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Focusing on Concepts by Covering Them Simultaneously

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Focusing on Concepts by Covering Them Simultaneously

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"Parallel" pedagogy covers the four mechanics concepts of momentum, energy, forces, and kinematics simultaneously instead of building each concept on an understanding of the previous one. Course content is delivered through interactive videos, allowing class time for group work and student-centered activities. We start with simple examples, building complexity throughout the course with the introduction of springs, two dimensions, vectors, energy diagrams, universal gravitation, and rotation. Success means that students ponder underlying physics concepts rather than hunt for formulas. Surveys indicate that students accept this learning model well and have considerable improvement in applied conceptual understanding.

Introduction: Getting away from "formula hunting"

In 1989, David Hammer reported[1] that some students look at physics as a collection of unrelated formulas used to solve problems, whereas other students attempt to relate concepts to their intuition about how the world works. He also proposed that the way the class is taught may support the development of one perspective over the other. For instance, lectures by an expert scientist on how to use formulas may foster the former worldview, whereas student-centered group discussions as to *why* something happens may develop the latter epistemology.

P. D'Alessandris authored the Spiral Physics program at Monroe Community College,[2] where the curriculum revisits concepts, increasing familiarity each time. He says "the plethora of equations presented in introductory textbooks serves to reinforce the typical student's misconception that physics is merely a collection of formula, and that solving problems is simply reducible to finding the correct one (sic)."[3]

In 1991, A. Van Heuvelen[4] reported conceptual gains for students who started physics with a two-week conceptual overview before developing mathematical models. One might view my parallel pedagogy as an extrapolation of D'Alessandris and Van Heuvelen: we start with a simplified introduction of the four mechanics concepts in a way that is superficially familiar to all people and learn physics somewhat like people learn their first language.

Most physics instructors agree that the important first step in solving a physics problem is to identify the underlying concept(s) and analyze the problem through the appropriate conceptual "lens" or "lenses." However, the conventional "series pedagogy" as well as the way exams are graded likely encourages formula hunting. By teaching one concept at a time, the underlying concept is obvious: In the momentum chapter, the correct answer likely results from using the momentum formulas at the chapter's end. Thus, students may not be challenged to distinguish concepts until they are studying for or taking an exam. Also, because students often receive credit for getting the right *answer* for homework and tests, and because time pressure is ever present, many students bypass concept identification, expediting completion by choosing a formula and "plugging in" numbers.

When I studied mechanics in college, I personally appreciated learning each concept built upon the understanding of the preceding concepts: starting with displacement to velocity to kinematics to dynamics to work/energy to momentum. I found beauty in the "perfectness" of building one concept on the foundation of the previous concepts. However, many of us are physics instructors *because* we understood and enjoyed the way physics concepts logically build on the previous concepts in series. But this is not the case for many students who may just want to find the formula to get the answer to get the grade to go on to the next class. Additionally, it is a rare student that learns the concept *perfectly* the first time, so most students may not benefit from or appreciate this series pedagogy the way it is intended. Lastly, most people learn iteratively, picking up pieces as they go along, so there are advantages in returning to concepts often rather than focusing on one concept at a time.[5]

I find that under the stress of an exam, students often default to the first thing they've learned, such as the kinematic formulas for constant acceleration:

$$x(t) = x_0 + v_0 t + \tfrac{1}{2}at^2 \qquad (1)$$

$$2\,ax = v_f^2 - v_0^2. \qquad (2)$$

Thus, I've often seen Eq. (1) or (2) as the first step for an exam question requiring (for instance) a work-energy approach. What if the first thing that students learn and practice is to pose the question, "What mechanics lens is the most appropriate for this problem? What's going on with momentum, energy, forces, and kinematics?" Would students then default to conceptual analysis? In this paper, I relate my experience but do not compare student performance with my past conventionally taught classes because many other things changed during this same time. I transitioned to: (a) student-centered activity-based instruction,[6] (b) presentation of class material via free online interactive videos, and (c) a free online textbook. During the process, I changed the grading scheme, how I grade exams, the expectations I have for the students; and I myself changed. Therefore, while I find recent exam results encouraging and will continue developing this teaching method, I have yet to quantitatively compare student *performance* with other "control" classes. Additionally, while the goal of this paper is to report the process and results of simultaneously teaching the four fundamental mechanics

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concepts, discussion of the other changes I invoked is intertwined.

Pedagogy: Instructing through free online videos

I have instructed introductory mechanics in series-based pedagogy 15 times between 2000 and 2013. Starting in fall of 2014, I have used the parallel pedagogy for seven classes: one with 68 students, five with ~ 48 students, and one in a studio classroom with 29 students.

The 10-week classes meet for four hours each week. Before each class students are introduced to the material via online videos (10-20 minutes) with optional reading in a free online textbook available via https://openstaxcollege.org/. In fall 2016, we built a short textbook that covers material consistent with the parallel pedagogy.[7] The curricula, videos, and text for these classes can be accessed at http://sharedcurriculum.wikispaces.com/. The order of topics has continued to evolve, and I summarize the spring 2016 timeline in the box below. For instance, we begin with the "four lenses" introducing:

1) **Momentum,** $p = mv$, is conserved, so that if a small cart runs into and sticks to a stationary cart, the two go off at a smaller speed. We can look at conserving momentum in this example two ways: The total mass increases, so the speed must decrease. Or the moving cart gives some of its momentum to the originally stationary cart.
2) **Energy** transformations without introducing formulas. The chemical potential energy in one's body can be used to pull back a projectile in a slingshot, storing the work as spring potential energy. Subsequently letting go of the projectile transforms the spring potential energy to kinetic energy in the speed of the projectile.
3) **Forces** cause acceleration. With simple examples of pushing a boy on a bicycle, I show that acceleration is in the same direction as the applied force.
4) **Kinematics** on the first day is restricted to constant velocity. Speed is the rate of change of position. Without a formula, we predict where something will be two seconds in the future.

Another example is at the end of week 4, we introduce vectors and components with applications for force, motion, work-energy, and momentum. Students visually estimate components without the "black box" of trigonometry. Once students have learned to estimate answers and check them against their experiences, we introduce trigonometry at the end of week 6.

I record most of my own videos, but also borrow videos from those freely available online. Video links are on the class website, and videos are watched via http://www.PlayPosit.com, which allows me to both present the viewer with questions during the video as well as record each student's participation. You can watch the two videos for week one via PlayPosit by following links:

- "How this Class is Different," https://www.playposit.com/public/32670/93718/different-mechanics-class and
- "Four 'Lenses' of Mechanics," https://www.playposit.com/public/32670/92803/4-possible-mechanics-questions.

On a daily basis we practice the lens method, starting a problem by identifying the underlying concepts. When addressing a problem, we ask how it looks through each of the four lenses. For instance, if we drop a rock off a cliff:

a) **Energy:** Gravitational potential energy is being converted to kinetic energy, then to thermal energy after the impact.
b) **Forces:** The unbalanced force of gravity accelerates the rock downward (and Earth upward).
c) **Kinematics:** The acceleration increases the downward velocity, and the displacement changes at an increasing rate that we can predict.
d) **Momentum:** The rock starts with zero momentum and

- ***Week 1:*** (Introductions, Philosophy, and the Four Lenses: momentum, energy, forces, and kinematics)

1) The four different "lenses" are introduced and students begin practicing concept identification. See explanation video: "How This Class is Different," https://youtu.be/cY_OMY4Vuhk, and first content video: "Four 'Lenses' of Mechanics," https://youtu.be/JDYtZzB5VL8
2) Time rate of change, work, energy, and power

- ***Week 2:*** (Measurements with Cell Phone Videos)

1) Students collect data on physical activities with cell phone videos
2) What is an equal and opposite force?
3) One-dimensional free-body diagram

- ***Week 3:*** (One-Dimensional Vectors)

1) Free-body diagrams & dynamics protocol
2) Springs
3) Potential energy graphs
4 Friction

- ***Week 4:*** (Two Dimensions) Exam #1

1) One-dimensional elastic collisions and changing reference frames
2) Vector components without trigonometry
3) Two-dimensional free-body diagram

- ***Week 5:***

1) Inclined plane
2) Universal gravitation and the inverse square law

- ***Week 6:***

1) Centripetal acceleration
2) Circular dynamics
3) More complicated kinematic equations, Eq. (1) and Eq. (2)
4) Projectile motion
5) Trigonometry

- ***Week 7***: Exam #2

1) Pulleys, systems of masses
2) Review

- ***Week 8:*** (Rotational Mechanics)

1) Four rotational mechanics lenses: energy, angular momentum, torque, kinematics
2) Statics
3) Conservation of angular momentum
4) Group video project due

- ***Week 9:*** (Torque as Angular Momentum Rate of Change)

1) Stability of a spinning object & precession
2) Parallel axis theorem

- ***Week 10:***

1) Rotational systems (yo-yo as an example)
2) Bicycle transmission
3) Evaluation of class

finishes with zero momentum, but has downward momentum just before impact. Explore: What interaction imparted this momentum onto the rock and then took it away again? Earth's momentum must be equal and opposite to that of the rock. Equate to Newton's third law.

The discussion may not always consider all four lenses. For instance, in considering the "catching the bus" problem, we *can* talk about forces, momentum, and energy. However, if we're interested in finding out if we catch the accelerating bus, a narrative of motion as an explicit function of time should direct us to kinematics.

Lastly, some events require more than one lens, such as the ballistic pendulum, which we introduce through discussion.

Results

• Old habits die hard

I relate my experience using the parallel pedagogy for six classes since fall 2014. Students were reluctant to transition from the "pick a formula" approach to a "lens" analysis. In fall 2014, even with the parallel pedagogy, students on the final exam did not take the time to identify and support the underlying concept but instead started answering questions with a formula. Therefore, in winter 2015 I made two changes: Students were not allowed to refer to a formula until it is introduced in a video. So, Eqs. (1) and (2) cannot be used before week 5, for instance, for a rock falling from a cliff. Instead, students use simple kinematics, graphical methods, or energy considerations. Additionally, I introduced a grading rubric[8] such that in order to earn a C a student must start a problem with identification, support for, and discussion of the appropriate lens, with an emphasis on *communicating an understanding* of what is being done. To earn a B, the student must additionally set up the problem with a good drawing and use units correctly. To earn an A, the student must additionally formulate a method to solve the problem and verify whether the answer makes sense.

Still, students in this class did not start questions with lens identification until after the grading policy was invoked. Even with full knowledge of the rubric and practice in class, the vast majority of the students (and two instructors sitting in on the class) did not identify a lens on the first quiz during week two and thus received a grade of D. Quiz grades do not count toward the final class grade. Subsequently, most students consistently began answering each question identifying the relevant concepts. It is possible that the change in grading alone would have resulted in students beginning each question with concept identification. Accordingly, a recent publication reports increased student learning with ungraded, timely feedback and other Formative Assessment techniques.[9]

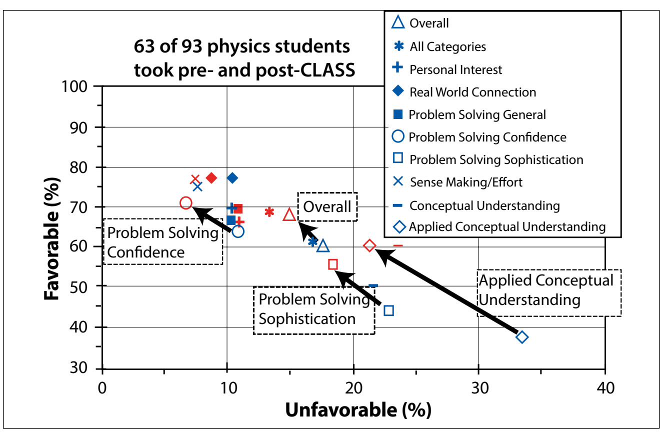

Fig. 1. CLASS survey results from two classes. Blue icons indicate pre-test results; red icons indicate post-test results. A positive shift is considered leftward (decreased agreement with novice statements) and upward (increased agreement with expert statements).

• Students think more like experts

Adams et al.[10] surveyed student beliefs about physics and about learning physics, finding that most teaching practices result in students thinking *less* like expert physicists after instruction. The parallel pedagogy approach results in students thinking *more* like experts. Before and after the quarter-long mechanics class in spring of 2016, 63 of my 93 students[11] in two classes completed an online version of the Colorado Learning Attitudes about Science Survey (CLASS).[12] The results indicate a modest positive average shift and a significant shift in applied conceptual understanding (Fig. 1). The CLASS measures student agreement on a scale of 1-5 with "novice" and "expert" statements. For example, one novice statement is "When I solve a physics problem, I locate an equation that uses the variables given in the problem and plug in the values," for which my students recorded agreements of 3.9 ± 0.6 and 2.6 ± 1.0 for the pre-test and post-test, respectively. One expert statement is "It is possible to explain physics beliefs without mathematical formulas," for which my students recorded agreements of 3.5 ±1.0 and 4.1 ± 0.9 for the pre-test and post-test, respectively. The comprehensive CLASS results for these classes are available online.[13]

• Good student acceptance

While many physics *instructors* express concerns that students would have trouble covering the physics concepts "out of order" (especially students with no previous physics), the *students* seem to readily adapt to the parallel pedagogy. Table I indicates the students' perspective that although it was daunting to get all the concepts at first, they adapted to the parallel pedagogy well, and it resulted in them thinking more about concepts.

Quotes from student evaluations (comprehensive student evaluations are available online[14]):

- "Learning the '4 physics questions' off the bat was initially difficult but I believe it ultimately was useful as I now have a clear understanding which is good for someone who has never had a physics class."
- "Since all topics are introduced day one, it's difficult to keep everything straight and make connections, but once you start 'getting it,' you really feel as though you understand what's going on."

Criticism about the class was rarely about the parallel pedagogy, but usually about the flipped classroom and my Socratic response to questions:

Table I. Survey results from 58 of the 93 physics students in spring 2016.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Total
I adjusted to the parallel pedagogy very well	2%	16%	17%	45%	21%	
	1	9	10	26	12	58
It was crazy at first getting all those concepts	3%	12%	10%	47%	28%	
	2	7	6	27	16	58
Parallel pedagogy resulted in my thinking more about concepts	2%	9%	16%	34%	40%	
	1	5	9	20	23	58

– "Enjoyed the online format. Did not appreciate the instructor not answering questions."

• *My relationship to students' experiences*

When I taught conventionally, my student evaluations were consistently close to the department average of three out of a total possible four points. As I changed the curriculum, there was great variation in my student evaluation scores and the average was considerably lower. Many students *did* like the innovations from the start. However, it seems to me that when students do *not* like aspects of a class that is *different* from other classes, they often feel angry and cheated because their peers have "regular" classes. Student feedback indicates that students disengage from a learning model if they reject it as ineffective, *making* the learning model ineffective for them. Thus, I became acutely interested in the students' experiences in physics and in their lives in general. I began to look to my students as co-learners in the study of education. I collect their thoughts, which I make available on each class website with my own thoughts added. I also speak directly to their motivation as well as their understanding. I might say, "This can appear to you as though I'm not doing my job, but studies show students learn better this way," and make these studies available. Over the past three years, my student evaluations[13] have steadily increased and presently average about three again. This transition in relationship with my students may be the most rewarding aspect of the pedagogy change for me.

• *Students become independent learners*

In the spring 2016 survey mentioned above, students self-reported what portion of their learning came from different sources. On average, they reported that most of their learning came from other students (36% of learning), followed by interactive videos (31%), class lectures (21%), other online sources (6%), office hours (4%), and textbook (3%). "Class lectures" should read "class activities" as I rarely lecture. The low textbook use may be partially because we lacked a parallel pedagogy textbook until fall 2016.[7]

• *Performance: Good enough?*

Compared to my previous series pedagogy classes, I evaluate average student learning in these six parallel pedagogy classes as better. However, this difference in performance between parallel classes and series classes is less than the variation between individual classes using the same pedagogy, so I am reluctant to report that parallel pedagogy "teaches physics better." Additionally, there were many other changes when I started parallel pedagogy so a clean comparison is not possible and has not been attempted.

• *Does all this go together?*

I've described adoption of several teaching strategies:

1) Parallel pedagogy: Teaching the four basic mechanics concepts simultaneously
2) The lens method of problem solving, and how its implementation is assessed on exams
3) The "flipped classroom," where students learn new material at home and use class time for group activities and demonstrations
4) Open access online interactive videos
5) Free online textbook
6) Transparent reflection of the student experience

Certainly, any of these practices could be adopted independently. The only two that may belong together are 1 and 2, because they both support a conceptually based way of looking at mechanics. However, parallel pedagogy could be adopted into a class that is taught via conventional lectures supported by a textbook.

Conclusion I

For seven classes of about 50 students per class, on the first day I introduced the four mechanics concepts (momentum, energy, forces, motion) and built depth throughout the quarter in a parallel pedagogy. I find results encouraging because:

1) CLASS survey results indicate a shift *toward* expert thinking.
2) Students accept this pedagogy well.
3) Students transition their problem-solving process to begin with concept analysis.
4) Students solve physics problems on par with or better than those in my previous series pedagogy classes.
5) The effectiveness will likely improve with the development of appropriate resources, and practice of the instructor and the physics community as a whole.

Conclusion II

I did something fundamentally different with mechanics classes and it wasn't a disaster. In fact, I think it improved the class considerably, but this remains to be quantified with future, rigorous comparisons. In the meantime, maybe you can try it too? Feel free to use any resources I have at http://sharedcurriculum.wikispaces.com/ and let me know how it goes.

Epilogue

In fall 2016, I further altered the curriculum to cover first one-dimensional mechanics, then rotational mechanics, and last two-dimensions, components, and trigonometry. Available at: http://sharedcurriculum.wikispaces.com/Introductory+Mechanics+Fall+2016 .

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