Beyond Astro 101: A first report on interactive education in an astrophysics class for *majors*

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Learner-centered, interactive instruction has a proven track record in improving "Astro 101" courses for non-majors, but has rarely been applied to higher-level astronomy courses, such as for majors. Yet the basic cognitive principles supporting active learning should hold true for students at all levels - so shouldn't we hope for similar gains in classes aimed at majors?

We present here an initial report on an updated calculus-based *Introduction to Astrophysics* class, taught at UCLA this spring using techniques such as Think-Pair-Share and Just-in-time teaching, that suggests such active-learning techniques can indeed enhance the learning experience for astrophysics majors, too.

The Class

- *Introduction to Astrophysics I: Light, Stars, and Nebulae.* The first course in the UCLA astrophysics major.
- 1 quarter (10 weeks) long, followed by another quarter on galaxies & cosmology.
- Two 75-minute lectures each week, plus one 50 minute discussion section
- ~ 20 students, mostly sophomores intending to major in physics or astronomy.
- Prerequisites include calculus, mechanics, and E&M, but students vary widely in previous exposure to more advanced physics, particularly including astronomy.

What We Did Differently

- Pre-class *online reading questions*, to motivate students to actually do the reading on time before class. Typically we asked 3-4 questions (multiple choice, matching, or free response) per 5-10 page reading assignment, designed to take no more than about 5 minutes after the reading was done. These were due by midnight the night before each class period, and counted for 5% of the grade.
- Students were also asked to submit online their own questions for clarifications of the readings, so that lectures could be tailored to focus on the topics students found most difficult. (*"Just-in-time Teaching"*)
- During class, *Think-Pair-Share questions* were used extensively to engage students and get them actively thinking about the material and working with their peers. For such a small class, rather than using electronic clickers, students just held up colored 3x5 cards to indicate their answers.
- An weekly "problem solving session" encouraged students to gather and discuss homework problems, working together in a classroom with several whiteboards.

What We Left the Same

- The content: Coordinates and sky motions, telescopes, the interaction of light and matter, atomic structure and spectral line formation, spectral types, the H-R diagram, orbital motions, binary stars, stellar structure, stellar evolution.
- The text: *Fundamental Astronomy* by Kartunnen et al. (Comparable in level to Carroll & Ostlie's book, or Kutner's book, etc.)
- Biweekly lectures at a blackboard with derivations of equations, explanations, etc.
- Challenging weekly problem sets, counting for 20% of the course grade The majority of problems were re-used from previous years, though some new ones were developed too. Students were encouraged to work in small groups, but write up solutions individually.
- 2 midterms, 1 final exam. These were given in class, no calculators allowed, and in total counted for 75% of the course grade.

Example Think-Pair-Share questions for the majors curriculum

Consider two stars:

Star A: *T = 3000 K* *R = 3* $R_\odot$
Star B: *T = 6000 K* *R = 1* $R_\odot$

How does star A's *B-V* color compare to that of Star B?

- A: $B_A - V_A > B_B - V_B$
- B: $B_A - V_A = B_B - V_B$
- C: $B_A - V_A < B_B - V_B$
- D: We need more information to decide

Assume you have two telescopes, which are exact copies of each other, but one is 3x bigger:
D = 0.1 m, focal length 0.3 m
D = 0.3 m, focal length 0.9 m

If you look at the surface of the Moon through each of these telescopes, in which does it look brighter?

- A: The 0.1 m telescope
- B: The 0.3 m telescope
- C: The brightness looks the same in both

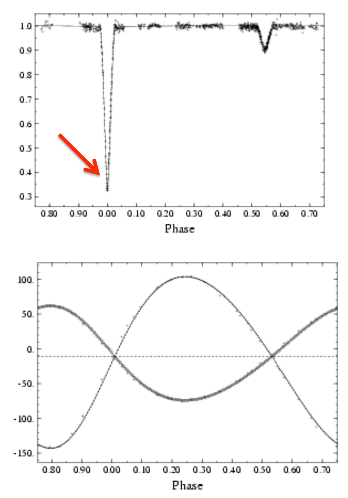
The Martian solar day is 24 h 39 m long, and the Martian year is 668.6 Martian solar days. Mars rotates and orbits both counterclockwise. Roughly how long is Mars' sidereal day?

- A: 24 h 31 m
- B: 24 h 35 m
- C: 24 h 37 m
- D: 24 h 41 m

Note: It is possible to answer this ***without*** using a calculator if you think carefully!

We developed a set of ~60 new Think-Pair-Share questions based on our content and skill goals, and used these in every class. Our aim was for these questions to be answerable in just a minute or two using basic reasoning and *simple* mathematics (e.g. ratios or scalings, rather than detailed calculations, which were left for problem sets). Writing good questions proved one of the hardest and most time consuming aspects of this whole process, and not every question worked out the way we'd hoped! Yet the surprises were often valuable lessons for us, when some questions we'd expected to be easy proved surprisingly challenging for students, thus showing us areas to cover more carefully.
Our library of questions (and our notes on how well each of them worked) are available for any interested instructors - just ask!

Consider this data for an eclipsing binary. At the marked eclipse, which star is closer to us?



- A: The more massive star.
- B: The less massive star.
- C: We can't tell without more information.

If the pressure at the center of the Sun is P_c, then what is the pressure at the center of an 0.5 $M_\odot$ star?

(Assume this star is on the main sequence)

- A: 0.25 P_c
- B: 0.5 P_c
- C: 2 P_c
- D: 4 P_c

A nonrelativistic degenerate gas is compressed from an initial density ρ_i to a final density ρ_f.

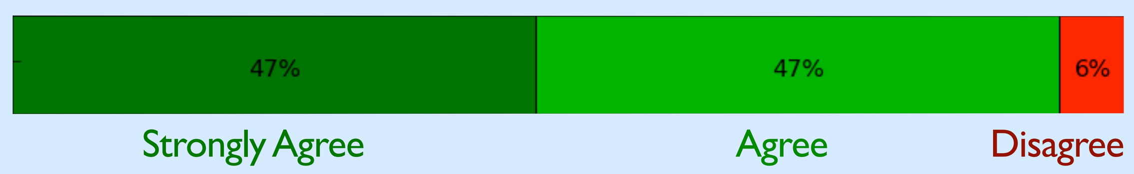
The average momentum of each particle in this gas will increase by a factor

- A: (ρ_f/ρ_i)
- B: $(\rho_f/\rho_i)^{1/3}$
- C: $(\rho_f/\rho_i)^{-1/3}$
- D: $(\rho_f/\rho_i)^{5/3}$

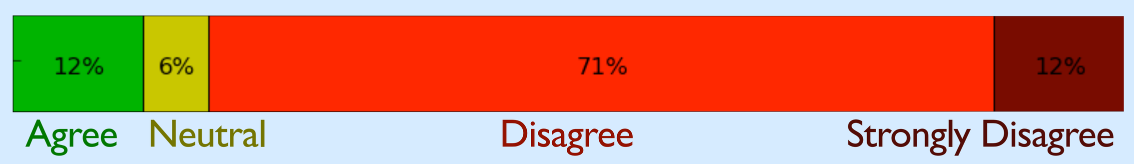
Students' opinions on these methods were very positive

"I found doing the reading before class helped me understand the material better."

"Think-Pair-Share questions help me understand the material better."



"I prefer more 'traditional' physics classes, with just regular lectures"



Opinions about Online Reading Questions:

"The online questions were good indications of important points in the book, and they helped me to focus on the important concepts."

"Reading before the lecture creates a background of what is going to be taught in the mind, which acts as an excellent base for learning… The online questions forced me to understand stuff rather than just using equations - which is my real goal!"

And about Think-Pair-Share Questions:

"The questions definitely gave me a more immediate working knowledge of the material, because I didn't have to wait to the homework before seeing problems."

"I really liked the questions because they broke up the topics. If it was just lecture things usually start running together for me… I would definitely like to see more classes use this technique."

"Their difficulty was just right: some of them were hard, but then that's how one learns. Concept questions are great as they encourage thinking and interaction with fellow students.

Conclusions

Our informal observations after one term with this approach are that students are more engaged and alert, and score higher on exams than typical in previous years. This is anecdotal evidence, not hard data yet, and there is clearly a vast amount of work to be done in this area. But our first impressions strongly encourage us that interactive instruction is superior to traditional lectures for this level of class, too. Interactive instruction does require more preparation than pure lectures, but we also found it to be more rewarding and enjoyable, since there is so much more immediate feedback on how well students are learning. We strongly encourage others to adopt this approach, and look forward to many classes ahead.

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References: Weimer, *Learner-Centered Teaching*, 2002. Slater & Adams, *Learner-Centered Astronomy Teaching*, 2002
Klionsky, (2002) in "Innovative Techniques for Large Group Instuction", NSTA Press. McCrady & Rice (2007), AER 7:13

Designing with Explicit Goals: An Example

Before the term began we developed a list of 72 specific goals for students (3-4 per class period). We constantly referred to these goals to guide our instructional design, ensuring that each goal was addressed in turn at every stage of activity. We show here one such thread through the course.

GOAL: After this class, students should be able to

- Apply Kepler's 3rd Law to calculate the period or semi-major axis of an orbit, or the mass of the gravitating body.

Before Class

Reading Handout

Reading Assignment #11

This reading covers orbital motions ("Celestial mechanics") as described by Newtonian physics. You have probably seen much of this material previously in your physics classes.

Read Karttunen sections 6.1 to 6.5 (7 pages total)

The first part of this chapter (up to 6.5) is a derivation of Kepler's Laws starting from Newton's laws. Section 6.2 in particular is fairly heavy mathematically. You should read through this to get a general flavor of how the derivation goes, but you're not going to need to remember all the details. We'll go over the important aspects in class.

Online Question

UCLA Common Collaboration and Learning Environment

You are logged in as PERRIN MARSHALL D. (Log

CCLE ▶ 09W-ASTR81-1 ▶ Quizzes ▶ Reading Questions 11 ▶ Attempt 1   Update this Qu

Reading Questions 11

2 Marks: --/3

If there were a planet in our solar system orbiting at a distance of 4 AU from the sun, what would its orbital period be? Give your answer in years.

Answer:

During Class

Lecture!

Concept Question

By watching the Alpha Centauri system for decades, we discover it has an apparent semi-major axis of 18" and the orbit takes 80 years to complete. Also, it has parallax = 1.3"

What is the total mass of the 2 stars?

- A: 1 $M_\odot$
- B: 2 $M_\odot$
- C: 4 $M_\odot$
- D: 6 $M_\odot$

After Class

Homework Problem

5. The velocity curves of a double-line spectroscopic binary are observed to be sinusoidal, with amplitudes 20 and 60 km/sec and a period of 1.5 years.
   (a) What is the orbital eccentricity?
   (b) Which star is the more massive and what is the ratio of stellar masses?
   (c) If the orbital inclination is 90°, find the relative semi-major axis (in astronomical units) and the individual stellar masses (in solar masses).

Exam Problem

Question 2

The dwarf planet, Pluto, and its moon, Charon, eclipse each other and revolve in circular orbits around the common center of mass. Doppler shift measurements reveal maximum velocities of v_p and v_c for Pluto and its moon, respectively. The orbital period is P_{pluto}. Derive expressions for the mass of Pluto, M_p, and for the mass of Charon, M_c, in terms of given quantities.