# Serving Dessert First:
## an inverted introductory course for potential majors

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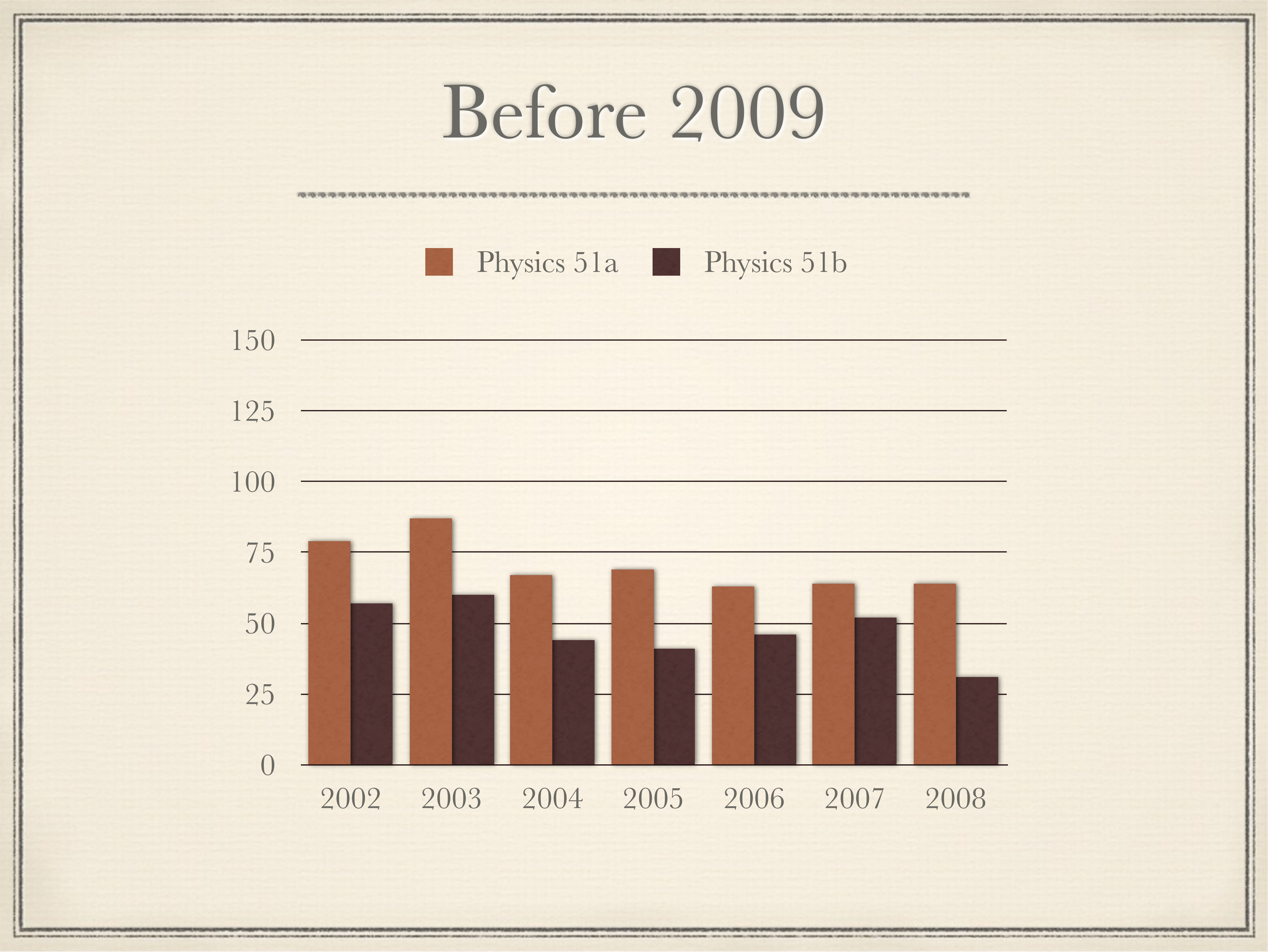
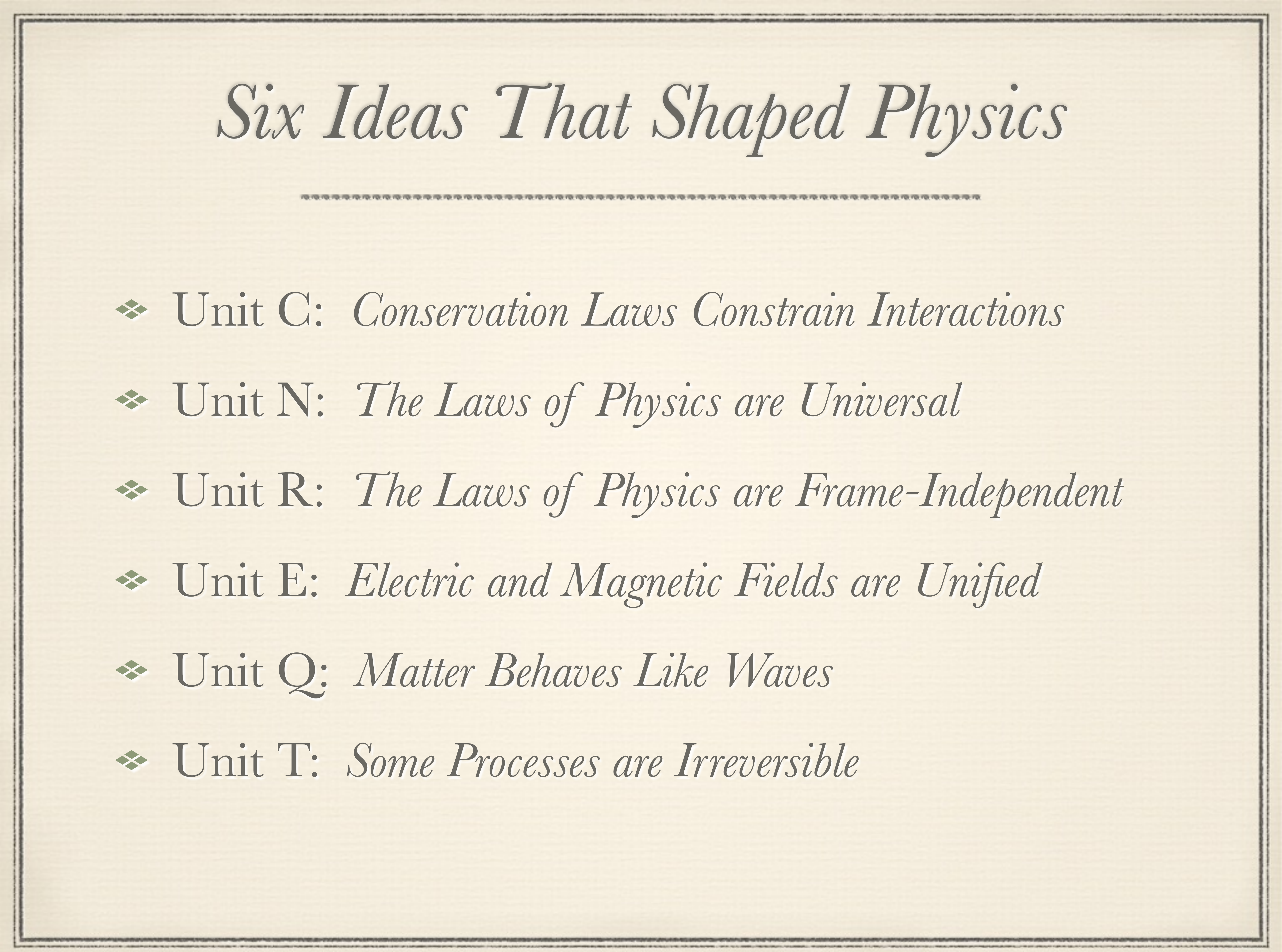
Before I begin, please note that I have handouts that I'd like everyone to have: they are available here. I have also posted this talk online at the URL on the screen. (time for handing out)

I want to talk to you this morning about an interesting change that we made in our introductory physics program at Pomona College that we made in the fall of 2009. In brief, we decided to break our calculus-based introductory physics course into two separate tracks, a basic (but still calculus-based) track for pre-meds and an advanced track for potential physics majors. The advanced track offered what we might call a "dessert-first" approach to the course, allowing students to explore relativity, quantum physics, and thermal physics without requiring them to eat the vegetables (that is, newtonian physics and electricity and magnetism) first. This change had a number of fascinating consequences, some that we expected, but some that we did not.

Let me set the stage. Pomona College is a selective liberal arts college in Claremont, CA, in the eastern suburbs of Los Angeles. Because we are pretty selective, virtually all of the students interested in introductory physics have had high school physics and are at least ready for calculus; we have not offered an algebra-based introductory physics course for more than 20 years. This slide illustrates the status quo before 2009.




Our two-semester introductory physics course before 2009 was numbered Physics 51a and 51b. This course included all students who needed to take physics: potential physics and astronomy majors as well as pre-meds and other STEM majors. (We do not have an engineering program: all students who are interested in engineering major in physics.) You can see that we typically had enrollments in the first-semester (51a) course of roughly 65 students, and between two-thirds and three-quarters continued with the second-semester course.




I want to make it clear that even before 2009 this was not a *traditional* physics course. We used the *Six Ideas That Shaped Physics* series of textbooks: this slide lists the six units of this course. I invite you to consider this list carefully: we use the same units in our revised course, though in a different arrangement. However, in the first semester of the old course, we studied unit C on conservation laws, unit N on Newton's second law and its implications, and unit R on special relativity. In the second semester, we went through unit E on electricity and magnetism, unit Q on quantum physics, and unit T on entropy and thermal physics.

I also want to make it very clear that our old course was not traditional in other ways. We taught each semester in two sections of 30-35 students each. In these small classes, we used active learning techniques based on peer instruction, clickers, just-in-time teaching methods, and so on. Our old course was quite successful in all the usual measures: we had normalized gains on the Force Concept Inventory of about 0.65 (solidly in the active-learning region) and good gains on the Basic Electricity and Magnetism assessment (in spite of spending only about half as much time on E&M as in a traditional course).

My point is that this talk is NOT particularly about the *Six Ideas* curriculum, nor about adopting active-learning methods. We had already done all that, and continued those practices in the new advanced track.
(5 min)

# Problems

- Pre-meds felt that the course did not serve them (though in fact it was skewed toward them)
- Prospective majors did not get their needs served
  - The level was wrong
  - The topics were wrong (for some)
  - The atmosphere was wrong
  - Bonding did not happen

In spite of this, the course had some significant problems. Pre-meds (and their advisors) felt that the course was not designed for them. This was actually not true: the course was heavily skewed in their direction because they were the majority clientele. It included both many examples and laboratory experiences designed especially for them, and we were able to document that students who took Physics 51a&b did at least as well if not better on the MCAT exams. But perceptions were what they were, and something like 60% of Pomona pre-meds took traditional introductory physics either at one of our sister institutions in the Claremont Colleges or (more often) over the summer.

Partly because of what we did to accommodate the pre-meds, the course was also ill-suited for our potential majors. Though we did not quite know this at the time, the level was wrong: first-year potential majors are simply not quite at the same intellectual place as junior pre-meds, so we were not addressing their needs. Also, while the pre-meds were quite happy with the material on classical mechanics, some of our advanced students were restive at having to go through nearly a whole semester of classical mechanics: this was the third time for some of them. Even so, we had found by sad experience that even these excellently-prepared students were rarely able to skip over the entire intro physics sequence, and when we allowed them to skip the first semester, we often lost them entirely to other majors before we even got to the second semester.

We had thought that mixing frosh with juniors would have a good effect, in that frosh would see junior-level learning skills modeled. And maybe this did happen, but the mix also had significant negative consequences. The junior pre-meds were in the course because they had to be: they were (usually) not interested in the material for its own sake, and (because they were the majority) this significantly affected the course atmosphere. Also the frosh were often intimidated by the very capable and driven premeds, and so got the message that they were not as capable.

Finally, the frosh were also sprinkled among both sections in small numbers among the premeds.

# Our Plan for Change

- Physics 41/42 (for Pre-Meds)
  - Traditional Sequence (41 in the spring)
  - Textbook: Knight
- Physics 70/71*/72* (for Potential Majors)
  - 70: Spacetime, Quanta, and Entropy (Units R, Q, T)
  - 71: Conservation laws, Newtonian mechanics (C, N)
  - 72: Electricity and Magnetism (E)

*half-courses, with test-out option

After lengthy discussions in the department, we eventually developed the following plan for change. We would offer a more traditional physics course (Physics 41/42) especially targeted for premeds. For the most part, those teaching this course did not give up on active teaching methods, but we did initially offer larger sections than in the past. We also offered this sequence starting with 41 in the spring and 42 in the fall, an arrangement that (until last fall) better fit a typical premed's schedule. Finally, because the *Six Ideas* textbook was firmly associated in the premeds' advisors' minds with the old course, which they believed was not suitable for premeds, offering a course specifically for premeds required, for political reasons, moving away from the *Six Ideas* textbook.

The track for potential majors was Physics 70, 71, and 72. Our main idea was to offer a course for frosh that would explore material that *none* of them had seen: relativity, quantum physics, and thermal physics. This would put all of our incoming students at roughly the same level irrespective of their high school physics, while not boring the students who had already covered mechanics very well. This would also expose students to material we thought they would find exciting as well as giving them a real sense of what physics looks like in the 21st century. The only requirements for this course are (1) high-school physics of some type and (2) concurrent registration in Calculus 1.

However, we knew that most of the students who had high school physics would still need a college-level introduction to mechanics, and even more students would require some E&M. This is the point of the 71/72 half courses. Near the end of the 70 course, we give placement exams to any student who asks. On the basis of the results from these exams, we allow some students to place out of either 71 and/or 72. Students who place out of both can take our sophomore-level mechanics class and/or electronics classes instead, and starting last year we have started offering a numerical methods half-course for those students who place out of 71 but not 72. Because some students will skip one or both of these courses, 71 and 72 do NOT have an associated lab, though Physics 70 does.
(12 minutes)

**TENTATIVE SYLLABUS for PHYSICS 70** **FALL 201x**

| MONDAY | WEDNESDAY | FRIDAY | LAB (M or T) |
|---|---|---|---|
| 29<br>NO CLASS | 31 (no reading)<br>Introduction to the Course | 2 **C1**<br>The Art of Model-Building | (No Lab) |
| 5 **C2**<br>Particles and Interactions | 7 **C3**<br>Vector Mathematics<br>**HW 1 Due** | 9 **C4**<br>Systems and Frames | Ohm's Law and Photovoltaics |
| 12 **C5**<br>Conservation of Momentum | 14 **C6**<br>Conservation of Angular Momentum<br>**HW 2 Due** | 16 **C8**<br>Conservation of Energy | Reference Frames and Oscilloscopes |
| 19 **C9**<br>Potential Energy Graphs | 21 **R1**<br>The Principle of Relativity<br>**HW 3 Due** | 23 **R2**<br>Coordinate Time<br>**1:15 or arr: 1st EXAM** | The Speed of Light |
| 26 **R3**<br>The Spacetime Interval | 28 **R4**<br>Proper Time<br>**HW 4 Due** | 30 **R5**<br>Coordinate Transformations | Video Analysis (Introduction) |
| 3 **R6**<br>Lorentz Contraction | 5 **R7**<br>The Cosmic Speed Limit<br>**HW 5 Due** | 7 **R8**<br>Four-Momentum | Video Analysis (Project) |
| 10 **R9**<br>Conservation of Four-Momentum | 12 **Q1**<br>Wave Models<br>**HW 6 Due** | 14 **Q2**<br>Standing Waves and Resonance | Interference and Diffraction |
| 17<br>FALL BREAK | 19 **Q3**<br>Interference and Diffraction | 21 **Q4**<br>The Particle Nature of Light | No Lab<br>(**lab report 1 due**) |
| 24 **Q5**<br>The Wave Nature of Particles | 26 **Q6**<br>Spin<br>**HW 7 Due** | 28 **Q7**<br>The Rules of Quantum Mechanics | Coupled Oscillators<br>**(lab 1 rewrite)** |

This slide shows the Physics 70 syllabus. This also appears in your handout (after the slides): you may find it easier to read in the handout than on the screen. This is actually not a real syllabus from any past year (though the class dates happen to be from 2011): it has been updated to reflect the chapter numbers from the new 3rd edition of the *Six Ideas* textbook, which will be available from McGraw-Hill late this year. I should note that chapters in the *Six Ideas* book are deliberately organized so that one chapter corresponds to one 50-minute class session, and so are much shorter than chapters in most textbooks.

The first few weeks of the course starts with the first few chapters of unit C on conservation laws, just as a normal *Six Ideas* course would. This gives students of all preparations a common foundation in vectors, vector notation, force, momentum, and energy. Unit C approaches this core Newtonian material from a sufficiently different perspective that even the very well-prepared students are challenged. After three weeks, students are already exploring the concepts of special relativity: the principle of relativity, coordinate time, proper time, spacetime interval, coordinate transformations, Lorentz contraction, the cosmic speed limit, and conservation of four-momentum. After six weeks, we begin with quantum mechanics, starting with basic wave mechanics, going through two-slit interference, the photoelectric effect, and the de Broglie relation. We then take a detour through spin and the Stern-Gerlach experiment so that we can expose the basic conceptual structure of quantum mechanics using two-dimensional column vectors instead of wavefunctions. The new edition of *Six Ideas* allows students to do this without having to get into complex numbers.

| | | | |
|---|---|---|---|
| 31 **Q8** Quantum Weirdness | 2 **Q9** The Wavefunction **HW 8 Due** | 4 **Q10** Simple Quantum Models **1:15 or arr: 2nd EXAM** | Photoelectric Effect and Spectroscopy |
| 7 **Q11** Spectra | 9 **Q12** The Schrödinger Equation **HW 9 Due** | 11 **T1** Temperature | Spectroscopy of Hydrogen **(lab report 2 due)** |
| 14 **T2** Microstates and Macrostates | 16 **T3** Entropy and Temperature **HW 10 Due** | 18 **T4** The Boltzmann Factor | Exponential Decay |
| 21 **T5** The Ideal Gas | 23 NO CLASS **HW 11 Due** | 25 THANKSGIVING | |
| 28 **T6** Distributions | 30 **T7** Gas Processes **HW 12 Due** | 2 **T8** Calculating Entropy Changes | Lab Tours |
| 5 **T9** Heat Engines | 7 **T10** The Physics of Climate Change **HW 13 Due** | 9 READING DAY | Heat Engines |
| 12 | 14 **3rd EXAM 9:00 am** | 16 | |

Talking about spin allows us to talk about quantum weirdness: Bell's theorem, Schrodinger's cat, the quantum Zeno effect, and so on, without getting bogged down in the mathematics. Only after students are comfortable with using spin vectors do we introduce the idea of the wavefunction, simple models such as the particle-in-a-box, the Bohr atom, the simple harmonic oscillator and the spectra that such systems can produce. In the chapter on the Schrodinger equation, we teach students how to sketch energy eigenstates (both by hand and with a computer) rather than solve the differential equation. Indeed one of the great ironies of the course is that one can talk about all the "advanced" material presented up to this point without any calculus at all: this chapter on the Schrodinger equation is the first where we use even the *concept* of the derivative. This allows students who are concurrently registered for Calculus I time to learn about derivatives before seeing them in the class.

Finally, we start working on the concepts of statistical mechanics in unit T, making entropy the starting point (as the number of microstates in a macrostate) rather than leaving it until the end as in most treatments. The simple Einstein model of a solid makes this starting point possible. From this starting point, we can develop the concept of the Boltzmann factor, derive the ideal gas law, explore the Maxwell and Planck distributions, figure out how to calculate entropy changes in gas processes, and work with heat engines. This syllabus ends with discussion of the physics of climate change. We show students that they do not have to *believe* in climate change: they can calculate it for themselves using the Stefan-Boltzmann law and a very simple zero-dimensional model of the earth. This closes the course with a terrific example of both the power and relevance of physical model-building.

I should say that the *Six Ideas* textbook made it much easier to design and execute this course than would have been possible with any other textbooks that I know about. We wanted to cover modern physics material in some depth, but in a way accessible to first-year students with only high-school physics. The *Six Ideas* material only took a bit of tweaking to make this possible.

**TENTATIVE SYLLABUS for PHYSICS 71** **SPRING 2014**

| | MONDAY | WEDNESDAY | FRIDAY |
|---|---|---|---|
| JANUARY | 20 | 22 (no reading due)<br>Introduction to the Course | 24 **C6**<br>Conservation of Angular Momentum |
| JANUARY | 27 **C7**<br>More on Angular Momentum | 29 **C8**<br>Conservation of Energy<br>**HW 1 Due** | 31 **C10**<br>Work<br>**HW Corrections Due** |
| FEBRUARY | 3 **C11**<br>Rotational Energy | 5 **C12**<br>Thermal Energy<br>**HW 2 Due** | 7 **C13**<br>Other Forms of Internal Energy<br>**HW Corrections Due** |
| FEBRUARY | 10 **C14**<br>Collisions | 12 **N1**<br>Newton's Laws<br>**HW 3 Due** | 14<br>**FIRST EXAM**<br>**HW Corrections Due** |
| FEBRUARY | 17 **N2**<br>Forces from Motion | 19 **N3**<br>Motion from Forces<br>**HW 4 Due** | 21 **N4**<br>Statics<br>**HW Corrections Due** |
| FEBRUARY | 24 **N5**<br>Linear Motion | 26 **N6**<br>Coupled Objects<br>**HW 5 Due** | 28 **N7**<br>Circularly Constrained Motion<br>**HW Corrections Due** |
| MARCH | 3 **N8**<br>Reference Frames | 5 **N9**<br>Projectile Motion<br>**HW 6 Due** | 7 **N10**<br>Oscillatory Motion<br>**HW Corrections Due** |
| MARCH | 10 **N11**<br>Kepler's Laws | 12 **N12**<br>Orbits and Conservation Laws<br>**HW 7 Due** | 14<br>**SECOND EXAM**<br>**HW Corrections Due** |

**Bold chapter numbers** specify the assigned reading for that day. You should write out all assigned homework problems by Wednesday (I recommend starting during the weekend.) Homework *corrections* are due at the beginning of class on Fridays.

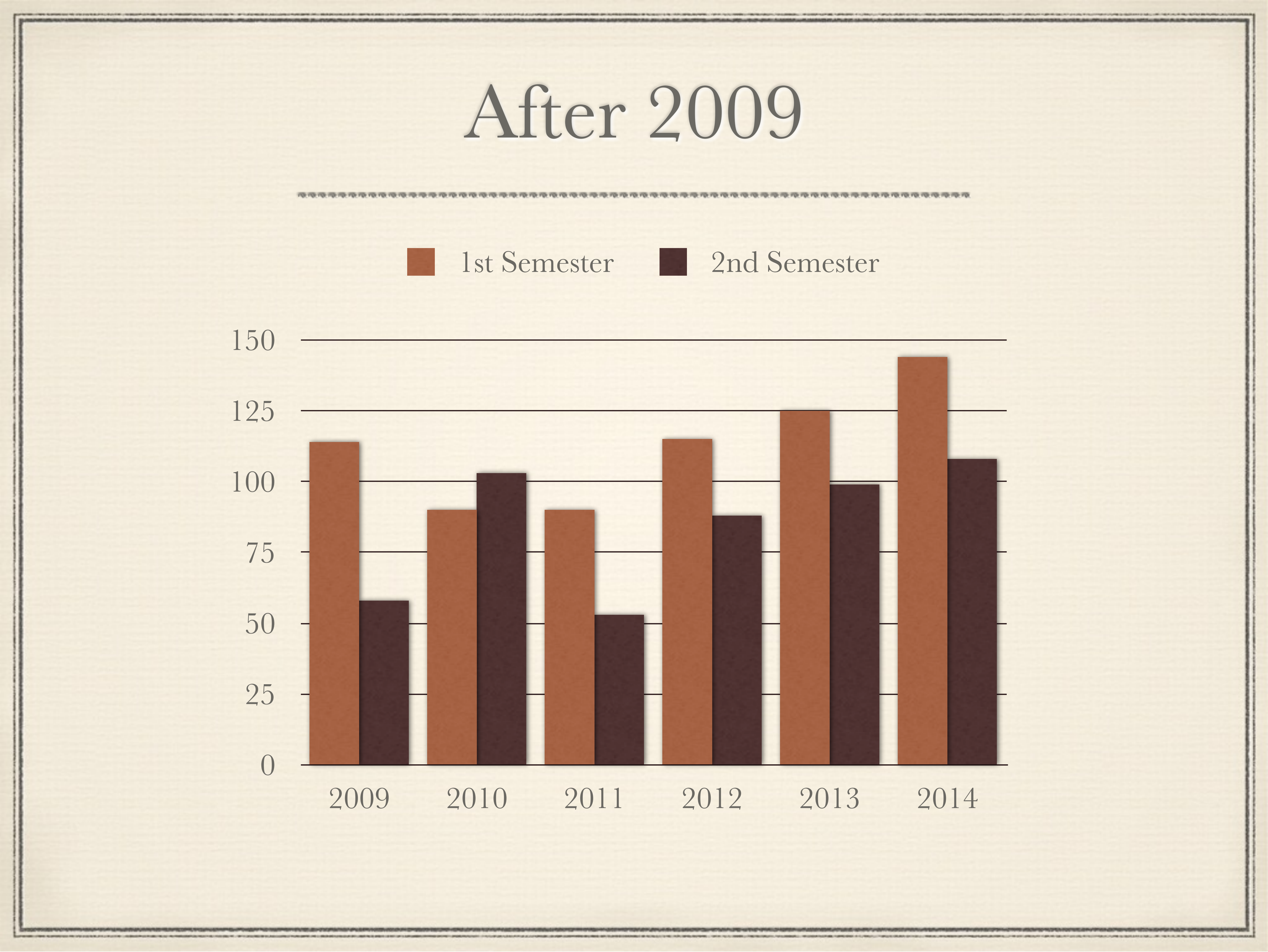
The physics 71 course finishes up with the material from unit C (on conservation laws) that was omitted in Physics 70, and then goes through unit N on the applications of Newton's second law, ending with a chapter on orbits that brings us back to a nice application of conservation laws.

## TENTATIVE SYLLABUS for PHYSICS 72 — SPRING 2014

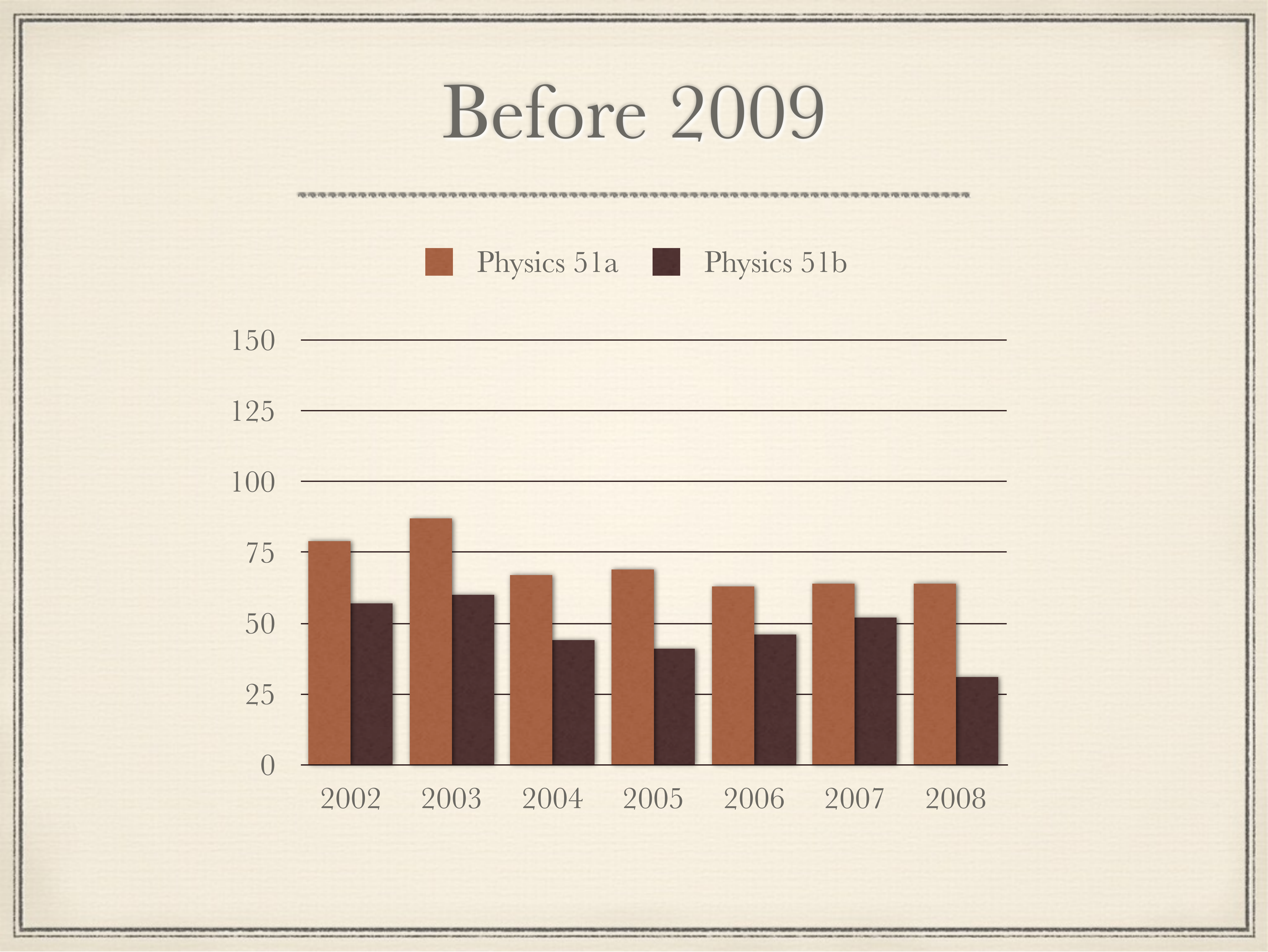
| | MONDAY | WEDNESDAY | FRIDAY |
|---|---|---|---|
| MAR | 24 (no reading due)<br>Introduction to the Course | 26 **E1**<br>Electric Field | 28<br>Cezar Chavez Day |
| APRIL | 31 **E2**<br>Charge Distributions | 2 **E3**<br>Electric Potential<br>**HW 1 Due** | 4 **E4**<br>Static Equilibrium<br>**QUIZ** **HW Corrections due** |
| APRIL | 7 **E5**<br>Current | 9 **E6**<br>Dynamic Equilibrium<br>**HW 2 Due** | 11 **E7**<br>Analyzing Circuits<br>**QUIZ** **HW Corrections due** |
| APRIL | 14 **E8**<br>Magnetic Fields | 16 **E9**<br>Currents Respond to Magnetic Fields<br>**HW 3 Due** | 18 **E10**<br>Currents Create Magnetic Fields<br>**QUIZ** **HW Corrections due** |
| APRIL | 21 **E11**<br>The Electromagnetic Field | 23 **E12**<br>Gauss's Law<br>**HW 4 Due** | 25 **E13**<br>Ampere's Law<br>**QUIZ** **HW Corrections due** |
| MAY | 28 **E14**<br>Integral Forms | 30 **E15**<br>Maxwell's Equations<br>**HW 5 Due** | 2 **E16**<br>Faraday's Law<br>**QUIZ** **HW Corrections due** |
| MAY | 5 **E17**<br>Induction | 7 **E18**<br>Electromagnetic Waves<br>**HW 6 Due** | 9<br>READING DAY |
| MAY | 12 | 14 \| 15 (Thursday)<br>**FINAL EXAM**<br>(9:00 am) | 17 |

**Bold items** are reading assignments.

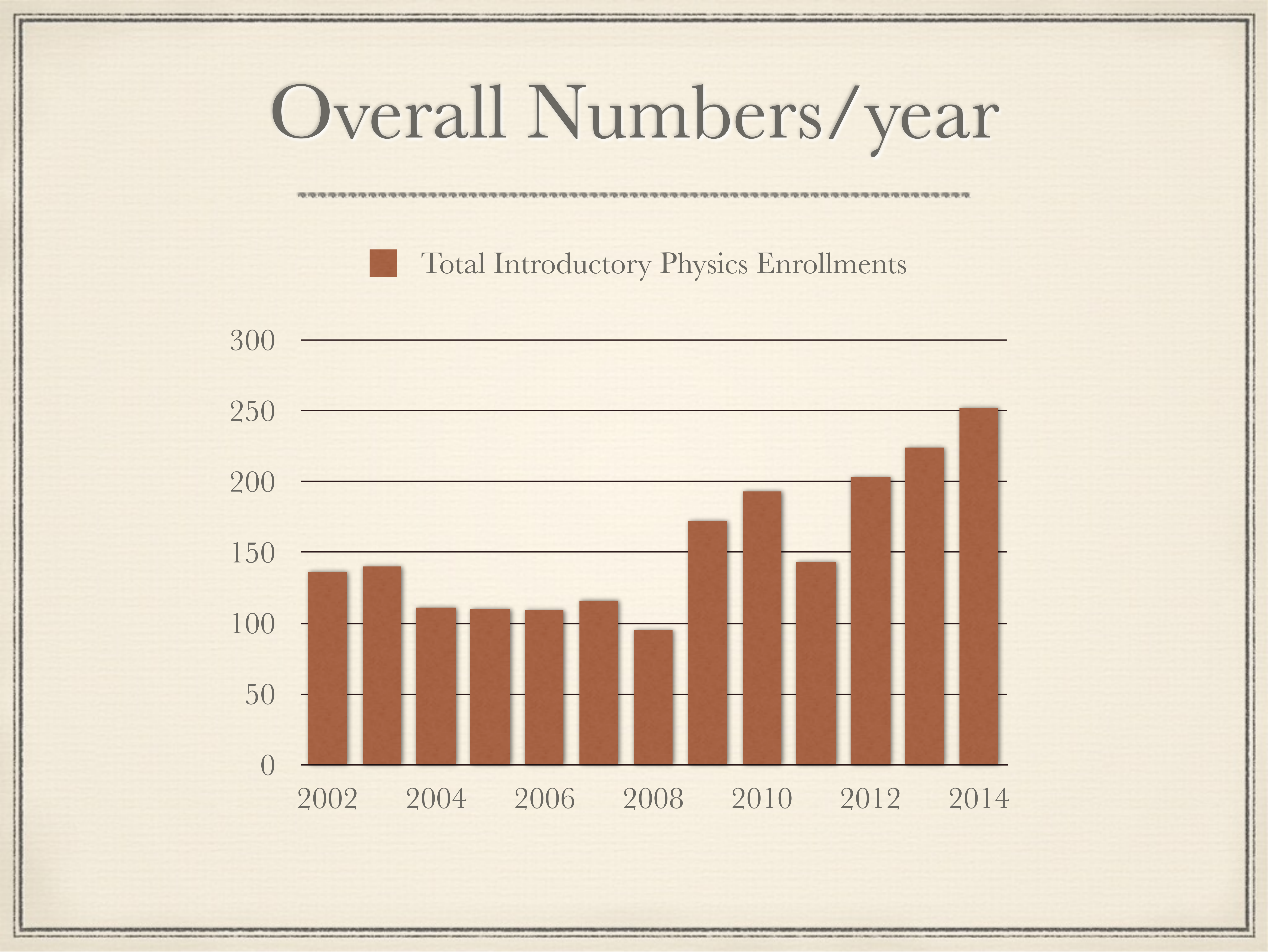
Physics 72 goes through the basic material of E&M: charges and fields, the electric potential, static equilibrium in conductors, simple circuits, magnetic fields, the concept of the electromagnetic field and Maxwell's equations, ending (as usual) with electromagnetic waves and the speed of light. Users of Six Ideas will note that the 3rd edition is a bit longer than the 2nd edition: 18 chapters instead of 16. Also, some material has been cut, and the remainder streamlined to make the pace of the course easier than before.
(18 min)



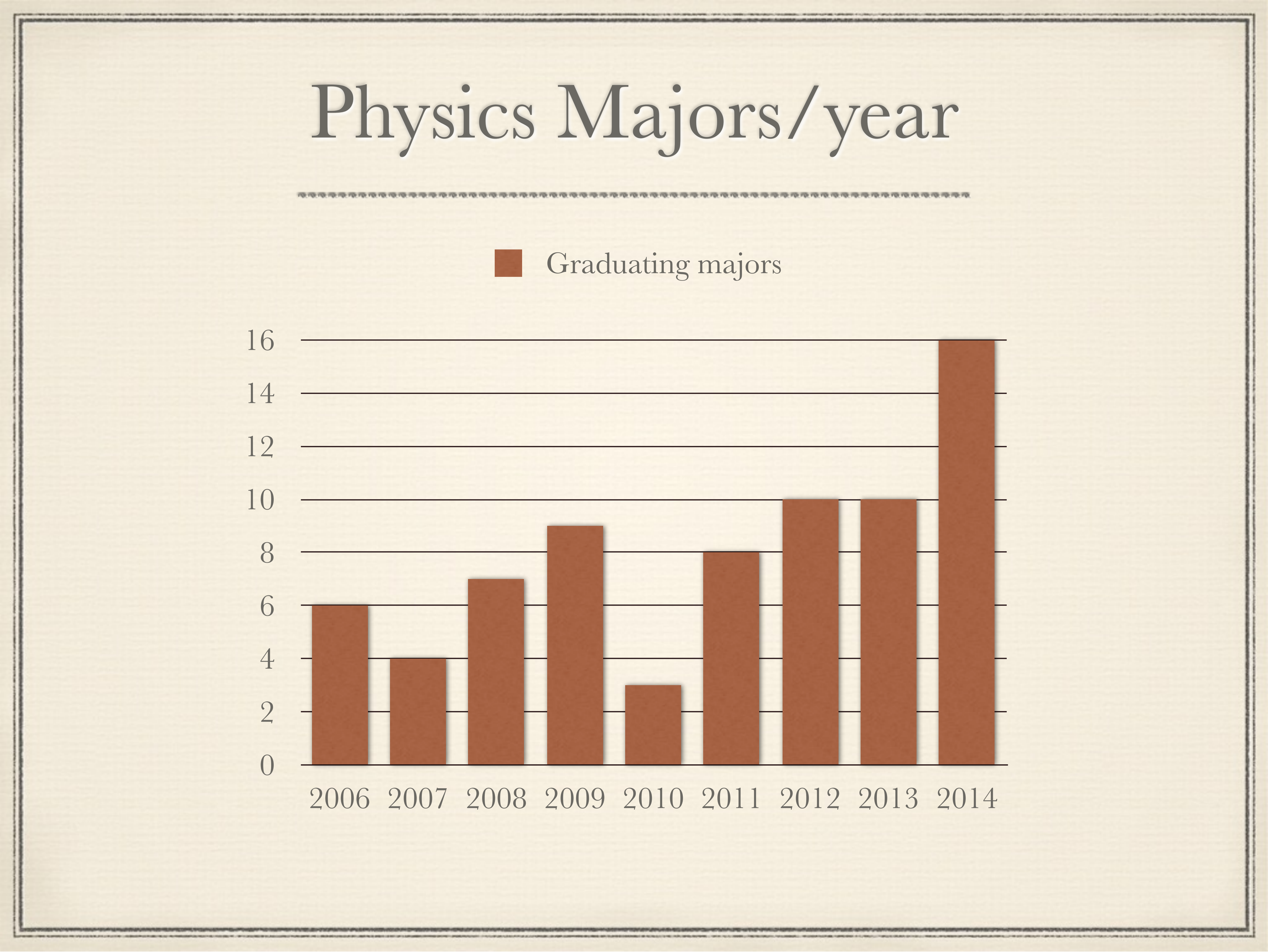

So what happened? This chart shows our post-2009 enrollments in introductory physics. This data combines enrollments in both Physics 41 and 70 in the “first semester” category, and Physics 42 and 72 in the “second semester” category. What do you see? (total enrollments are climbing!)



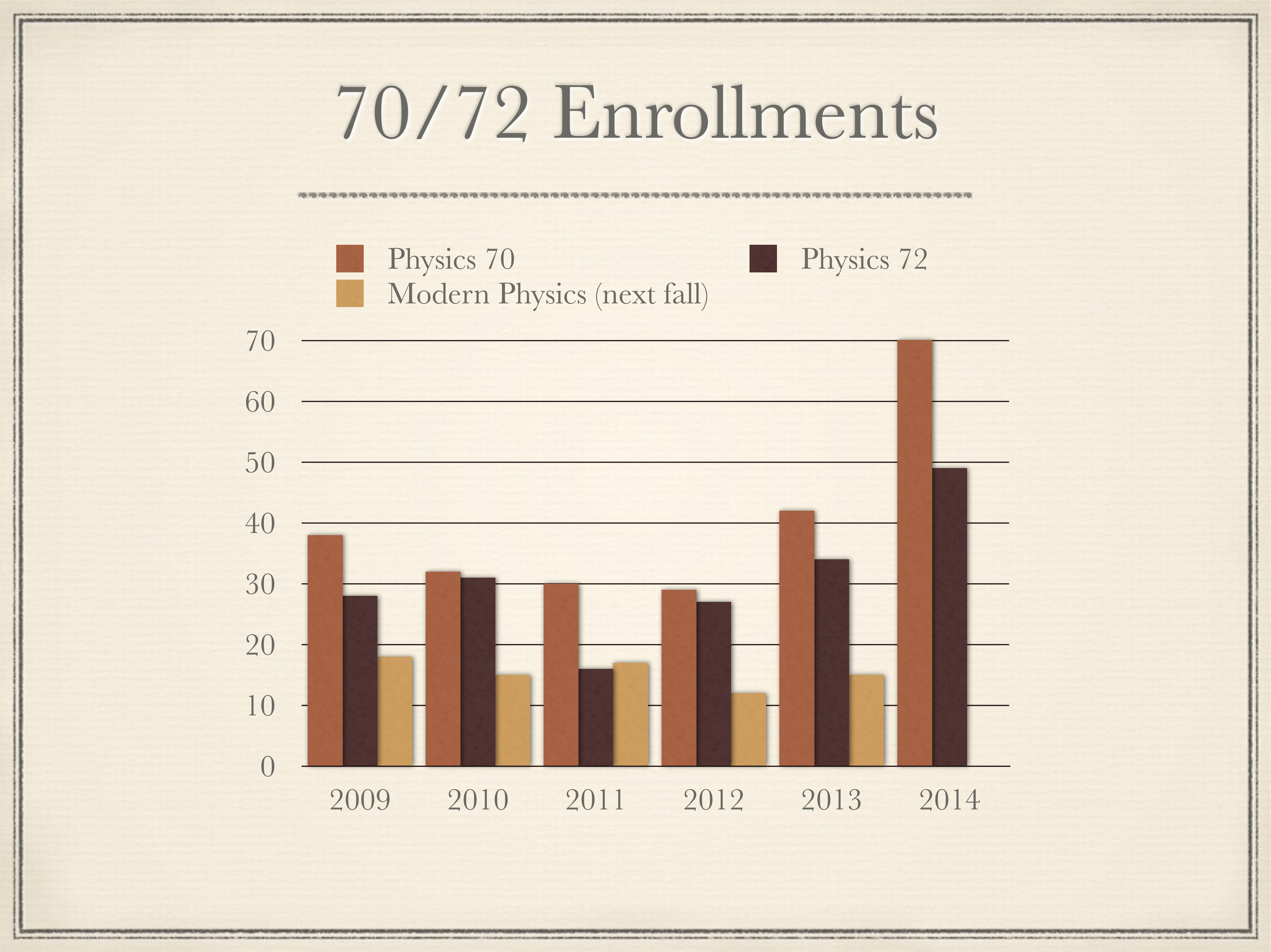

Yes! Here is the data before 2009 on the same scale. You can see that enrollments were significantly smaller in the old 51a and 51b courses.



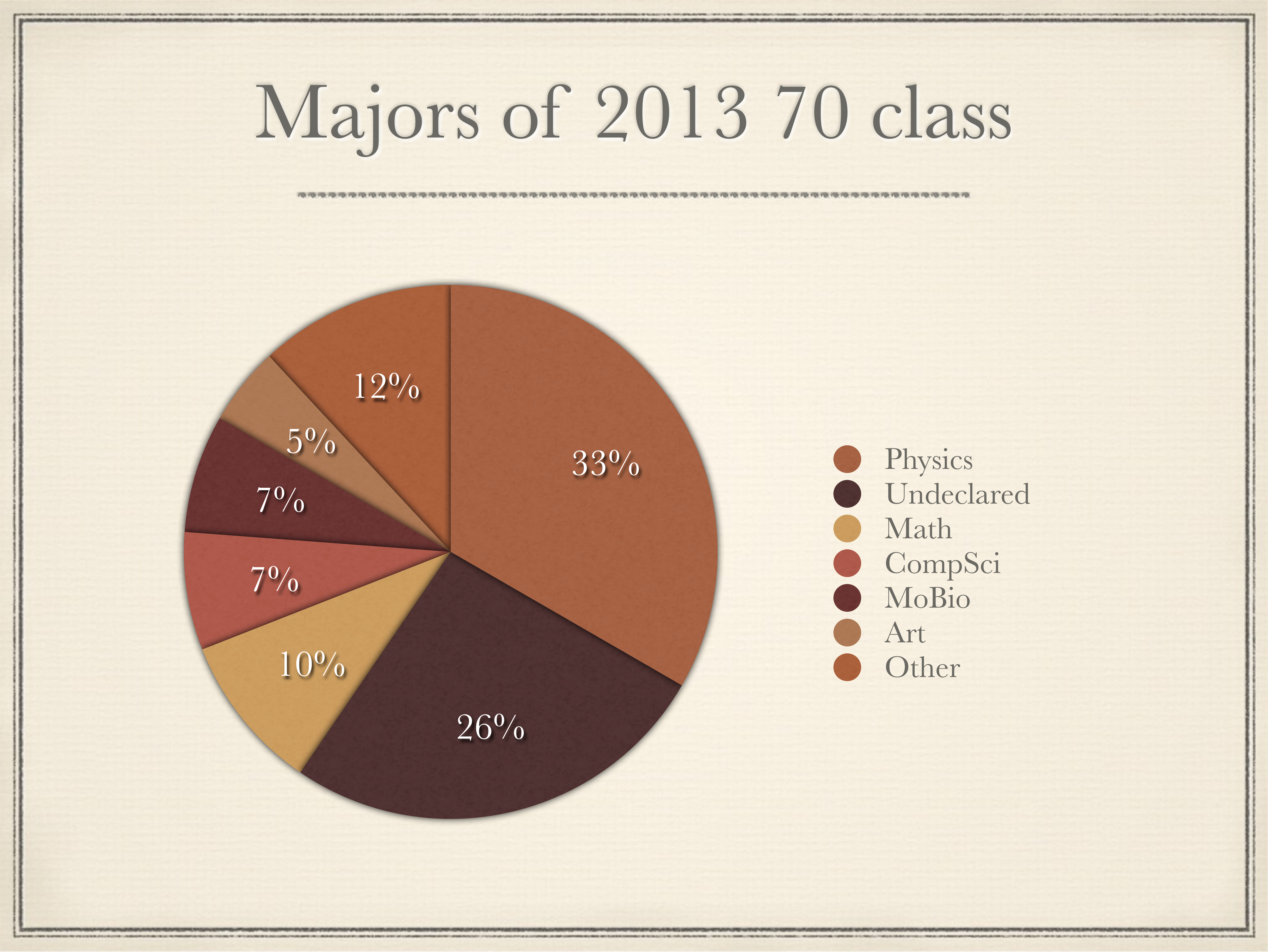

This shows the total number of students enrolled in Physics 51a&b before 2009, and in 41/42 and 70/72 after 2009 (enrollments in 72, the E&M course were used instead of 71, because only a very few students tested out of physics 72). We see that number immediately jumped up in 2009, mostly because of an increase in premed students who were electing to take the new premed-specific courses. But total enrollments have continued to increase with time in both classes, but especially in the 70 class recently.




This graph shows the number of physics majors that graduated from Pomona in each year from 2006 to last spring. Remember that students who took physics 70 in the fall of 2009 would graduate in the spring of 2012. What do you see? (sharp increase in physics majors). Indeed, the graduating class of 2014 was the largest since 1965, and also included the second greatest fraction of women ever (44%).




This graph shows the number of student enrolling in physics 70 in the fall of the numbered year, those enrolling in physics 72 in the spring of the following year, and in our sophomore-level modern physics course in the fall of that following year: the latter is an approximate proxy for the number of majors we would expect to graduate in the year given by the bar year + 3. What do you see? (Majors in the teens. Huge recent increase in enrollments in 70 and 72, without necessarily a correspondingly large increase in majors.) We were *completely* blindsided by this jump last fall: we had to break the class in two and hire a couple of new lab instructors very suddenly during the first week of classes. What is going on?




This chart suggests one interpretation. This is from 2013, where we see that about ⅓ of students taking Physics 70 eventually became physics majors. The next biggest slice is students who are sophomores this year who have not yet declared a major, but who we do not expect to become physics majors (I already counted those sophomores we are pretty sure about in the major category). The remaining students are molecular biology, math, computer science, and other majors (including two from art).

We think that word is going around out that Physics 70 is interesting and even useful for people who are not headed for the physics major. Anecdotal evidence is that the sudden bulge in enrollees this semester is due primarily to people who do not intend to be physics majors, though we will have to see how this plays out.

# What Did We Learn?

- It was the right thing to do!
- We are serving a growing number of non-majors in the 70 sequence
- Frosh are different than juniors
- More students than expected take 71
- More majors are entering via 71/72

So, what did we learn? First of all, this move was the right thing for us to do. Though managing two different introductory courses is difficult, the growing enrollments in the premed course, the 70 course, and in our major show that we are more effectively meeting the needs of our students. Secondly, though we had designed this course specifically for potential majors, we are finding that students from many majors are attracted by this course and are now the majority clientele, something we did not expect.

Thirdly, separating the premeds from the frosh clearly exposed how different the two groups of students were. Some material that seemed to work well with the combined 51a/b courses did not fly very well with the first-year students, something that we simply did not see until these students were isolated. This led us to modify our materials to better reach the first-year students.

We also saw that many fewer students than expected even *tried* to test out of Physics 71 (the one on Newtonian mechanics). Many of them realized while taking Physics 70 that they might really benefit from a college-level review of Newtonian mechanics, and so much more happily submit to this than they might have if we had offered this first.

Finally, we are also seeing that the new course arrangement provides a new opportunity for students that did not exist before. An increasing number of students are requesting access to Physics 71/72 without taking 70, many of whom either got bad advice in the fall or discovered after their first semester that something else that they thought they were interested in did work for them. A fair number of these students end up as majors. A significant number of these people are women, so this has become an important pathway for women to enter the major.

So, in summary, this change has been terrific for us in a number of ways, and we recommend it! Thank you for your attention, and I'd be happy to take some questions.