

Excerpts from

Peer Instruction for Astronomy

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Visit the Web site and ConcepTest Library at

<http://hea-www.harvard.edu/~pgreen/educ/PIA.html>

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Chapter 1: INTRODUCTION

(excerpts)

As any teacher knows, the real test of learning is to be able to explain what you've learned to others. Regardless of the subject matter, when students are actively involved, they learn more and retain it longer than when they try to absorb knowledge passively. Small group learning techniques are now in use in science classes all over the country. Students are becoming accustomed to this method in high schools, and will not be surprised to see it in introductory college astronomy. Various forms have been tested and evaluated, and are even now being sculpted by experience in the class and laboratory. Students who work collaboratively report more satisfaction with their classes (Beckman, 1990; Cooper et al. 1990; Johnson, Johnson, and Smith, 1991a). This form of learning has a variety of names and implementations falling under the classification of collaborative learning (CL), including cooperative learning, collective learning, peer teaching, peer learning, Peer Instruction, team learning, study circles, study groups, work groups, etc.

Group work can take the form of informal learning groups, formal learning groups, or study teams. The latter two usually are formed for projects that span many classroom or laboratory sessions, with the aim of completing a project. *Peer Instruction for Astronomy* focuses on what instructors can do in class to boost student learning and satisfaction, and so the emphasis here is on informal learning groups. These are temporary clusters of students, formed as needed, often within a single class session.

These informal groups help gauge students' understanding of the material, allow students to apply what they are learning, and provide a change of pace. Peer Instruction (sometimes called peer teaching) is a form of collaborative learning. Peer Instruction has been developed and implemented for introductory Physics by Eric Mazur at Harvard University. The improvements in student performance have been widely publicized in Sheila Tobias' book *Revitalizing Undergraduate Science* (Research Corporation, 1992). By encouraging student participation and interaction during lecture, Peer Instruction encourages students to critically think through the arguments being developed, and to discuss and defend their ideas and insights with their neighbors. At any time and in a class of any size, you can implement Peer Instruction. For instance, you may simply ask students to turn to a neighbor for 2 minutes to solve a puzzle or question you've just posed during a lecture.

The goal of this book is to facilitate the implementation of Peer Instruction in introductory astronomy classes by providing ideas, guidelines, and a wealth of examples ready for your use in the classroom. First, I'll outline active learning techniques like Peer Instruction, and the wealth of usage and research behind them. When you first undertake

to incorporate Peer Instruction, you will not be alone! I will also provide detailed classroom recipes for the implementation of Peer Instruction, with specific examples. A broad library of ConcepTests forms the core of the book. ConcepTests are short, conceptual multiple-choice questions for use during class, that serve to gauge comprehension of scientific principles in real-time, to challenge misconceptions, and to foster student engagement through Peer Instruction. All along the way, I provide quick summaries of how to implement Peer Instruction in the classroom for the harried instructor. In addition, I will encourage you to participate in a broad range of assessments. I describe options for assessing your students, and for evaluating your own implementations of *Peer Instruction for Astronomy* using input from students or colleagues. I also invite you to join a broad-based collaboration of instructors working to enhance Peer Instruction by building and improving the library of ConcepTests, and by assessing and improving Peer Instruction itself using data from the field - the reported experiences of you and other astronomy instructors.

Chapter 3: RECIPES FOR THE CLASSROOM

Don't panic. There is no need to throw away your lecture notes and radically restructure your class for the next semester. Implementation of Peer Instruction can happen gingerly if you prefer. Of the many college and university classes using cooperative learning techniques, most employ them between 15 and 40% of the available class time (Cooper 1990, ref. in Millis & Cottell p14). These techniques supplement, but need not replace, direct instruction and lectures

A BRIEF RECIPE

Briefly, lectures are broken into sections covering key points. Start with a more-or-less standard format mini-lecture on one of the fundamental concepts to be covered. This mini-lecture might last about 10 minutes, and is then followed by a ConcepTest, a short multiple-choice question that tests the students' understanding. After one minute, you may ask the students to record or display their individual answers. Recording the initial answers affords the opportunity to track the improvements in understanding that Peer Instruction later builds. You may then ask students to turn to their neighbors to try and convince them of their individual answers. This invariably leads to animated discussions. After another minute or so, the students are asked to reconsider their answer and record it again. You then take quick poll to decide whether to move on to the next concept, or to

continue exposition on the same material. A variety of options are available to suit your taste; some are sketched below. The process, lecture/test/discuss/retest, may repeat several times until the end of the class. Depending on the material, you may thus expect to cover 3-4 key points during a typical one hour lecture period. When you implement Peer Instruction in your classroom, a good plan might be to break your lecture outlines into 3-4 subsections.

As an example, a lecture on quasars can be broken up as follows:

- 1.How nearby 'active' galaxies differ from normal galaxies
- 2.Evidence for supermassive black holes
- 3.Quasar distances and luminosities
- 4.The epoch of quasar formation

Before class, you can choose (or compose) a couple of ConcepTests for each key point you plan to cover. Following your mini-lecture on one such point, the briefest possible use of a ConcepTest might be as follows - simply as a real-time gauge of class comprehension.

ConcepTests for Feedback Only - High Comprehension

1. Mini-lecture
2. Quick-read tally via ConcepTest
Yields >90% correct answers
3. Identify and explain the correct answer
4. Move on

After every ConcepTest, you should allow a moment for an explanation, even when the vast majority of students chose the correct answer the first time, without recourse to peer discussions. First, an explanation should be available to those students who did answer incorrectly. Second, some students will glean the correct answer without true understanding, either from wording, context or from watching others.

After a ConcepTest, you may instead discover that comprehension is so low that you feel the students should not try to convince each other of the correct answer since so few of them know it.

ConcepTests for Feedback Only - Low Comprehension

1. Mini-lecture
2. Quick-read tally via ConcepTest

- Yields <20% correct answers
3. Continue mini-lecture, allow for greater detail, review and questions
 4. Re-tally with a new ConcepTest to gauge comprehension

The figures of 90% and 20% are of course simply suggestions. Use your own judgment. If the comprehension is intermediate, as is most often the case for well-chosen ConcepTests, then Peer Instruction comes fully into play. Here I provide some time estimates as a guide.

ConcepTests with Peer Instruction

1. Mini-lecture (10 minutes)
2. Pose ConcepTest (1 minute)
3. Quick-read tally (1 minute)
Yields 30-80% correct answers
4. Students break into peer groups for discussion (2 minutes)
5. Re-tally after discussion (1 minute)
6. Iterate or move on

If students have already had their first peer group discussion, and a tally shows that a significant but not overwhelming fraction (say half) of the groups found the right answer, then you can ask each group to combine with the nearest group that has chosen a different answer. For a concept this knotty, I suggest allowing about 4 more minutes of discussion for the new large groups to arrive at a single answer.

For Peer Instruction, the largest and most crucial investment of instructors' time is in choosing good ConcepTests that fall in the middle group, allowing students to teach each other most effectively. This generates the greatest student engagement, but also relieves you from having to cram material into a full-time lecture, since you now emphasize key concepts over rote learning. I cover hints for constructing good ConcepTests later on, and a primary goal of this book is to provide many of them, so that the skids are greased for your foray into Peer Instruction.

Now you can see that in the most common situation, covering a key topic should take just about 15 minutes of class time, even allowing for the real-time feedback and the student interaction and discussion that Peer Instruction provides. While the back-and-forth with students may seem to throw a wrench into the clockwork of a traditional lesson plan, your adaptation will be easier than you might think. Wander around and listen to the discussions and debates going on. While the students deliberate, you will have some time to think, and an opportunity to evaluate where any confusion might lie and how to address it.

Chapter 4: CONCEPTTESTS

(excerpts)

Short, conceptual, multiple-choice questions can be used for two purposes simultaneously - feedback and learning. *Feedback* gives you the ability to quickly gauge student comprehension during class, allowing real-time adaptation of the lecture. *Learning* is facilitated by challenging students to reorder their preconceptions and confront their misconceptions by discussing conceptual puzzles with peers in a collaborative atmosphere.

Accessing ConcepTests

One of the most labor-intensive parts of using Peer Instruction is the creation of a large collection of appropriate multiple choice 'puzzlers' of this type. A significant number would be needed simply to cover all the many major topics spanned by most beginning college astronomy courses. However, since class levels vary dramatically both within and between institutions, an even larger collection is advisable. The sample of ConcepTests provided in this chapter is meant to ease an instructor's entry into Peer Instruction for Astronomy. This collection contains contributions from instructors across the country, and should be considered a truly collaborative, ongoing community effort of astronomy educators who are interested in progress and innovation in the classroom. The ConcepTests Library remains accessible on the web at

<http://hea-www.harvard.edu/~pgreen/PIA.html>

Astronomy instructors can both access and contribute to this library. Furthermore, as discussed later, feedback from instructors on the content and scoring of individual ConcepTests will be used to continually adapt and refine the Library in the future, making it a dynamic, accessible tool suitable for direct use in the classroom, but also as a potential *database* for research on and assessment of the technique of Peer Instruction and its results.

Chapter 5: A LIBRARY OF CONCEPTTESTS

(excerpts)

The Night Sky

The reason stars twinkle is because of motion

- a) on their surface.
- b) of the Earth.
- c) of the Solar System.
- d) of gas in Earth's atmosphere.
- e) relative to the observer.

Which of the following stellar properties can you estimate simply by looking at a star on a clear night?

- a) Distance.
- b) Brightness.
- c) Surface temperature.
- d) Both a and b.
- e) Both b and c.

Seasons

What causes winter to be cooler than summer?

- a) The Earth is closer to the Sun in summer than in winter.
- b) The daylight period is longer in summer.
- c) The Sun gets higher in the sky in summer.
- d) both B and C.
- e) all of the above.

Imagine a planet whose rotation axis is perpendicular to its orbital plane. How would you describe its seasons?

- a) shorter than those on Earth.
- b) longer than those on Earth.
- c) constant.
- d) the same as those on Earth.

Orbital Motion

Kepler's 3d law (that the period squared is proportional to the semi-major axis cubed) does NOT apply to the motion of

- a) a satellite around the Earth.
- b) a comet around the Sun.
- c) one star about another in a binary star system.
- d) one galaxy about another.
- e) All of the above apply.

A description for the relationship between the period of revolution P and the distance from the center R of a point on a record on a turntable would be

- a) P^2 is proportional to R^3 .
- b) P^2 is proportional to R .
- c) P is proportional to R .
- d) P does not depend on R .

Forces & Acceleration

Which situation(s) does NOT describe an acceleration:

- a) a car traveling with constant speed on a straight road.
- b) a car traveling with constant speed around a bend.
- c) a planet traveling in its orbit around the Sun.
- d) a car decreasing speed on a straight road.
- e) an electron traveling around a nucleus.

The escape velocity from the Moon is less than that from the Earth because of the Moon's

- a) lower density.
- b) smaller mass.
- c) smaller radius.
- d) higher temperature.
- e) distance from the Earth.

Scales

The establishment of a reliable cosmic distance scale is a "bootstrap process" because

- a) distance steps are all calibrated independently.
- b) each distance step calibrates the next step.
- c) scientists build from past work.
- d) the Hubble Constant calibrates all the steps.

The cosmological principle enables astronomers to generalize from what they observe to the properties of the universe as a whole. The principle states that any and all observers, everywhere in space, should see, on average, the same picture of the universe as us on scales comparable to

- a) the Solar System.
- b) the galaxy.
- c) superclusters of galaxies.
- d) atoms and subatomic particles.

The distance between the Sun and its nearest star is smaller than the distance from the Milky Way Galaxy to the next nearest large galaxy Andromeda by a factor of about

- a) a hundred.
- b) a thousand.
- c) a million.
- d) a billion.

Continuous Radiation, Emission and Absorption

A star with a continuous spectrum shines through a cool interstellar cloud composed primarily of hydrogen. The cloud is falling inward toward the star (and away from Earth). Which best describes the spectrum seen by an Earthbound observer?

- a) blueshifted hydrogen emission lines
- b) blueshifted hydrogen absorption lines
- c) redshifted hydrogen emission lines
- d) redshifted hydrogen absorption lines
- e) a redshifted hydrogen continuum

The Sun

Compared to the Sun, most other stars in the Milky Way Galaxy are

- a) as small relative to the Sun as they appear in the sky.
- b) smaller.
- c) about the same size.
- d) much larger.

The photosphere (the visible surface) of the Sun is like

- a) the surface of the Earth; you could stand on it, if you could survive the heat.
- b) the surface of the ocean; you couldn't stand on it, but you would clearly be able to detect differences above and below it.
- c) an apparent surface; you would notice very little change as you go through it, as when you fly through a cloud.
- d) the surface of a trampoline; you could land on it, but the intense pressure would push you away again.

Energy Generation in Stars

Why does fusion of hydrogen release energy?

- a) Fusion breaks the electromagnetic bonds between hydrogen atoms, releasing energetic photons.
- b) The mass of a helium nucleus is smaller than the mass of four protons.
- c) The mass of a helium nucleus is larger than the mass of four protons.
- d) The velocity of four protons is larger than the velocity of a helium nucleus.
- e) None of the above are true.

Why would two protons combine to form an atom of deuterium (heavy hydrogen) in the core of a star like the Sun?

- a) The electromagnetic force strongly attracts the protons.
- b) The gravitational force strongly attracts the protons.
- c) The velocity of protons in the core of the Sun is very large.
- d) Protons never combine to form deuterium in the core of the Sun.
- e) Both a and c.

Stellar Evolution

If two stars burning hydrogen in their cores (are on the main sequence), and one is more luminous than the other, we can be sure that the

- a) more luminous star will have the longer lifetime.
- b) fainter star is the more massive.
- c) more luminous star is the more massive.
- d) more luminous star will have the redder color.

You are an immortal alien being, hiding in the photo archive room of a library on Earth. You can best learn about the life cycles of people by bringing home the drawer filled with photographs of

- a) individuals.
- b) crowds on the street.
- c) people lined up at the voting booth.
- d) doctors.

The Hubble Expansion

Your job is to compile a representative catalog of galaxies. Assuming our region of the universe is typical, the best criterion to use to decide whether to include galaxies in the catalog is to include all galaxies on the sky with

- a) magnitudes brighter than some chosen limit.
- b) apparent diameters larger than some chosen limit.
- c) recession velocities less than some chosen limit.
- d) surface densities of stars larger than some chosen limit.

Suppose the universe were not expanding, but was in some kind of steady state. How should galaxy recession velocities correlate with distance? They should

- a) be directly proportional to distance.
- b) reverse the trend we see today and correlate inversely with distance.
- c) show a scatter plot with most recession velocities positive.
- d) show a scatter plot with equal numbers of positive and negative recession velocities.

Suppose the Hubble Constant were measured and found to be twice as large as it is now believed to be. The implied maximum age of the universe in a Big Bang model would be

- a) halved.
- b) the same.
- c) doubled.
- d) squared.

Cosmology

Which of the following observations about the nature of the universe can be made with only a small telescope?

- a) The universe is expanding.
- b) Most of the matter in the universe does not emit light.
- c) Luminous matter in the universe occurs in clumps rather than being evenly distributed.
- d) There is background radiation in all directions that came from the Big Bang.

The cosmological principle enables astronomers to generalize from what they observe in the nearby universe to the properties of the universe as a whole. The principle means that no matter where you are in space, you should see that

- a) galaxies are all moving away from the same point.
- b) the universe does not change with time.
- c) space looks approximately the same in all directions.
- d) every region of space is unique.

Olber's Paradox asks why the night sky is dark, when every line of sight must eventually fall on a star. Which of the following reasons would best explain the darkness at night? It is because the universe is

- a) infinite and mostly empty.
- b) clumpy, so not every sightline intercepts a star.
- c) expanding, so distant stars are redshifted.
- d) young, so there are only stars to a finite distance.

READING ASSIGNMENTS & READING QUIZZES

Peer Instruction relies heavily on students having read the relevant assigned material before class. Only then can they have the knowledge and insight necessary for fruitful interactions with the instructor (via ConcepTests) and with other students (in their discussion groups).

Below I include an example of the web form that I use for reading quizzes. The web form is at a standard web address of which I remind students in class. The quizzes are due before the next class begins, as indicated on the web form. When students fill out the form and submit it, I receive a standard format response that is easy to grade and tally. Below the responses, space is offered for a quick assessment of student confidence, or for comments about the quiz or readings.

Web Reading Quiz: Astro 101

Chapter 3, due BEFORE class 31 Feb, 2007

Giant stars are rare because

- a) they do not form as often as main sequence stars.
- b) giant stars are unstable.
- c) the giant stage is very short compared to the main sequence stage.
- d) elements heavier than helium are relatively rare.

In a color-magnitude diagram of a star cluster, the blue end of the main sequence is useful for defining the age of the cluster because

- a) blue stars are not affected by extinction and reddening by dust.
- b) stars just slightly brighter and redder are just now evolving off the main sequence to become giants.
- c) older, metal-poor stars are blue.
- d) the hottest stars are the oldest stars in a cluster.

Your NAME (required for credit!)

How confident are you about your answers?

- 1) Guessing!
- 2) Some idea.
- 3) Good idea.
- 4) Absolutely certain.

Any brief comments or questions about this quiz or the reading?

Please only press the Send button once!

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CHAPTER 7: EPILOG

Try Peer Instruction in your college introductory astronomy class. It's not hard to implement, and yields rapid rewards for both you and your students. While Peer Instruction is scalable to your level of interest and commitment, you will benefit by putting much more than a toe in the water. Experience shows that a full implementation, meaning two or three ConcepTests and discussions per lecture hour, accomplishes a lot. *Peer Instruction for Astronomy*, thoughtfully administered will almost surely

1. raise class attendance and lower course attrition.
2. boost and hold the interest of your students.
3. heighten your awareness of students' comprehension.
4. highlight common misconceptions to be addressed directly in lecture.
5. increase student understanding of key physical concepts.
6. improve student retention.
7. develop students' ability to communicate scientific ideas.
8. enhance students' collaborative skills.
9. raise student satisfaction with your course and appreciation of your teaching.

Now, why should you buy all that? While there is a huge body of research documenting the effectiveness of cooperative learning techniques like Peer Instruction, the effectiveness of the specific techniques discussed here, and their particular application to astronomy have only begun to be studied. Are all the above points true? In what circumstances? How can you trouble-shoot your implementation of Peer Instruction for Astronomy? It is crucial that the experience of teachers like yourself be shared in the community of astronomy instructors and educators. Peer Instruction for Astronomy should be researched and documented in detail. Don't just go it alone. Check the web sites, readings, and references below so we can all learn and benefit from each other. Share the wealth!

Chapter 8: READINGS & RESOURCES

(excerpts)

<http://aer.noao.edu>

The **Astronomy Education Review**, hosted by the National Optical Astronomy Observatories, has articles on a broad range astronomy and space science education topics, ideas for innovative teaching and outreach, funding opportunities, meeting announcements etc.

<http://www.astrosociety.org/education/resources/resources.html>

The **Astronomical Society of the Pacific's** Education Resource page, authored in large part by Andy Fraknoi, lists and links astronomy education projects and resources in the U.S., and provides publications, some free.

<http://solar.physics.montana.edu/aae/adt/> or <http://www.aacc.cc.md.us/scibrhufnagel/>

The **Astronomy Diagnostic Test** is provided in the Appendix of this book, but updates, statistics of usage, and a Spanish language version are provided at this web site.

<http://shiraz.as.arizona.edu/>

The **Conceptual Astronomy and Physics Education Research** (CAPER) team's mission, focussing on collaborative learning strategies, is to develop and disseminate effective instructional interventions and authentic assessment strategies based on research in student understanding. The team conducts research and public outreach activities in the areas of physics, astronomy, and earth/space science.

<http://hea-www.harvard.edu/~pgreen/PIA.html>

At this *Peer Instruction for Astronomy* web site, the ConcepTests Library from Chapter 5 remains accessible on the web where Astronomy instructors can both access and contribute. Feedback from instructors on the content and scoring of individual ConcepTests will be used to continually adapt and refine the Library in the future, making it a dynamic, accessible tool suitable for direct use in the classroom, but also as a potential *database* for research on and assessment of the technique of Peer Instruction and its results.

<http://mazur-www.harvard.edu/education/pi.html>

Peer Instruction for physics by Eric Mazur's group at Harvard explores collaborative learning in large lectures. The related site <http://galileo.harvard.edu/home.html> from the Galileo project includes a growing, searchable database of ConcepTests for Physics and other sciences. Mazur's method is described in *Peer Instruction: A User's Manual* (see **Readings**), where Physics ConcepTests are provided. The book also includes two nationally recognized evaluation tools, the Force Concept Inventory and the Mechanics Baseline Test, usable as pre-tests and post-tests to evaluate both teaching effectiveness and student learning. Reading quizzes, conceptual exam

questions, and ConcepTests intended for a one year introductory college physics course are included.