kinematics, mechanics, work/energy, and electromagnetism[11]. I employ a mixture of traditional and PER active learning methods to **satisfy departmental goals 1, 4, and 6**. As in the algebra-based classes, I implement *Peer Instruction (PI)* [1] and *Physics Education Technology (PhET)* [3] modules when necessary. Because PHYS150 and PHYS180 require tools from single and multi-variable (vector) calculus, students taking those courses concurrently benefit from PhET simulations to help visualize calculus 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. My total teaching credits and number of students for this course is listed in Tab. 1.

My PHYS150/180 classes are taught with the same methods and format as the algebra-based courses, with the inclusion of the full calculus-based version of introductory physics concepts. Since the subjects of calculus and Newton's Laws were developed concurrently, often by the same scientists, these two subjects are linked. During the warm-up phase of class, I will sometimes pose a calculus problem (when necessary) to familiarize the students with a technique that is required to understand the concepts we will encounter during class. Occasionally (and

[7]e.g. "What?" A meme indicating confusion.
[8]I named this trick "board problems" in my previous PEGP.
[9]See supplemental material for an example of such a unit.
[10]Included in the supplemental material.
[11]See supplemental material for example syllabi.

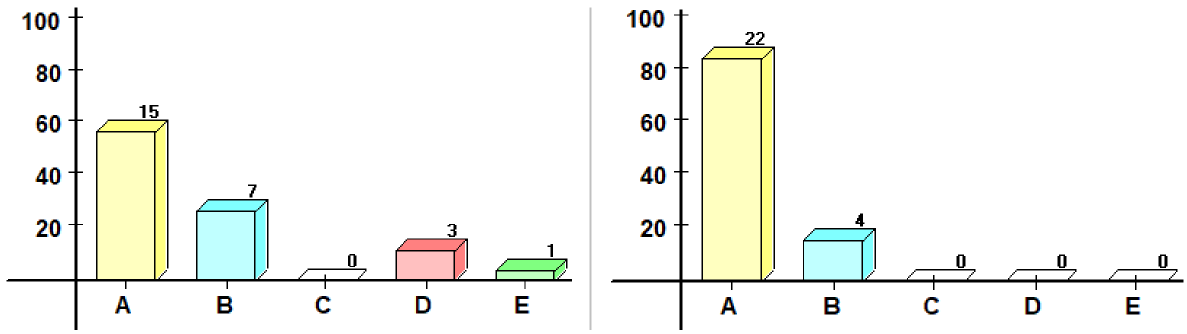

Figure 1: (Left) An answer distribution of my 25-student introductory algebra-based physics class, for a question that had a correct answer of A. This distribution triggered a table discussion, because the fraction of correct answers was 0.6. In addition, one student pressed E, indicating they were confused. This prompts the professor to give a clue, or work another example. (Right) After a table discussion with their peers, the students responded a second time, and the fraction of correct answers rose to $22/25 = 0.88$. The key concept for the question is that velocity and acceleration are not the same quantity (see text).

this is especially true in PHYS180) the physics requires calculus concepts that the students have not encountered yet in their concurrent courses. These cases usually involve vector calculus (Calculus III, or MATH241), which helps to explain electric and magnetic fields. I gauge the comfort level of the students, and typically restrict my vector calculus content via traditional whiteboard content and examples. *As a rule, we do not place calculus concepts on exams that the students have not encountered in pre-requisite or concurrent courses.*

In Sec. 0.2.1, I reflect on the student evaluation data in the same fashion as with the algebra-based courses. Similar to the conclusions for PHYS135A/B, the data in Sec. 0.2.1 show that calculus-based student date shows an increase in their curiosity for physics over time, and *great progress in measures touching upon their problem solving skills.* I received almost perfect scores for data collected from my most recent PHYS180 course. Although the reduced class size made this easier to achieve, I have reflected on the fact that the students place a high value on *building a relationship of trust with them* in order to satisfy their curiosity and increase their analysis abilities. **Include examples of final projects.**

Descriptions of each Module Type

The following descriptions provide more detail about our PER instructional modules, in list form.
PI Modules - Implementation of an active learning strategy involving group problem solving and discussion. Several good references are found in [1] [8] [9].

- PI-based modules contain conceptual, multiple-choice questions for the class about a physical system. The question corresponding to the results in Fig. 1 was

  "If the slope on a position vs. time graph is positive before a time t_0, zero at t_0, and negative after t_0, which of the following is true?

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

- Students respond *individually and anonymously* with an electronic device, and the distribution of answers for choices A-D is shown on the class screen (see Fig. 1).
- Students know to answer E if they are confused, and the anonymity is ensured so that students feel comfortable and the class is made more inclusive.
- One of two actions is taken next:

1. If the fraction of correct answers to the conceptual question is larger than 0.7, class proceeds to the next exercise or new material. This was the recommended fraction at the AAPT conference I attended in 2017.
2. If the fraction is less than 0.7, the professor initiates **table discussion**.

- **Table discussions** take place between students at the same table. During this time the professor circulates, searching for the struggling students and answering questions. After approximately 3-5 minutes, the discussion ends.
- A second poll of the class is taken after table discussions, if they take place. The *shift* in the distribution towards the correct answer indicates an improved understanding of the concepts. If the shift is not observed, the professor takes appropriate action. If more than one person selects E, the material is covered again regardless of the shift.
- The overall procedure is repeated for several exercises, and table discussions take place when necessary. After several exercises, the class proceeds to new material, or the next concept in the unit.

PhET Modules - Simulations written in HTML and JAVA, and published by The University of Colorado, Boulder, with public support from the National Science Foundation and private support from Google and the Moore and Hewlett Foundations [3]. The goals of the simulations are that anyone should be able to operate them, and that they be based on proven PER. The benefits of the simulations are researched and they are only published if the benefits to the students has been proven.

- The OpenStax textbooks for PHYS135 A/B and PHYS150/PHYS180 have built-in links to PhET simulations that allow students to illustrate concepts by visually simulating physics systems.
- Several HTML5-based examples are here:
  1. Electric charge and electric field: `https://phet.colorado.edu/en/simulation/charges-and-fields`
  2. DC circuit construction: `https://phet.colorado.edu/en/simulation/circuit-construction-kit-dc`
- PhET simulations are incorporated into active learning in the classroom in four situations:
  1. When a PhET simulation re-creates a laboratory measurement we are about to perform, it is useful to first simulate the expected results with the HTML or Java code and then perform the measurement to confirm the behavior of the system.
  2. PhET simulations are also used when a desired measurement or experiment cannot be performed or constructed in the lab, such as altering gravity or changing the amount of friction between two surfaces. Students benefit by being able to "fine-tune" a system, in order to expose the behavior of a system in real time.
  3. PhET simulations are used to *visualize* physical objects which are invisible. Obvious examples are magnetic, electric, and gravitational fields, which are real but not (always) visible.
  4. In special units, such as studying the behavior of electrical signals in the human body, there are PhET simulations from other fields (biology, chemistry, earth science, etc.) that prove useful to engage students' curiosity.

Question	135A-01 N	135A-01 result	135A-02 N	135A-02 result	135B-01 N	135B-01 result
10	24	4.58 ± 0.16	25	4.24 ± 0.17	24	4.46 ± 0.16
11	24	4.42 ± 0.17	25	4.56 ± 0.15	24	4.42 ± 0.16
12	24	4.54 ± 0.12	25	4.4 ± 0.14	24	4.54 ± 0.16
13	24	4.54 ± 0.15	25	4.4 ± 0.14	24	4.42 ± 0.19
14	24	4.38 ± 0.17	25	4.16 ± 0.2	24	4.46 ± 0.17
15	24	3.78 ± 0.26	25	3.76 ± 0.25	24	4.25 ± 0.21
16	24	3.92 ± 0.18	25	3.88 ± 0.22	24	4.33 ± 0.19

Table 2: Mean and error in the mean for questions 10-16 on the student evaluation form, for PHYS135A/B taught in Fall 2018 and Spring 2019. These questions pertain to the *course*.

Question	135A-01 N	135A-01 result	135A-02 N	135A-02 result	135B-01 N	135B-01 result
17	24	4.42 ± 0.13	25	4.46 ± 0.14	24	4.57 ± 0.15
18	24	3.83 ± 0.24	25	3.92 ± 0.26	24	4.48 ± 0.17
19	24	4.00 ± 0.21	25	3.76 ± 0.21	24	4.38 ± 0.17
20	24	4.38 ± 0.17	25	4.32 ± 0.14	24	4.52 ± 0.17
21	24	4.08 ± 0.22	25	4.36 ± 0.22	24	4.54 ± 0.17
22	24	4.09 ± 0.25	25	4.29 ± 0.22	24	4.48 ± 0.20
23	24	4.45 ± 0.14	25	4.44 ± 0.18	24	4.64 ± 0.13
24	24	4.65 ± 0.10	25	4.44 ± 0.16	24	4.75 ± 0.11
25	24	4.13 ± 0.16	25	3.96 ± 0.22	24	4.46 ± 0.17

Table 3: Mean and error in the mean for questions 17-25 on the student evaluation form, for PHYS135A/B taught in Fall 2018 and Spring 2019. These questions pertain to the *professor*.

0.2.1 Analysis of Student Evaluations, Introductory Courses

What follows is a analysis of student evaluations and reflections on my teaching in the 2018-2019 academic year for the introductory algebra-based and calculus-based courses, PHYS135A/B and PHYS150/180, respectively. The analyses pertain to modifications and improvements that I have made following recommendations from my department and FPC, as well as insights I have gained through valuable interactions with the students in my second year. The reflections focus on qualitative evidence and anecdotal experiences from class that show I am reaching the specific goals within the learning focuses defined in Sec. 0.1, and also on areas in which I hope to improve further.

0.2.2 Analysis of Algebra-Based Introductory Physics Student Evaluations

The data from the 2018-2019 academic year for the *algebra-based* courses demonstrates significant improvement in my teaching methods. Tables 2, 3 and 4 contain student evaluation data from PHYS135A/B for 2018-2019, and Tab. 4 contains my most *recent* algebra-based course and the *first* algebra-based course I taught in Fall 2017. Professor Zorba was on sabbatical in Fall 2018, so I had the pleasure of teaching both sections of PHYS135A, while Professor Lagan taught both sections of PHYS150. The mean values and errors in the mean are shown from the responses to student evaluation questions 10-25. Questions 10-16 pertain to the course (Tab. 2), and questions 17-25 pertain to the professor (Tab. 3). Almost every measurement of both the course and myself lies between 4 and 4.5, with most measurements statistically consistent with 4.5.

The data in Tab. 2 regarding Questions 15-16 merits further discussion [12]. One huge challenge we face in teaching PHYS135A/B is that students are *required* to take these courses for physical therapy and medical school, but do not *want* to take them. These students have a varying degree of mathematical ability, and responded to Question 9[13] with an average of 3.13 ± 0.24, 3.92 ± 0.22, and 3.83 ± 0.26. These responses reflect common anxiety held by many people when *forced* to do physics. I have strived to address these concerns by including modules which show the students exactly how algebra-based physics relates to *their field.*

[12] Question 15 reads "This course increased my interest in the subject matter," and Question 16 reads "Overall, I would recommend this course to others."

[13] "I had a strong desire to take this course."

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 4: 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.

Approximately 40% of PHYS135A/B students are kinesiology majors, and another 30% are biology majors. Thus, my special units focus on medical applications. The increase in response values to Questions 15-16 over time is due in part to the increasing inclusion of these modules, and allowing the students to choose science articles for group discussions. **Figure 2 contains Question 15-16 mean values over time, and the data show an unmistakable and significant improvement.** Further, the data in Tab. 4 show that *every student evaluation measurement has increased*, with the exception of the question pertaining to course difficulty, Question 11[14]. This was by design and in alignment with **three main department and FPC recommendations.**

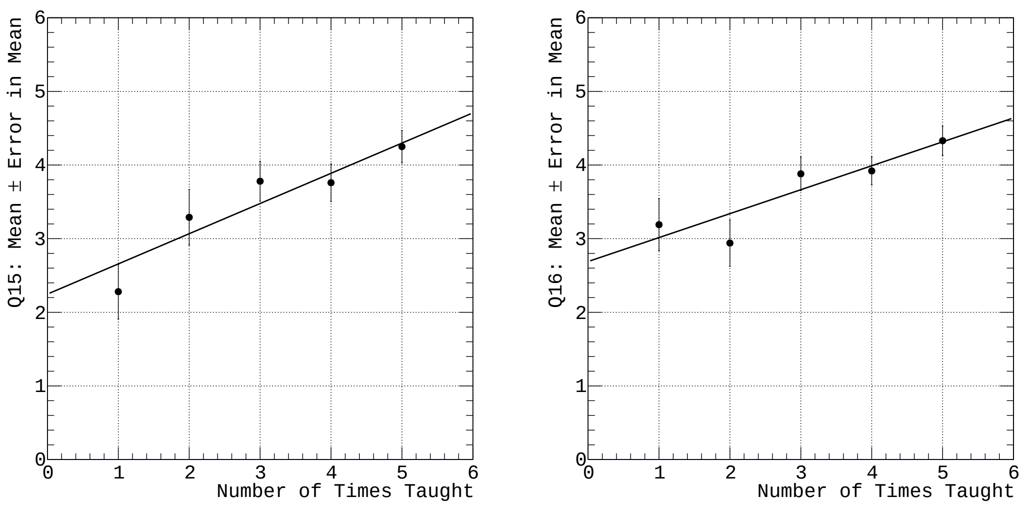

Figure 2: (Left) Student responses to Question 15 in algebra-based physics versus number of times taught. (Right) Student responses to Question 16 in algebra-based physics versus number of times taught. The y-axis of the data points are the mean values, and the errors are the standard error in the mean. The x-axis of the data points correspond to each time I've taught these courses. The solid black lines are best-fit linear trend lines that minimize the χ^2 value.

[14] "This course was academically challenging."

First, the pace of my algebra-based courses had to be slowed. Second, I needed to include more step-by-step example problems. Third, I needed to include more traditional lecture content. Although one outcome is that the students reported a decrease in course difficulty (Question 11 in Tab. 4), the most recent mean value was still 4.46 ± 0.159. When I began to put these three changes in place, some students expressed such a general sense of relief that they told me in person. One student joked that "You could be an online professor for Chegg.com!" He was complimenting my style by referencing a website in which instructors specialize in demonstrating solutions to common physics problems in step-by-step traditional style (similar to Khan Academy).

Struggling students copy the examples verbatim and compare new problems to these examples for reference, so beginning class with slowly worked examples appears to be the best way to establish a reference point on which students may fall back if they don't understand something. I've learned that more structure is especially helpful when trying to create more **inclusive classrooms** [10]. Figure 2 demonstrates measurable improvement in the satisfaction of my first introductory course learning focus by *measurably increasing the interest of the students in physics* (Fig. 2). The simple classroom structure of 1) traditional content introducing concept 2) slow step-by-step example 3) PI module 4) laboratory activity/PhET seems to keep the highest number of students engaged, and therefore interested in the material. Examples of student-designed experiments and presentations are included in the Supplemental Material, which also serve the first learning goal of curiosity through performing their own experiments.

Agenda

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

Memory

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

Homework

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

Homework1
(ExpertTA) - Sept. 16

Figure 3: (Left) The class agenda presented on the white board is always concise and based on student progress. It is presented to the students before each class period. (Middle) The memory bank is a list of equations on the whiteboard used during class, and is a practice that I began using in 2017. (Right) The homework box on the whiteboard now includes specific reading assignments, in addition to placing them on the syllabus. This practice follows the suggestion of a student from a 2018 section of algebra-based physics (135A).

Another strategy that improved introductory physics class structure was to follow advice from Chapter 4 of Eric Mazur's work on PI modules [11]. In my notebook the morning before class, I write the agenda for the class. I ensure that the agenda has no more than four to five items on it, and I present it to the students before instruction begins. This benefits the students in two ways. First, basing the agenda on the students' actual progress helps me to find the correct course pace. Secondly, keeping the agenda simple and taking several minutes to explain it to the class communicates further structure to the students, and primes them for what is coming in the next 90 to 120 minutes. Second, I provide a list of equations I'll use in the lecture in the *memory bank*. Third, I remind the students of the current homework and specific chapter sections of reading I expect them to do in the next few days. In 2018 an algebra-based physics student suggested I break the reading into smaller sections, rather than whole chapters. This apparently feels less intimidating to the students, who now focus on 10-15 pages of reading, rather than 30-40. An example of these items placed on the white board to increase perceived class structure are shown in Fig. 3.

Two additional comments are relevant regarding the pace of the introductory courses. First, the number of textbook chapters covered in PHYS135A/B was not reduced. By attending the classes taught by Professor Zorba and Professor Lagan, I obtained a better sense of *how much* content within each chapter is covered. Drs. Zorba and Lagan have been very helpful in demonstrating how a slow and methodical lecture on a single physics topic is better retained and appreciated by the students than a faster lecture on several topics. Professor Piner has also attended lectures in my recent classes and offered useful and positive feedback. Second, we removed the topic of physical oscillations from PHYS150, and thermodynamics and optics from PHYS180. In the past, PHYS180 was a

5.0 credit course because of the sheer volume of content. In the 2018-2019 we as a department decided to create a calculus-based physics III called PHYS185 which now contains the thermodynamics, oscillations, and optics topics. The advantage is that the pace of PHYS180 is naturally reduced by four chapters, from 15 to 11. By taking these two major actions, my department and I are working together to accommodate the needs of our students.

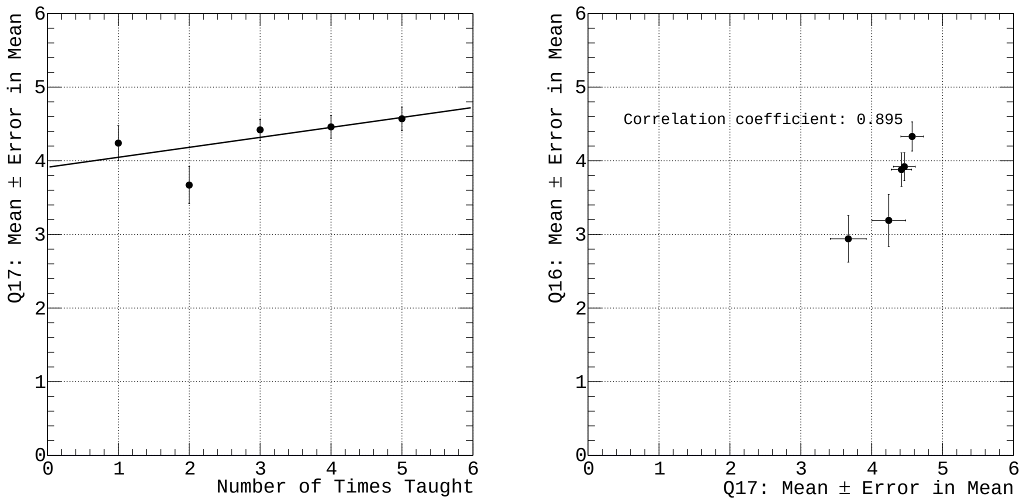

Figure 4: (Left) Student responses (mean values and errors in the mean) to Question 17 in algebra-based physics versus number of times taught. (Right) Student responses to Question 16 in algebra-based physics versus responses to Question 17. The x and y-axis values of the data points are the mean values, and the errors are the errors in the mean.

My department also recommended that I focus on Question 17 mean values[15]. Data regarding Question 17 is shown in Fig. 4. My department suggested that this measurement is correlated with other key measurements like Question 16. Figure 4 (right) contains data suggesting this correlation is strong. The Pearson correlation coefficient is 0.895. In my experience, the JITT modules did not work well, and probably contributed to lower Question 17 mean values in Spring 2018 (x-value of 2 in Fig. 4, left). These modules involve the students responding to questions assigned 1 day before class and analyzing their answers in class. I would attempt to modify class content based on their answers in order to help the struggling students. However, it was common for struggling students to not respond rather than risk sending me wrong answers. This is despite the fact that I assured them they received points for completion, not accuracy. Thus, It was difficult therefore to modify the upcoming content. I have subsequently replaced JITT modules with traditional content and step-by-step examples.

The second of my three learning focuses for introductory physics courses is to improve the analysis skill of the students. My strategy of combined traditional and PER based content appears to be working as I improve it over time. Figure 5 contains student response data to Question 14[16]. The data point well-below the trend line corresponds to the PHYS135B section in which I introduced JITT modules. Since then I have removed that type of module and implemented the three main changes (control of the pace, step-by-step examples, and more traditional content). **The student response data shows that their understanding of the material is improving substantially.** The linear trend suggests that with each subsequent round of teaching algebra-based physics, the modified approach we are taking in these courses will continue to yield good results for our students in this area.

The third of my learning focuses is *applications to society*, with measurable goals of requiring the students to present articles they find relevant due to societal impact and to manage and aid in student-designed experiments presented in class. I have included examples of my students' wonderful work in this area in the Supplemental Material, including both articles and student-designed experiments. For the experiments and presentations of the

[15] "The professor used class time effectively and demonstrated preparation for class".
[16] "This course improved my understanding of the material."

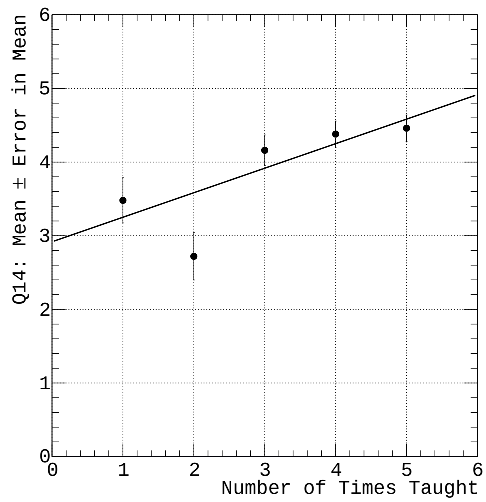

Figure 5: Student responses (mean values and errors in the mean) to Question 14 in algebra-based physics versus number of times taught. The solid black lines are best-fit linear trend lines that minimize the χ^2 value.

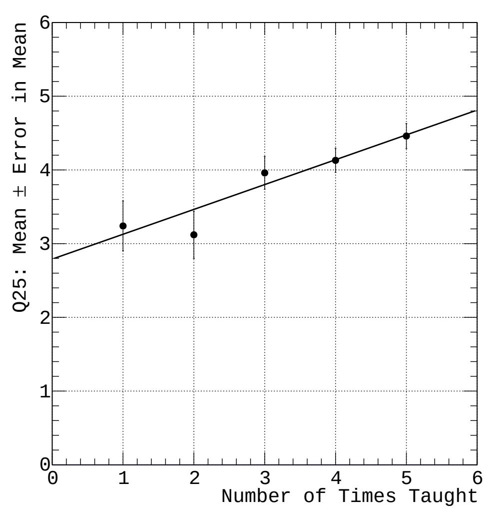

Figure 6: Student responses (mean values and errors in the mean) to Question 25 in algebra-based physics versus number of times taught. The solid black lines are best-fit linear trend lines that minimize the χ^2 value.

results, groups have correctly predicted maximum model rocket flight times, measured the speed of sound with musical intruments, and build DC circuits from citrus fruits. The articles the students chose were often thought-provoking, and related to their field of interest, including medicine and environmental science. My questions during their discussions would usually steer them back to the physics involved, and the class would therefore learn about the utility of physics in situations beyond the classroom. I have included example articles we covered in the Supplemental Materials. Perhaps my favorite was an inspiring case study in which a University of Texas undergraduate used machine learning to help find extra-solar planets.
Finally, I am thrilled to report an increase in student responses to Question 25[17]. **Figure 6 contains Question 25 mean values over time, and the data show an unmistakable and significant improvement.** It turns out there has been similar improvement in the calculus-based versions of the introductory physics courses I teach. By thoughtfully implementing the changes recommended to me by my department and FPC, I see in the data that the students are endorsing me as their professor at increasing mean values over time. I have found upon reflecting on algebra-based physics methods, that the final piece of the puzzle was to *build relationships* with the students. What follows are anecdotal stories from class that illustrate what I was able to accomplish by building relationships with students who needed help with a difficult subject.

0.2.3 Anecdotes from Class, Relationships with Introductory Physics Students

My first story involves a senior Kinesiology major named LaJana Morris. LaJana found the courage to approach me during the test, and ask a question about a problem. The exercise required the students to write an equation based on the words, and solve for the missing variable x. It appeared that LaJana was close to forming the correct equation, and I asked her to think conceptually about which equation from her equation sheet she should be trying to deploy. Eventually she chose the correct one, based on the context. I assumed she'd be able to finish, given that the problem was now reduced to solving for x. I will never forget her next words: "How do I move x to get it by itself, without plugging in numbers?" I was shocked and disappointed as I began to realize LaJana was *unfamiliar with the concept of algebra.* Of course I did not blame the student, but the question in my mind was: "Who allowed this to happen?" Knowing that this was a college senior who had never been shown algebra, I knuckled down and resolved to get the job done. I made it my personal mission to ensure that LaJana passed my class, and she did. Her midterm grades improved, and by the end of the course we were both pleased.

My second story involves a senior WSP major named Jasmine Cao who was my student in PHYS135A/B. Jasmine is an example of an excellent student who intends to apply to medical school. Three main changes I put in place for the algebra-based physics were to slow and control the pace, include more examples, and include more traditional lecture content. As part of the pace control I would include more group discussion time in PI modules, and I would focus my attention on tables of students I knew were struggling. Jasmine and her friends formed a table that almost never struggled. I worried that my new tactics would leave students like these feeling ignored. However, by the end of the course, Jasmine told me they had a wonderful experience! Apparently I was able to balance my focus enough such that no one student felt left out. Jasmine's Thank You note is included in the Supplemental Material.

My third story involves a senior Biology major named Daniel Diaz. I identified Daniel as someone struggling with the material during my PI discussion rounds during PHYS135A and PHYS135B (2018-2019). During our PI discussion rounds, I got the sense that Daniel was close to get the right answers but was just short of making the vital connections necessary for word-problem solving. I made a concerted effort to spend more time at his table, and worked quick examples for their table during discussion time. Not only did it benefit him but it benefit the three other students because I later observed him teaching them! After the final exam he wrote me this note:

Thank you for a fun year! Physics is hard, but I definitely learned more than I thought I would. - Daniel Diaz

0.2.4 Analysis of Calculus-Based Introductory Physics Student Evaluations

As with the algebra-based courses, the data from the 2018-2019 academic year for the *calculus-based* courses demonstrates significant improvement in my teaching methods. Table 5 contains student evaluation data from

[17] "Overall, I would recommend this professor to others."

Question	180-02 N	180-02 result
10	8	5.00 ± 0.00
11	8	5.00 ± 0.00
12	8	5.00 ± 0.00
13	8	5.00 ± 0.00
14	8	5.00 ± 0.00
15	8	5.00 ± 0.00
16	8	5.00 ± 0.00

Question	180-02 N	180-02 result
17	8	5.00 ± 0.00
18	8	5.00 ± 0.00
19	8	5.00 ± 0.00
20	8	5.00 ± 0.00
21	8	5.00 ± 0.00
22	8	4.75 ± 0.25
23	8	5.00 ± 0.00
24	8	5.00 ± 0.00
25	8	5.00 ± 0.00

Table 5: (Left) Mean and error in the mean for questions 10-16 on the student evaluation form, for PHYS180-02, taught in Spring 2019. These questions pertain to the *course*. (Right) Mean and error in the mean for questions 17-25 on the student evaluation form, for PHYS180-02, taught in Spring 2019. These questions pertain to the *professor*.

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 6: 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.

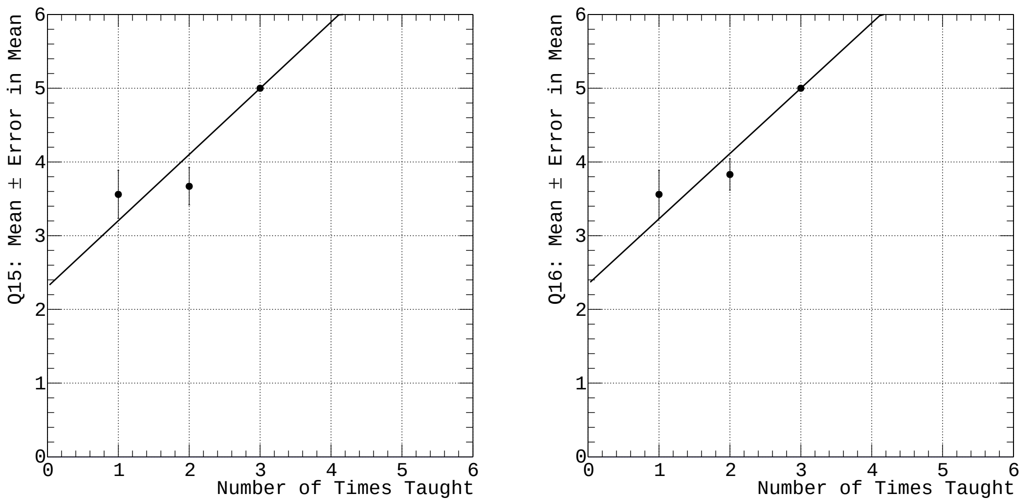

Figure 7: (Left) Student responses to Question 15 in calculus-based physics versus number of times taught. (Right) Student responses to Question 16 in calculus-based physics versus number of times taught. The y-axis of the data points are the mean values, and the errors are the standard error in the mean. The x-axis of the data points correspond to each time I've taught these courses. The solid black lines are best-fit linear trend lines that minimize the χ^2 value.

PHYS180 for 2019. In Tab. 6 the student evaluation data from the *first* time I taught calculus-based physics is compared to the most *recent* time. The mean values and errors in the mean are shown from the responses to student evaluation questions 10-25 for both tables. Questions 10-16 pertain to the course (Tab. 5, left), and questions 17-25 pertain to the professor (Tab. 3, right). The data reflect high quality teaching and a substantial improvement compared to the first time I taught calculus-based physics.

The PHYS180 section from which the data in Tab. 5 is derived shows almost perfect scores. This is partly a credit to the changes I've put in place, and the reflecting I have done this past year. However, it is also due to two other factors. First, the aforementioned rearrangement of the thermodynamics curriculum made our lives easier in PHYS180. Second, I had the chance to get acquainted with these students as advisees in the prior Fall 2018 semester before teaching them in Spring 2019. Thus, reducing the pace of content and building relationships before class also made the course go much more smoothly.

The students in the PHYS180 course from 2019 were a combination of physics majors, 3-2 engineering program majors, and computer science. I knew this particular set of students from Fall 2018, when I shadowed Dr. Lagan as he mentored them during Freshman Orientation. By forming a relationship with them early on, I think they trusted that the class activities and methods I chose for them were for the best. I performed my three usual changes to the course style (slower pace, more examples, and traditional content). I followed with PI modules and laboratory activities/PhET activities. They dived in to the PI modules with fervor, and we had many interesting discussions.

Something that made the PI module process different than algebra-based physics was that there were only two students per table. Thus, each time I addressed a table when they hadn't gotten the answer yet, I was speaking with half the usual number of students compared to algebra-based physics. This seemed to reduce complications and make my life easier. When speaking with the usual four students in algebra-based physics, I sometimes notice that I can turn the light on in three students and one will stay quiet. Although I try to reach everyone, it is sometimes awkward when I have other tables to approach and a limited time. The smaller class-size of PHYS180 (2019) didn't have this problem and I was able to target struggling students with speed and accuracy. There were originally nine students in my section of PHYS180, but one dropped the course because he was struggling to balance varsity sports and studying. I welcomed him to office hours to discuss his priorities, but ultimately he had to rearrange his schedule and postpone PHYS180.

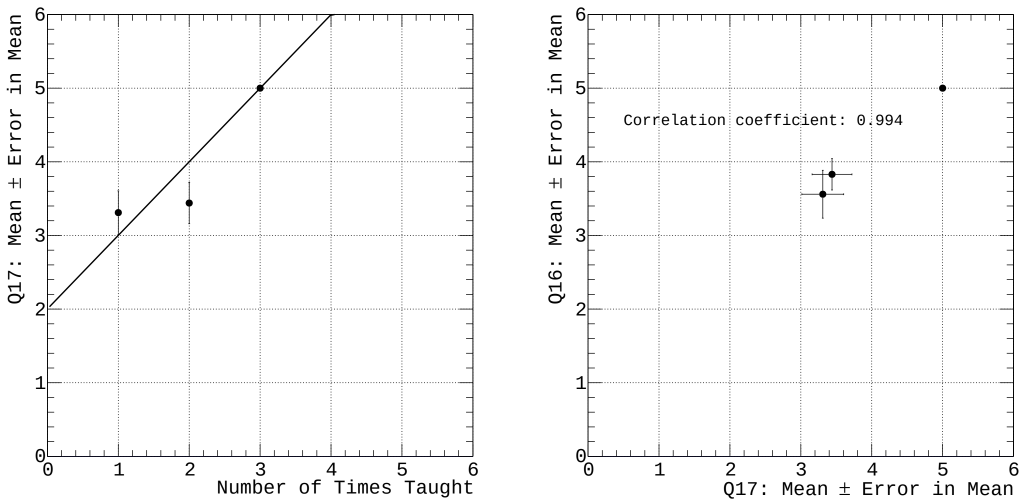

Figure 8: (Left) Student responses (mean values and errors in the mean) to Question 17 in calculus-based physics versus number of times taught. (Right) Student responses to Question 16 in calculus-based physics versus responses to Question 17. The x and y-axis values of the data points are the mean values, and the errors are the errors in the mean.

Figure 7 shows the evolution of student responses to Questions 15-16 over time[18]. The data show that I am perfecting my ability to boost student curiosity over time, in satisfaction of my first learning focus for introductory courses. The final data point drives the trend line since it has no error. Needless to say I look forward to teaching PHYS150 this Fall 2019 with my new advisees. This upcoming semester will be the first time I've been a freshman mentor and adviser to my own students.
Similar to algebra-based physics, my department asked me to think about Question 17 mean values[19] in the context of calculus-based physics. Data regarding Question 17 is shown in Fig. 8. My department suggested that this measurement is correlated with other key measurements like Question 16. Figure 8 (right) contains data suggesting this correlation is strong. The Pearson correlation coefficient is 0.994. As with algebra-based physics, the JITT modules have been dropped from my calculus-based course style. What I predict for Fall 2019 is that the data points Questions 16-17 will be between 4 and 5, and that the numbers will remain correlated. The PHYS150 section upcoming in Fall 2019 will have my advisees in it, but also it is filled to capacity (25). To further boost responses to Questions 16 and 17, I will introduce pre-lecture material in the form of reading quizzes to ensure the students begin the class on the same page. This is a technique I have observed in Dr. Lagan's PHYS180 course.

The second of my three learning focuses for introductory physics courses is to improve the analysis skill of the students. My strategy of combined traditional and PER based content appears to be working as I improve it over time. Figure 9 contains student response data to Question 14[20]. **The student response data shows that their understanding of the material is improving substantially.** This was in part due to the aforementioned smaller class size, but also due to the changes I put in place. During my first two rounds of calculus based physics, the students report an improvement of their understanding of the material consistent with 4.0. In my most recent calculus-based version, this increased to a 5.0.

The third of my introductory learning focuses is *applications to society*, and we served this goal in calculus-based physics in similar ways to algebra-based physics. The main difference between algebra-based and calculus-based was the sophistication of the student-designed experiments. Students designed electromagnetic lifting devices (similar to cranes that lift metal objects), and presented elloquently and in quantitative detail (see Supplemental Materials). Students also chose articles for daily class presentation that they felt had interesting applications to business and engineering. One student even included an example on how metallurgy is done after learning how to forge metal tools for a project outside of PHYS180.

[18] Question 15: "This course increased my interest in the subject matter," Question 16: "Overall, I would recommend this course to others."
[19] "The professor used class time effectively and demonstrated preparation for class".
[20] "This course improved my understanding of the material."

Figure 10 (left) contains student response data to Question 25, from calculus-based physics versus time[21]. **The data show an unmistakable and significant improvement.** The trend line is driven by the final data point, and as with the other measurements, will likely fall somewhere between 4-5 for Fall 2019 PHYS150 if I continue to refine my approach to the three learning focuses for introductory physics. To make this point more clearly, I have graphed the mean value responses to *all* questions on the student evaluation form versus semesters taught at Whittier College.

Initially, as I was learning how to serve the diverse student population at Whittier College, the results were mixed. As time progressed, however, a general trend upwards is observed in all student response data. There are several courses where the students gave me straight 5.0 scores. PHYS180 (2019) was one of them, and the other two are two instances of PHYS396 (physics research for credit). PHYS396 is a course for which we don't receive teaching credit, but is reserved for students who want to do a research project with a physics professor. The January term of 2019 I denote as the fourth semester, in which I taught COSC390, which was a huge success (see Sec. 0.3.2). Overall, the data show that the students recognize that I care about their learning, and that as I evolve as a professor the methods and modules I execute benefit the students in their minds.

[21] "Overall, I would recommend this professor to others."

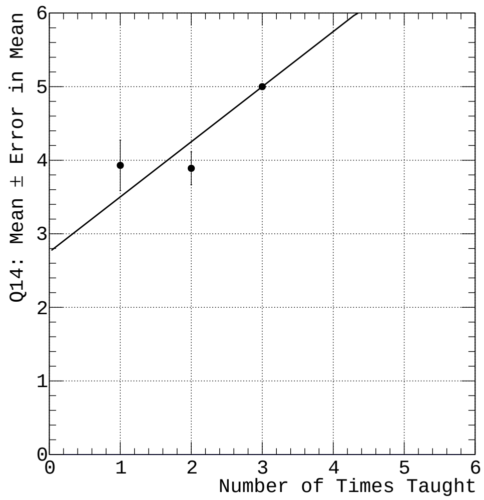

Figure 9: Student responses (mean values and errors in the mean) to Question 14 in calculus-based physics versus number of times taught. The solid black lines are best-fit linear trend lines that minimize the χ^2 value.

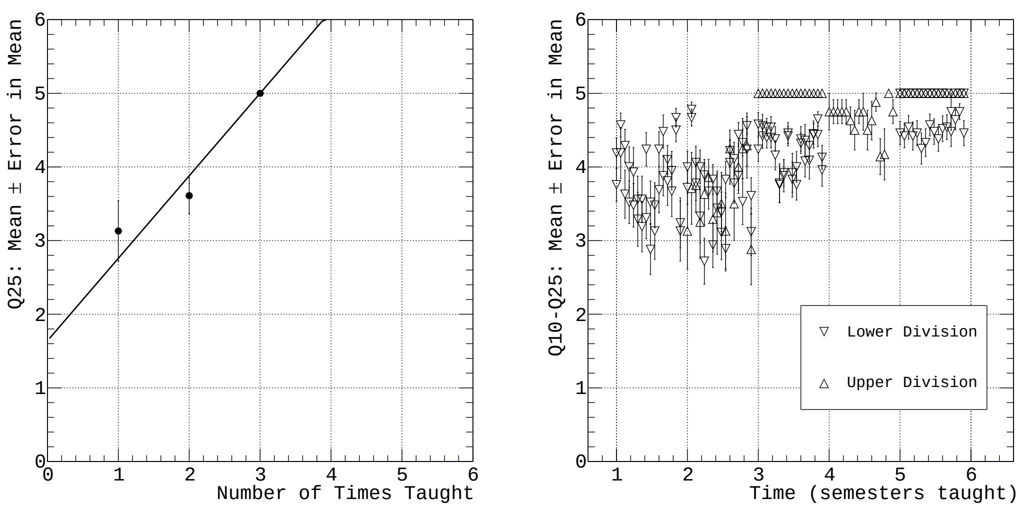

Figure 10: (Left) Student responses (mean values and errors in the mean) to Question 25 in calculus-based physics versus number of times taught. The solid black lines are best-fit linear trend lines that minimize the χ^2 value. (Right) Student responses (mean values and errors in the mean) to Questions 10-25 in all courses versus semesters taught at Whittier.

0.3 Advanced Course Descriptions

Computer Logic and Digital Circuit Design. Computer Logic and Digital Circuit Design is cross-listed as PHYS306/COSC330. I have to be prudent about content selection in covering such a broad topic in an undergraduate setting. 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**. 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, non-decimal base systems, and boolean logic
2. Basic digital components, clocks and gates
3. Implementation of boolean algebra with digital components
4. Complex digital components

Coverage of the above list with challenging and thought-provoking course content is how I reach my first advanced course learning focus, of *mental discipline.* Additionally, any good digital design course at a liberal arts setting must evenly cover the following phases of the field: *mathematics, computer programming and modeling, hardware design and testing, and digital data analysis.* In other words, in implementing this course I must reach my second learning focus of *strength in all phases of science.* The Supplemental Materials contain an example syllabus for this course. The final learning focus is *communication*, and we reached this learning goal through final group-projects coupled with a presentation at the end of the course. In a similar fashion to the introductory courses, my student groups were required to submit a project proposal to me before beginning work, and were given the chance to polish their presentations with me in office hours in advance of the class presentation.

We began by diving into number systems and boolean logic, and the students seemed to engage with the material. I required them to solve problems in pairs, in a lecture/laboratory format similar to calculus-based physics (compare to PHYS180 in 2019). I assigned homeworks that had both quick math problems, and extended thought-provoking design questions. This style was meant to reach my first learning focus of *mental discipline*, and the first goal of my second learning focus[22] strengthen the theoretical problem solving of the students. Group projects focused on computational modeling of digital circuits with LogicWorks software, in order to reach the second goal of my second advanced course learning focus: to expose the students to numerical modeling with computer code. I had planned on the construction of digital circuit experiments in the lab that would meet the third goal of the second learning focus for advanced courses. Unfortunately, we although I ordered the digital components for these experiments over a month in advance, the purchase orders were not followed by the vendor and we did not received the parts until halfway through the course.

This issue disrupted my curriculum and we had to focus on the first two goals of the second learning focus, theoretical problem solving and numerical modeling. Once the parts arrived, we began to push forward with the final two learning goals: design and execution of technical experiments, and data analysis. We completed our transistor radios while waiting for the digital parts to arrive, but the students felt that the radio project took too long and that the hardware portion of the course was too tedious. To remedy this, we will be ordering more digital components this coming Fall 2019 semester to prepare for the second iteration of the course (Spring 2020), and I have worked with our department staff to streamline the procurement processes[23]. A second improvement to better reach these goals in the second learning focus would be to incorporate more traditional content, with examples. This is a change I made to my advanced course approach with COSC390, Digital Signal Processing that yielded excellent results (see below).

The final learning focus for my advanced courses is *communication*, with specific goals being that the students must submit one major written or oral assignment, and that I must provide them with the opportunity to refine and clarify their work before presentation. In the advanced course setting, the latter goal takes on more significance than it does for introductory courses. I helped students debug faulty code, refine presentation design,

[22] "Strength in all phases of science."

[23] Some large electronics vendors do much beter with credit-card orders rather than traditional purchase orders. Our department now has a department credit card and we can use it to acquire class components more efficiently.

and troubleshoot broken digital circuits, all during office hours or outside of class. I felt this was important so the students could achieve success in the final results. I further refined this process in Digital Signal Processing by requiring the students to submit their proposals much earlier in the semester. This in part was due to the course being in January term, and partly because I've reflected on the fact that early project proposals are better. Although the students have been exposed to less course content earlier in the semester, they have more time to refine their idea with me before beginning the project. This strategy yielded some sharp and interesting final presentations in COSC390 (see Supplemental Materials).

Digital Signal Processing. Digital Signal Processing is listed as COSC390, and I taught it for the first time in the January term of 2019. Similar to PHYS306/COSC330, Digital Signal Processing requires prudent selection of course material in a subject that can be very broad. COSC390 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. I also keep in mind **Physics Department goals 4-7** when implementing this course, even though it is technically not a physics course.

My first goal for the students was to reach my advanced learning focus of *mental discipline* by requiring analytic and creative thinking in class and in the problem sets. Because this was a January term course, we met for three hours each morning for three weeks. Homework sets were assigned each day, and kept *short*, but challenging. This is the first time I tried such a style, and was more or less forced to do it due to the format of the schedule. The students really liked it, and performed well on the assignments. The style ensured that the problems I assigned came straight from the lecture of that day (or occasionally one day prior). The course content touched upon the following key areas:

1. Statistics and probability, complex numbers, and noise in digital systems
2. Linear time-invariant (LTI) systems and filtering
3. Various DSP applications
    - Audio systems
    - Digital images
    - Digital circuits
    - Fourier and Laplace techniques

The second learning focus for advanced courses is *strength in all phases of science.* COSC390 follows COSC330 conceptually, and therefore contains less hardware construction and testing, and more data analysis. One can think of Computer Logic and Digital Circuit Design as learning the logical building blocks of digital components, and some of those components lead to the ability of a computer system or scientific instrument to *sample and digitize* analog data. Digital Signal Processing (DSP) is the subject of what follows *after* the sampling and digitization. The idea that COSC390 continued from COSC330 gave me the opportunity to focus more on the data analysis and software programming phases, and to broaden the analysis to sub-topics like financial data analysis. Indeed, one of the student-designed projects in COSC390 was an analysis of Federal Reserve interest rate data over many decades using DSP techniques. Other presentations included image processing within the context of criminal justice (smoothing images to identify a face), and audio processing of a student's guitar songs.

The overall trajectory of COSC390 is to become the completion of COSC330. That is, after taking COSC330, students could proceed to COSC390 and thus have a "coast-to-coast" or A-to-Z understanding of the collection, transfer, and analysis of digital data. The pedagogy and style of both courses was done similarly, however, with COSC390 I had the benefit of FPC and physics department feedback. The three main themes of this feedback were pace control, step-by-step examples, and traditional lecture content. The results were encouraging, and I reflect on them in Sec. 0.3.2. In Sec. 0.3.2 I compare the results from COSC330 to those of COSC390, and demonstrate the improvement. This is a fair comparison for two related reasons. First, the type of material taught in COSC330 and COSC390 is similar in that it pertains to mid-level computer science and physics content. Second, the types of students that subscribe to these classes are similar. The academic majors of students in both courses follow a similar profile: physics, math, and integrated computer science are common, and 3-2 engineering, business, and economics are present but less common. Since DSP is a topic that applies to digital media and audio processing, it is my hope to attract music and design students in the future by actively recruiting them.

Question	COSC390 N	COSC390 result
10	8	4.75 ± 0.71
11	8	4.75 ± 0.46
12	8	4.75 ± 0.46
13	8	4.75 ± 0.46
14	8	4.75 ± 0.46
15	8	4.63 ± 0.52
16	8	4.50 ± 0.76

Question	COSC390 N	COSC390 result
17	8	4.75 ± 0.46
18	8	4.75 ± 0.71
19	8	4.50 ± 0.76
20	8	4.63 ± 0.74
21	8	4.88 ± 0.35
22	8	4.14 ± 0.69
23	8	4.17 ± 0.98
24	8	5.00 ± 0.00
25	8	4.75 ± 0.46

Table 7: (Left) Mean and standard deviation for questions 10-16 on the student evaluation form, for COSC390, taught in January 2019. These questions pertain to the *course*. (Right) Mean and standard deviation for questions 17-25 on the student evaluation form, for COSC390, taught in January 2019. These questions pertain to the *professor*.

0.3.1 Analysis of Student Evaluations, Advanced Courses

What follows is a analysis of student evaluations and reflections on my teaching in the 2018-2019 academic year for the advanced courses. Similar to the introductory course patterns, the analyses reflect the modifications and improvements made following recommendations from my department and FPC. I also strived to improve COSC390 based on my experience in COSC330 by focusing on building productive relationships with the students. The reflections focus on qualitative experiences from class that show I am reaching the specific goals within the learning focuses defined in Sec. 0.1, and also on areas in which I hope to improve further.

0.3.2 Analysis of Student Evaluations for Advanced Courses

Table 7 contains the student evaluation responses to Questions 10-16 (left) and Questions 17-25 (right). **The data shows that the students were very pleased with this course**, and I am particularly proud of two specific results. Question 16[24] reflects the fact that the students approved of the course. This was the first time I have taught DSP, and the first time it has been taught *ever* at Whittier College. This is especially interesting considering that the accelerated January term schedule carried the potential for the students to feel lost with the onrush of a lot of material. Apparently this was not the case, and their answers to Question 14 indicate that their understanding of the material *increased*.

Table 7 also shows that **the students approved of my teaching**. Question 25[25] indicates they were pleased with my style, and Question 19[26] shows that even though the DSP material can be challenging, the students understood what I was trying to show them. I would have liked to score higher on Question 22[27], but there was only so much time I could devote to open-ended discusions. Question 23 I consider linked to 22, since it pertains to differing viewpoints[28], but DSP is not a topic that offers itself to sharing opinions and thoughts in open-ended discussions in the same manner we might encounter in, for example, a philosophy or public-health course. I should think more carefully about connecting the DSP topics covered in COSC390 to real-world applications, and include discussion time to brainstorm how the topics might be applied in new ways.

I have reflected on the written responses from student evaluations from COSC390, and there are two common threads. The most common thread is that they want this course to be made into a semester-long course, in order to cover the topics they liked in more detail. They would have liked more deep dives into the later chapters, when we began to reach the image and audio processing in detail. I encouraged students to take these deeper looks at those topics for their final presentations, but ultimately time constraints limited what we could do. The second thread is that people liked the course, but wanted to slow the pace and focus more on the applications over the basics of DSP. I agree that we should do this, and making the course a full semester would help a lot.

[24] "Overall, I would recommend this course to others."
[25] "Overall, I would recommend this professor to others."
[26] "The professor was able to explain complicated ideas."
[27] "The professor encouraged meaningful class discussions."
[28] "The professor was receptive to differing views."

Question	First Time	Most Recent Time	Raw change	Standard deviations
10	3.13 ± 0.516	4.75 ± 0.251	1.62 ± 0.574	2.82
11	3.71 ± 0.488	4.75 ± 0.163	1.04 ± 0.514	2.02
12	3.75 ± 0.368	4.75 ± 0.163	1 ± 0.402	2.49
13	3.25 ± 0.491	4.75 ± 0.163	1.5 ± 0.518	2.9
14	3.63 ± 0.421	4.75 ± 0.163	1.12 ± 0.451	2.48
15	3.86 ± 0.244	4.63 ± 0.184	0.77 ± 0.305	2.52
16	3.29 ± 0.442	4.5 ± 0.269	1.21 ± 0.517	2.34
17	3.38 ± 0.566	4.75 ± 0.163	1.37 ± 0.589	2.33
18	3.5 ± 0.424	4.75 ± 0.251	1.25 ± 0.493	2.54
19	3.13 ± 0.516	4.5 ± 0.269	1.37 ± 0.582	2.35
20	4.25 ± 0.251	4.63 ± 0.262	0.38 ± 0.363	1.05
21	3.5 ± 0.499	4.88 ± 0.124	1.38 ± 0.514	2.69
22	4 ± 0.315	4.14 ± 0.244	0.14 ± 0.398	0.352
23	4.25 ± 0.41	4.17 ± 0.346	-0.08 ± 0.537	-0.149
24	4.29 ± 0.442	5 ± 0	0.71 ± 0.442	1.61
25	2.88 ± 0.481	4.75 ± 0.163	1.87 ± 0.508	3.68

Table 8: Comparison of COSC330 results (mean and error in the mean) for the first time taught (first column) to the first time teaching COSC390. The raw change is given in the third column, and the change divided by the standard deviation is given in the fourth column.

Table 8 compares the student evaluation results from Computer Logic and Digital Circuit Design (COSC330) to Digital Signal Processing (COSC390). I think this is a fair comparison for the reasons given in Sec. 0.3. **The data show significant increases in student evaluation scores when comparing the two courses.** Like the introductory courses, each Question shows an increase of 2-3 standard deviations (errors in the mean). The only exception is Question 23, pertaining to being receptive to differing views. It is difficult to have opinion-based discussions in both DSP and Computer Logic, because these topics are not as ammenable to such discussions as other courses. That being said, I think there is a venue for sharing differing viewpoints regarding the *applications* of the technologies we create. I was relieved and excited to see that the increase in the mean value to Question 25 regarding recommending me as a professor has increased by almost four standard deviations (errors in the mean).

Below I include a letter my student John-Paul Gòmez-Reed sent to myself and the chair of the Department of Mathematics at the conclusion of the course:

Hello Dr. Kronholm,

I have recently completed the January term COSC390 and would like to say that it was an excellent course. It was incredibly informative and related many concepts that were foreign to me with concrete examples, like the math behind image processing. Furthermore, it also provided with exposure with a new programming language: OctaveMatlab. I am emailing you to say that I feel that the course should be promoted from a January term course to a full semester course. I enjoyed my time learning during Jan term, but I feel that making COSC390 a full semester course would allow the course to reach it's full potential; time constraints led to less topics being covered, like the Laplace transform. In any case, I enjoyed my time in the course and hope that COSC390 does become a full semester course.

Thank you for your time and have a good afternoon,
John Paul Gomez-Reed

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