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A Decade of Teaching Contemporary Physics First at Pomona College

Thomas A. Moore — Winter AAPT Meeting — Monday, 1/20/2020

Courses for Potential Majors

- ◆ Fall Term:

- ◆ **Physics 70:** Spacetime, Quanta, and Entropy
(*Six Ideas That Shaped Physics*, Units C, R, Q, T)

- ◆ Spring Term:

- ◆ **Physics 71:** Newtonian Mechanics
(*Six Ideas*, Units C, N; half-course)
- ◆ **Physics 72:** Electricity and Magnetism
(*Six Ideas*, Unit E; half-course)

Why did we do this?

- ◆ **Prior to 2008** (for *all* science students):
 - ◆ **Fall: Physics 51a:** Mechanics
(*Six Ideas*, Units C, N, R)
 - ◆ **Spring: Physics 51b:** E&M, Quantum, Thermal
(*Six Ideas*, Units E, Q, T)
 - ◆ Various schemes to better engage majors

Why did we do this?

◆ Reasons for the old approach

- ◆ It was efficient (to teach, run labs)
- ◆ All students should learn physics with calculus

◆ Problems with this approach

- ◆ Many students bored by Newtonian mechanics
- ◆ Potential majors were diluted in a sea of others
- ◆ Life-science students felt they were secondary
- ◆ Schemes for exciting majors were not working

Goals of the Great Split (2008)

- ◆ **Physics 41/42** (for life-science students)
 - ◆ Use a standard topic sequence (but with calculus)
 - ◆ Make it clear that we *were* targeting their needs
 - ◆ Offer Spring / Fall to better fit pre-med schedule
- ◆ **Physics 70-71-72** (for potential majors)
 - ◆ Gather *all* potential majors together
 - ◆ Teach material *all* would find new and interesting
 - ◆ Allow better-prepared students to skip 71 and / or 72

Goals for Physics 70

- ◆ **Physics Beyond High School**

Fresh for everyone, “level the playing field”*

- ◆ **Contemporary Physics**

Give potential majors an honest picture of the field, preparation

- ◆ **An Introduction to Thinking Like a Physicist**

Focus on model-building, active learning, problem solving

- ◆ **Build Excitement**

Relativity and quantum physics are fascinating!

- ◆ **Build Community**

Bring all potential majors together

Physics 70 Topics in More Detail

- ◆ **Conservation Laws** (7 (50-minute) sessions, C1–C6, C8, C9)
Modeling, interactions, vectors, systems & frames
conservation of \mathbf{p} , \mathbf{L} , E ; potential energy graphs
- ◆ **Relativity** (9 sessions, Unit R)
Principle of Relativity, three kinds of time, metric equation
spacetime diagrams, Lorentz transformations, 4-momentum
- ◆ **Quanta** (13 to 14 sessions, Unit Q)
Waves, physical optics, two-slit interference, spin,
wavefunctions, weirdness, Schrödinger equation, nuclei
- ◆ **Entropy** (10 sessions, Unit T)
Temperature, macrostates & microstates, multiplicity and entropy,
Boltzmann factor, ideal gas, distributions, engines, climate change

Active Learning Classes

- ◆ Currently we teach two sections of ~ 20 students each
- ◆ “Flipped” class plan (using text instead of videos)
 - ◆ Students read text chapter *before* class
 - ◆ Pre-class exercises
 - ◆ 3 short conceptual or basic problems from text
 - ◆ Students submit before class online (or in person)
 - ◆ Answers graded mostly on effort
 - ◆ 15-minute mini-lecture
 - ◆ Announcements, highlight important things, give big picture
 - ◆ 30-minute worksheet
 - ◆ Qualitative and simple quantitative problems
 - ◆ Students work together in groups
 - ◆ Professor, TA circulate to answer questions

Pre-Class Exercise

Q5T.4 Imagine that we shine a beam of electrons with a de Broglie wavelength of 0.1 nm through a pair of slits that have been miraculously constructed to be only 10 nm apart. What will be the approximate distance between bright spots on an interference pattern displayed on a fluorescent screen placed 1 m from the slits?

A. 1 cm B. 1 mm C. 0.1 mm D. 10 μm E. 1 μm

Q5 Activity Sheet

Core Concepts

- A. The de Broglie relation (for *free* quantons): $\lambda = h/|\vec{p}|$ or in terms of K : _____ (if nonrelativistic)
- B. Quanton-at-a-time two-slit interference
 1. Quantons are detected as if they were discrete particles
 2. But *statistically* contribute to an interference pattern
 3. So particle model works for detection, wave model for statistical behavior
 4. Note that *each quanton* must “know” about *both* slits. Why?
5. Therefore, it is actually contradictory to assume that the quanton even *has* a well-defined position at any time before it is finally detected at the screen
6. If we *force* the quanton to have a position by using detectors near each slit, we get *no interference* (!!)
- C. The ***Interference*** application simulates this.

Practice problem: Q5T.8. (a) Fill in the chart below (which is the same chart shown on page 82) *without* using the Interference application. (b) Then show your results to either your in-class mentor or Dr. Moore. (c) Then test your results “experimentally” using the Interference app. (d) Ask your mentor or Dr. Moore to explain if you, don’t understand why your “experimental” results disagree with your initially expected results (if they do).

Case	λ	Slit Width	Slit Separation	Detectors?	Pattern
Sample	5 nm	3 μm	10 μm	No	(Sample)
(a)	5 nm	6 μm	10 μm	No	
(b)	5 nm	6 μm	20 μm	No	

Practice problem: Q5T.8. (a) Fill in the chart below (which is the same chart shown on page 82) *without* using the Interference application. (b) Then show your results to either your in-class mentor or Dr. Moore. (c) Then test your results “experimentally” using the Interference app. (d) Ask your mentor or Dr. Moore to explain if you, don’t understand why your “experimental” results disagree with your initially expected results (if they do).

Case	λ	Slit Width	Slit Separation	Detectors?	Pattern
Sample	5 nm	$3\ \mu\text{m}$	$10\ \mu\text{m}$	No	(Sample)
(a)	5 nm	$6\ \mu\text{m}$	$10\ \mu\text{m}$	No	
(b)	5 nm	$6\ \mu\text{m}$	$20\ \mu\text{m}$	No	
(c)	10 nm	$6\ \mu\text{m}$	$20\ \mu\text{m}$	No	
(d)	10 nm	$6\ \mu\text{m}$	$20\ \mu\text{m}$	Yes	
(e)	10 nm	$6\ \mu\text{m}$	$10\ \mu\text{m}$	Yes	

Practice question: Explain why $\lambda = hc/E$ applies to photons, but does *not* to *any* particle with mass $m \neq 0$. (Hint: How is $|\vec{p}|$ related to E for photons? How is $|\vec{p}|$ related to E for relativistic particles with $m \neq 0$?)

Practice question: Do problem Q5T.7. Write your answers in the space below and on your whiteboard.

(a) _____

(f) _____

(b) _____

(g) _____

(c) _____

(h) _____

Classroom Design



Weekly Homework

- ◆ **Scheme where students correct their own homework**
 - ◆ Scanned initial efforts due electronically on Wednesdays
 - ◆ Solutions are posted online several hours afterward
 - ◆ Students correct their work using a green or purple pen
 - ◆ Students hand in corrected papers on Friday
 - ◆ TA grades corrected problems using this rubric:

I C

- | | | |
|--------------------------|--------------------------|--|
| <input type="checkbox"/> | <input type="checkbox"/> | Description (Sufficient / Clear & Correct) |
| <input type="checkbox"/> | <input type="checkbox"/> | Model (Correct Principles / Correct Application) |
| <input type="checkbox"/> | <input type="checkbox"/> | Good Notation (Symbolic Algebra / Units & Vectors) |
| <input type="checkbox"/> | <input type="checkbox"/> | Valid Math (Sufficient / Correct) |
| <input type="checkbox"/> | | Plausible (Right Units / Magnitude / Sign) |
| | <input type="checkbox"/> | Thoughtful Correction (not too much / too little) |

Deduction for Missing Parts: _____

Final Score:

Weekly Homework

- ◆ **Scheme where students get quizzed on homework**
 - ◆ Students hand in one “Rich-Context” problem
 - ◆ Must be clearly written and show all steps
 - ◆ Graded on presentation as well as correctness
 - ◆ Six other problems are assigned but **not** handed in
 - ◆ One problem is selected as the subject of an in-class quiz
 - ◆ Quiz is short (about 5 minutes)
 - ◆ Should be easy if one has done the work correctly
 - ◆ Lowest quiz score dropped

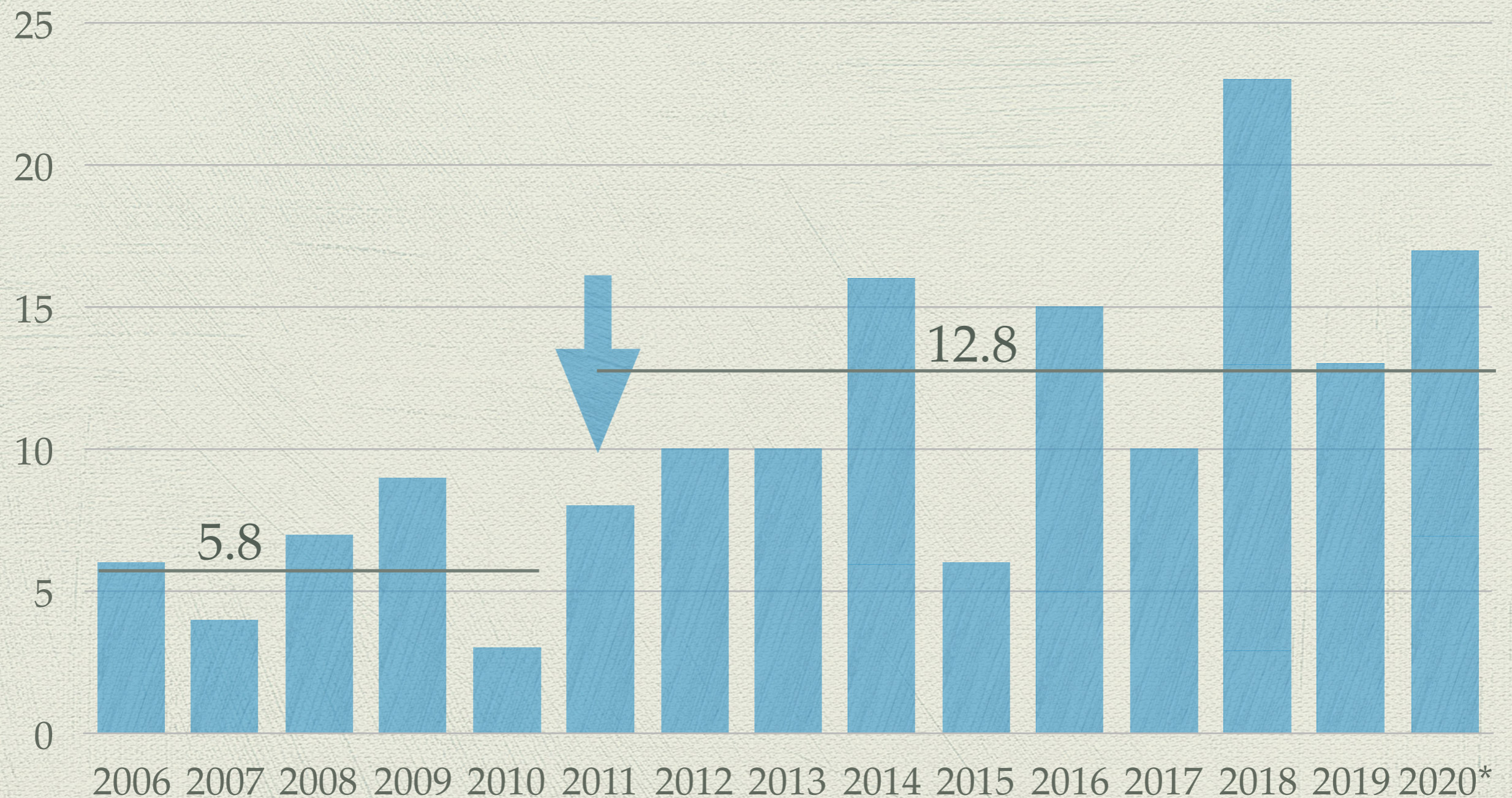
Labs (2019)

- ◆ Energy and power
- ◆ Sound and Doppler effect
- ◆ Speed of light
- ◆ Computational Physics
- ◆ Elementary School Outreach
- ◆ Coupled Oscillators
- ◆ Interference and Diffraction
- ◆ Hydrogen Spectrum
- ◆ Thermometry (or Lab Tours)
- ◆ Peltier Coolers, Heat Engines, IR Spectrum

Does this work?

- ◆ **Testing learning gains in Physics 70 is difficult**
 - ◆ Nothing like the FCI is available for this material
 - ◆ CLASS shows nothing unusual
- ◆ **Physics 71 material:** FCI normalized gain ~ 0.65
- ◆ **Physics 72 material:** BEMA score 58% (in only 6 weeks!)

Effect on Number of Majors



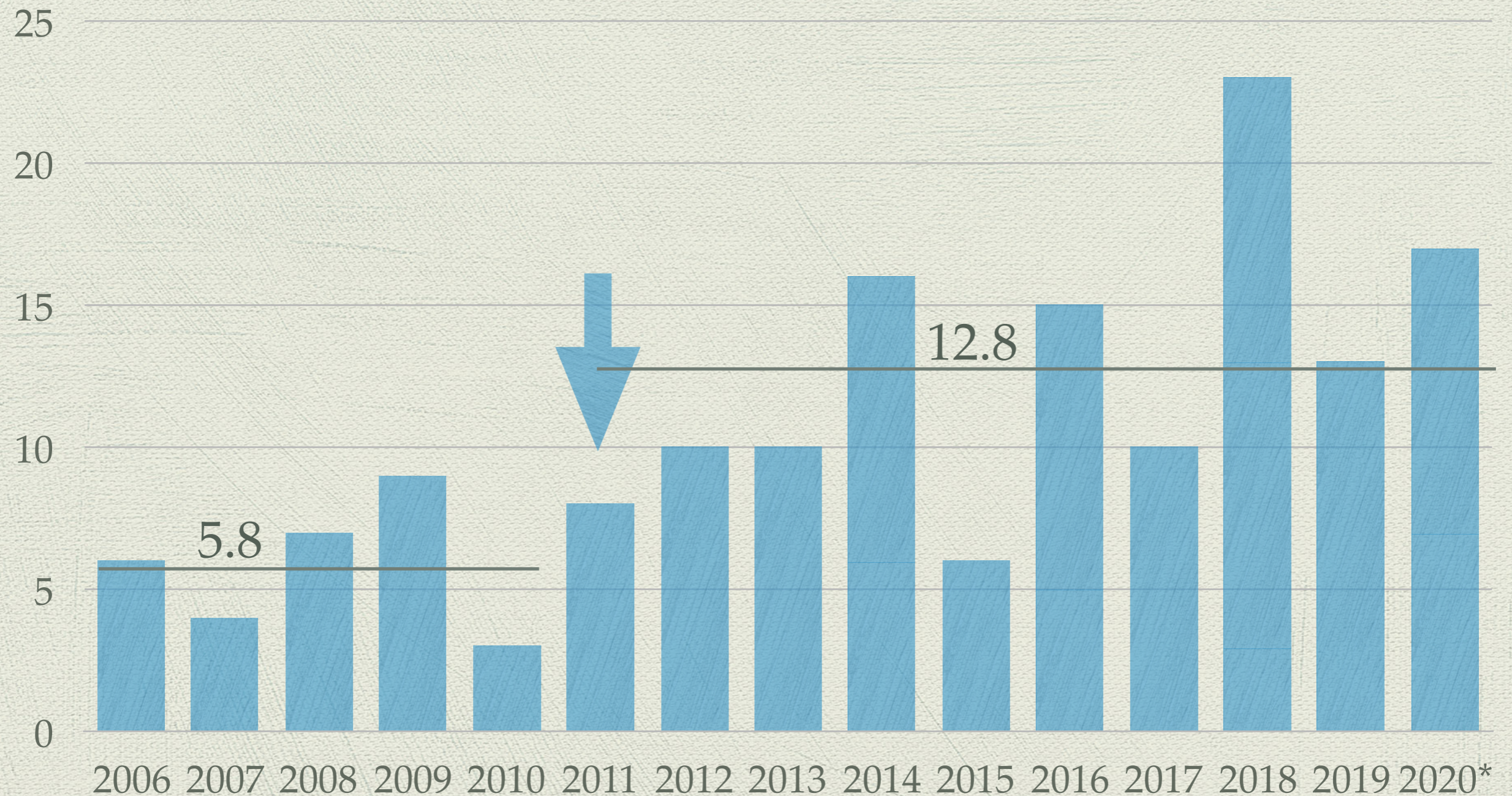
Observations and Surprises

- ◆ **Student-run study of retention (Hauser and Cui)**
 - ◆ Significant factors for continuity to our sophomore course
 - ◆ Sense of “belonging” in the field
 - ◆ Perceived difficulty of Physics 70
 - ◆ Having a study group
 - ◆ No “even playing field”
 - ◆ HS preparation in physics and math remains relevant
 - ◆ For continuers, class’s difficulty level was about right
 - ◆ Latinx students found the course harder (and were somewhat less likely to have taken AP physics)

Observations and Surprises

- ◆ *Six Ideas* wasn't designed for this, but was adaptable (with a little help from the author!)
- ◆ First-year problems suddenly became visible!
- ◆ Too many students for one section
- ◆ No clear place for non-majors who are not pre-meds
- ◆ Many people don't bother to test out of Physics 71, 72
- ◆ Not having lab for Physics 71, 72 remains contentious
- ◆ **Pace remains a problem** (possibly an increasing one)

Why we will never go back



Thanks!

tmooore@pomona.edu

www.physics.pomona.edu/sixideas/