Bianchini et al. (2002), Rosser (1997), and Banks (1999), suggest that merely adding side notes about the work of underrepresented people has merit, but is insufficient. They argue that teaching inclusively should focus on enabling students to consider concepts from diverse perspectives and to appreciate that knowledge is socially constructed. As much as we would like to, we are not in a position to provide guidelines on how to make ASTRO 101 more inclusive. All we can hope to do at this point is to make you aware that your class will be greatly improved if you can find ways to include astronomy as a diverse endeavor in which people of many different backgrounds engage.

Box 2.6 Principles of Good Practice

The *Seven Principles for Good Practice in Undergraduate Education*

1. Encourage student-faculty contact.
2. Encourage cooperation among students.
3. Encourage active learning.
4. Give prompt feedback.
5. Emphasize time on task.
6. Communicate high expectations.
7. Respect diverse talents and ways of learning.

Adapted from Arthur W. Chickering and Zelda F. Gamson (1987).

Chapter 3

Teaching for Understanding: Recent Results from Physics and Astronomy Education Research

Over the last two decades, our scientific community has witnessed an explosive growth in the number of scientists who are adopting research in teaching and learning as their principal area of academic scholarship. In particular, recent national conferences of the American Association of Physics Teachers (AAPT) have seen physics education research (PER)[1] presentations and PER participation go from being barely visible to dominating many conference attendees' schedules. The AAPT, with leadership from the PER community, is even publishing *Physics Education Research—A Supplement to the American Journal of Physics* to serve this community. Some of the recent results resulting from this flurry of activity have significant implications for teaching ASTRO 101; we summarize some of the most influential ones to provide the reader with a context for the recommendations in the following chapters.

Students Can Successfully Solve Seemingly Complicated Problems With No Meaningful Understanding

Although certainly not the first to present these ideas, probably the most publicized introduction to the impact of research in PER is the story of awakening told by Harvard physics professor Eric Mazur (1996). Mazur, a respected research physicist and award-winning teacher, had always enjoyed teaching introductory physics courses, found his students could

[1] Many members of the *Astronomy Education Research* (AER) community identify themselves as part of the *Physics Education Research* (PER) community while others have called for a new designation of a combined *Physics and Astronomy Education Research* (PAER) community. For the present purposes, we use PER to include astronomy and space sciences.

solve complicated physics problems on his tests, and consistently earned high marks on his end-of-term course evaluations from students. In short, by every traditional measure, he was an excellent teacher and had every reason to be pleased. His view of his own effectiveness was, however, about to change.

In the 1980s and early 1990s, David Hestenes and his colleagues at Arizona State University developed several conceptual tests—the results of which suggested that students could earn high marks in physics courses yet retain only a superficial understanding of physics. This work culminated in the creation of the *Force Concept Inventory* (FCI), which has become a standard tool in PER for assessing conceptual learning in the domain of basic mechanics (i.e., motion and Newton's laws). The great attention afforded this 29-item multiple choice test derives from four factors: (i) there is widespread agreement within the scientific community as to the importance of the content being assessed; (ii) the test items are deceptively simple leading most instructors to greatly overestimate the likely success rate of their students; (iii) the results are highly consistent across a large constituency ranging from classes in high schools to large research institutions; and (iv) students' responses are highly resistant to traditional instruction. Although the students' low scores on the FCI were troubling, what was more troubling was the relatively small improvement that occurred as a result of instruction—a result demonstrated not only at Hestenes's own institution but also for students at Harvard.

As a skeptical scientist, Mazur, upon hearing of Hestenes's results, developed a simple test in electric circuits to test this hypothesis of low gains after lecture for his students. The test required students first to perform numerical calculations for a complicated electric circuit and then to make general statements about the brightness of light bulbs in a very simple circuit. To Mazur's great surprise, his Harvard students could easily solve the numerical problem but fell woefully short for the simple, qualitative problem. In one case, a student asked Mazur if she should answer the qualitative question in the way that he taught her or in the way that she personally thought about electricity. In a process of self-discovery that continues to repeat itself again and again to scientists all over the world, Mazur realized that clearly showing students how to solve numerical physics problems was insufficient for developing their deep conceptual understanding of fundamental physical concepts. His students' deeply held misconceptions were easily masked by their facility to algebraically manipulate equations.

In reflecting on the results of these and many other similar experiments, a simple answer has repeatedly emerged—students fail to

develop a deep understanding because most traditional instructional approaches do not actually require them to do so! Students are in fact able to succeed on most faculty-created tests by memorizing a short list of facts and by being able to recognize homework-like problems and mimic solution algorithms. For students, the good grades that result from this strategy—one that is in most cases operates at a subconscious level—reinforces their belief that they are learning successfully. In fact, questions that probe (and generally uncover) deeply held misconceptions are often viewed by students as "trick questions." Moreover, for faculty, their belief that student learning is occurring is shored up in the same way. Students produce solutions to complex problems and, because the reasoning strategies that students use to arrive at those solutions (often a matching process to similar problems) are not evident, faculty reasonably conclude that students have an understanding of the underlying physical concepts and are reasoning the solution in the same way that faculty do.

Students Have Numerous Preexisting and Inaccurate Beliefs and Understandings that Interfere with Learning

A cornerstone to a constructivist approach to instruction is to identify and confront students' initial ideas about the world. In years past, faculty have looked at students as *tabla rasa*—the idea that students enter the ASTRO 101 as "blank slates" on which knowledge can simply be written (Mestre, 1991; Mestre & Touger, 1989). Although certainly not the first nor the most comprehensive study, the most public demonstration of how initial ideas can interfere with instruction was presented in the video "Private Universe" produced by Philip Sadler and his colleagues at Harvard. In this video, both Harvard college graduates and middle school students are asked to describe the reason for the seasons and the cause of Moon phases and they perform, to most viewers' great surprise, very poorly. This provocative video then goes on to show how instruction that does not adequately consider initial student ideas is unsuccessful in altering those ideas.

As the culmination of more than ten years of work, Neil Comins (2001) has identified more than 1600 misconceptions students have about astronomy. As if the presence of so many scientifically inaccurate ideas were not troubling enough for astronomy faculty, Hufnagel (2000) and her colleagues studied students at a wide variety of colleges and universities around the country over a wide range of introductory astronomy topics using a widely available survey called the *Astronomy Diagnostics Test*

(ADT)[2]. They report what most of us have always feared—that most astronomy lecture courses have only a limited impact on students' basic astronomy knowledge beyond the accumulation of facts.

Box 3.1 Thirty-three Common Misconceptions

1. Seasons depend on the distance between the Earth & Sun.
2. There are 12 zodiac constellations.
3. The constellations are only the stars making the patterns.
4. The North Star is the brightest star in the night sky.
5. Stars last forever.
6. All stars are same color.
7. Stars really twinkle.
8. All stars are isolated.
9. Pulsars are pulsating stars.
10. Asteroid belt is densely packed, as in Star Wars.
11. Meteors, meteorites, meteoroids, asteroids, and comets are the same things.
12. A shooting star is actually a star falling through the sky.
13. Comet tails are always behind the comet.
14. Comets are burning and giving off gas as their tails.
15. All planetary orbits are circular.
16. All planets have prograde rotation.
17. All moons are spherical.
18. We see all sides of the Moon.
19. Ours is the only moon.
20. Spring tide only occurs in the spring.
21. Only the Moon causes tides/the Moon has no effect on tides.
22. High tide is only between the Earth and Moon.
23. Once the ozone is gone, it's gone forever.
24. Mercury is hot everywhere on its surface.
25. Giant planets have solid surfaces.
26. Saturn is the only planet with rings.
27. Saturn's rings are solid.
28. Pluto is always the farthest planet from the Sun.
29. The Sun primarily emits yellow light.
30. The Sun is solid and shines by burning gas or from molten lava.
31. The Sun always rises directly in the east.
32. Black holes are empty space.
33. Black holes are huge vacuum cleaners in space, sucking everything in.

Adapted from Neil Comins's book *Heavenly Errors*, Columbia University Press, 2001.

We now understand that if students are going to abandon their self-formed and scientifically inaccurate ideas, they must not only be dissatisfied by the current knowledge, but the new knowledge must fit with other existing ideas and be more productive in terms of understanding a

[2] The *Astronomy Diagnostics Test* (ADT) is included in Appendix C at the end of this book and can be downloaded from http://solar.physics.montana.edu/aae/adt/.

wide range of phenomena (Posner, Strike, Hewson, & Gertzog, 1982). Otherwise, new ideas presented in class will not be successfully integrated into existing knowledge, will not be easily accessed when required, and even if memorized for the exam will be quickly abandoned afterward. This applies no matter how clearly the lecturer describes the concept. This recognition has led faculty and PER researchers to develop teaching strategies, often known as "cognitive change" strategies, that *elicit* student ideas, *confront* student ideas to help students see inconsistencies, and guide students to build accurate ideas that *resolve* these inconsistencies. Although not the only pedagogical approach to address issues of cognitive change, this is the approach that has been used most widely in recent reforms of physics and astronomy curriculum and is one that can lead to demonstrably better student learning.

Most Students are Dissatisfied with Our Introductory Science Courses

If you are not concerned yet, hang on. The situation is actually worse than it seems. Not only are students leaving our courses with a far lower level of understanding that we would like, but work done independently by Shelia Tobias (1994) and Reddish, Saul, & Steinberg (1998) suggests that too many students leave introductory science courses with more negative attitudes toward science than they originally arrived with. Tobias reports that students find that the path to an A in most introductory science courses involves memorizing what faculty write on the board and then regurgitating it back on a test—a process that most students find dreadfully boring. Reddish reports that students enter physics courses excited to learn about how mathematics and science are integrated and how science describes phenomena in the "real world." To his great dismay, he found that students leave physics courses believing that success in physics is about "finding the right formula" and that contrived physics problems have little to do with the

In an English literature class, students are expected to read the Shakespeare, and the professor's job is to help students interpret it. In stark contrast, it appears that most faculty teaching introductory science courses believe their role is to tell students the same things that are already in the textbook.

"real world." Perhaps surprisingly, these results apply to high-ability students as well, who often leave science majors to study in the humanities or social sciences, a result presented by Elaine Seymour and Nancy M. Hewitt in their groundbreaking book *Talking About Leaving: Why Undergraduates Leave the Sciences* (1997).

In terms of introductory astronomy specifically, students' expectations of what the course is going to be about are often quite different from what professors plan. Students most often think that learning astronomy is going to be first and foremost about learning constellations and, second, about black holes, space travel, and the Big Bang. Imagine students' surprise, and subsequent disappointment, when black holes and the Big Bang Theory usually get at most a single a lecture each and that constellations and space travel might only receive a cursory mention as a side note in lecture (Adams, Brissenden, Duncan, & Slater, 2001). Although many faculty state that one of the goals of the introductory astronomy course should be to engender positive attitudes toward science, it should be of little surprise that too many astronomy students find astronomy to be boring if the topics that are covered are based on what astronomers find interesting and not what students find interesting.

Active Engagement Strategies Work

Most calls for reform in college classes call for professors to develop courses in which students to become more active participants in their own learning. With the development of powerful conceptual tests, such as the aforementioned FCI and the ADT, it should be of no surprise that researchers have begun to compare various approaches to instruction. Time and time again, students in classes featuring some form of active learning experience perform better—using a variety of measures—and enjoy their learning more than students who have only been lectured to.

The most comprehensive of these comparisons was compiled by Richard Hake (1998) who compared 6542 students in 62 introductory physics courses across the nation. He found a significant difference between the gains demonstrated by students in classes characterized by some kind of "active engagement" compared to students in "traditional" courses as measured by the FCI. Students in "active engagement" classes had much larger pretest/posttest FCI gains than students who took physics in more traditional contexts, and the results were independent of the size or prestige of the institution.

Active Learning Lasts

A common complaint among faculty—and one that is confirmed by talking to students—is that, all too often, material is "learned" for an exam and then promptly discarded—the "cram and flush" approach. The primary goal of education is to do more than train students to take a near-term test; the goal is to change students' worldviews permanently and profoundly. In fact, an early criticism leveled against so-called active learning classes was that they were doing little more than a more effective version of cram and flush. However, there is a now general sense among the faculty who significantly modified their courses and are regularly achieving high FCI gains that they were witnessing real and long-lasting conceptual change. To assess this, one of us (JA) and colleagues (Adams, Francis, & Noonan, 1998) conducted a long-term follow-up of students' retention. If students' worldviews had not truly been changed, it was expected that they would gradually forget the "right answers" leading to large declines in FCI scores measured several years later. Remarkably, though, what this study found was that up to three years after the course was over, students retained more than 80% of their initial gains and were still scoring significantly higher than students in traditional classes immediately following instruction. In other words, students who learned via active engagement really do learn, and this learning is not superficial as many critics initially charged; it is the kind of deep learning for which we all strive.

Collaborative Group Activities Remove Gender and Ethnic Differences

One form of interactive engagement teaching that is getting a lot of attention is the use of collaborative groups. The theoretical underpinning of collaborative group learning is one that many scientists find difficult to swallow— that most students learn best through social interactions. This is antithetical to how many physical scientists conceive of the learning process—an individual view born out of personal experience that fails to recognize just how different most us Ph.D.s in science are from the general student population (dare we say "geeks?") Some faculty are taking advantage of students' natural inclination to social learning by inserting collaborative group learning tasks

Excellent Resources

Summaries of astronomy education research:
Astronomy Education Review
http://aer.noao.edu
AER Online Bibliography
http://www.cdes-astro.com
Astronomical Society of the Pacific
http://www.astrosociety.org/education/resources/educ_bib.html

right into the lecture portion of astronomy courses (Chapter 6 is devoted to this idea). From a PER perspective, Michael Zeilik and his colleagues at the University of New Mexico (1997), who had a high percentage of students from non-Caucasian ethnic backgrounds, were looking carefully at the effectiveness of using collaborative groups and concept mapping techniques in his introductory astronomy course. Results on their precourse surveys confirmed a well-known problem that females of all backgrounds and students from non-Caucasian ethnic minorities enter courses with lower preparation and more negative attitudes than Caucasian males. Serendipitously, what they were surprised to find was that, as measured on postcourse surveys, these initial differences among the populations were erased even though there was no intentional focus on these traditionally disadvantaged students.

Teaching for Understanding

The current state of affairs for most students is that *professors talk and students learn.* The studies briefly described here, and the scores of others with similar results that we didn't mention, strongly suggest that such a view of college science courses is insufficient. What we are advocating in this book is a change in faculty perspective on teaching—from a view of the professor as a *teacher-centered* dispenser of knowledge to a *learner-centered* orientation where the professor's role is to engineer productive learning environments. In short, learner-centered teaching considers the preexisting ideas students bring to class, helps students develop meaningful understanding that is flexible and long lasting through a variety of experiences, and provides a means for frequent student feedback to help students monitor their own progress. We also fully appreciate that few well-meaning professors exclusively embrace a teacher-centered view—most would agree with the fundamental precepts of learner-centered teaching. What they struggle with are strategies for translating this view into effective approaches in the large-enrollment class, where the physical environment, sheer size of the class, and even students' very traditional views of the teaching/learning process conspire to make this a daunting task.

Box 3.3 Levels of Understanding

What does it mean to understand an idea in science?
1. name
2. recognize
3. describe
4. compare
5. apply
6. generalize
7. integrate with other ideas

Chapter 4
Designing an Effective Syllabus

Fundamentally, a syllabus communicates to your students the key elements of your course[1]. It explains what they will be learning, why, and how their learning will be assessed. As such, it serves as a contract defining both what they can expect of you and what you expect of them. Although a minimalist syllabus might only list office hours, exam times, and how a final grade is calculated, we believe that the up-front time invested in creating a comprehensive syllabus that conveys to students a complete picture of your course will, in the end, pay many dividends over time. Viewed in this way, creating your syllabus is really a process of comprehensive instructional planning designed to maximize students' possibilities for achieving your stated learning objectives (see Chapter 2). This chapter is therefore really about course planning.

PRE-PLANNING

Pre-planning is time spent thinking about how exactly you want your students to be different as a result of your course.

Pre-planning is the stage in which you develop (or refine if you have taught the course before) an overall picture of how you would like the course to operate and what experiences you hope to provide for your students. If you have taught the course before, this is a time to reflect on what you learned last semester (see Chapter 9) and contemplate what new instructional strategies you might want to try (see Chapter 5). If this is the first time you have taught this course, especially if you are new to the institution (which frequently happens because ASTRO 101 is often viewed as an undesirable

[1] The syllabus is also important for students transferring to other institutions who need to have transfer credits assessed.