

We ask the Decadal survey committee to call on the American Astronomical Society and funding agencies such as NSF and NASA to take three actions that would significantly and systemically improve astronomy teaching in the US.

- I. Continue to support creation of research-based instruments that probe how well students learn astronomy, more deeply than typical course exams probe. Instruments should also measure the attitudes of non-major students about astronomy, and their understanding of science and ability to think scientifically.
- II. Encourage those who teach astronomy, and department chairs, to make use of these instruments, so that significant national data are collected. Adoption of changes in teaching, such as new technologies, should be based on data.
- III. Adopt a policy statement that anyone who teaches astronomy should have received at least some training in how to teach effectively, including an introduction to the scientific literature that describes the strengths and weaknesses of different teaching methods.

Nearly 700 Astronomy teachers now belong to a list-serve on which these topics are discussed and teaching results are shared. This is a significant fraction of AAS membership! This large constituency says that it is time to routinely apply the scientific method to teaching, just like we apply it to our “regular” research. Also, the National Academy has called on scientists to teach in ways that are known to be effective (*How People Learn*; Bransford et al. 2000). The National Academy recommendations are research – not opinion – based.

These three actions do not require significant funding increases. They require taking the teaching mission seriously, and targeting what is supported. They require breaking the paradigm, “I will teach the way I was taught; that was good enough for me,” which is not a scientific or data-based statement. Research in physics shows that both majors and non-majors can benefit from research-based teaching improvements.

That the American Astronomical Society has just taken over publication of the *Astronomy Education Review* is an important and commendable step. That *Phys. Rev.* now has an education part and that journals such as *Science* publish important papers on science teaching (e.g. Smith et al. 2009) are recognition of the national need for better science teaching. A Decadal Survey that does not address this key national need is incomplete.

I. Continue to support creation of research-based instruments that probe how well students learn

During the past two decades a number of physics departments have achieved large (30-50%), systematic gains in how well their students learn physics. These advances required extensive research work and grant support, like any other significant project in science; they represent more work than a single researcher can do. The methodology has now been repeated many times and proven to work. It is just starting to be applied in astronomy, and the field needs to support such efforts if astronomy is to make similar advances.

Using the method, which is based on the idea that oral exams or oral interviews are the best way to probe how well students have learned, researchers:

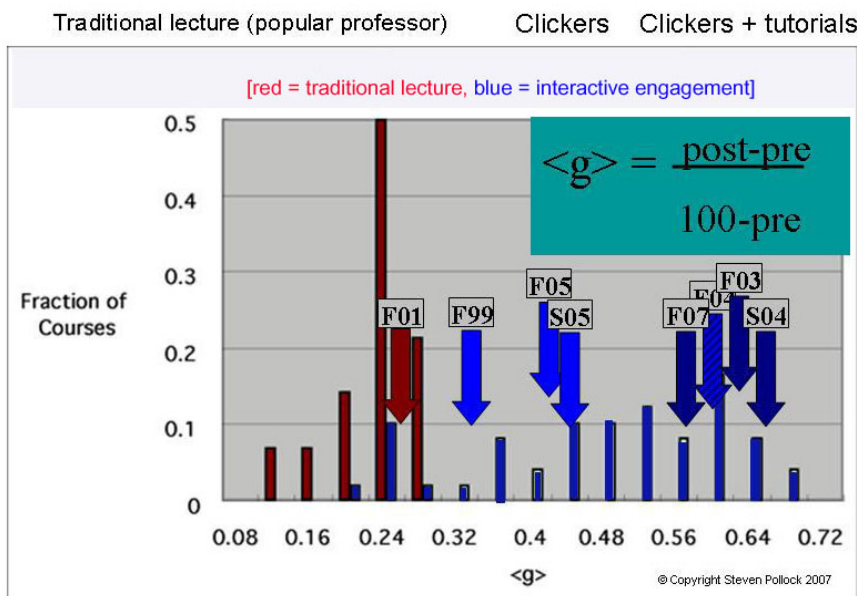
- Conduct dozens or hundreds of interviews with students. As in any good oral exam they extensively probe what students mean when they give an answer.
- Determine right and common wrong answers (misconceptions) to important questions. Important misconceptions tend to show up repeatedly (e.g. Most students are Aristotelian thinkers.)
- Construct a multiple-choice test where the wrong answers are commonly believed misconceptions.
- Give the test to thousands of students.
- Construct curricula that address the known misconceptions in ways that force students to confront their misconceptions.

The first and perhaps most well-known of the physics instruments is the Force Concept Inventory (FCI; Hestenes et al. 1992). It was given to over 6,000 students in 52 classes, in different schools, with results reported by Hake 1998. The impact of the graph below can hardly be overstated. Note:

1. The FCI is given twice, once at the start of semester and once at the end
2. The X-axis is the fraction of all the material students didn't know coming in that they learned by semester's end. (Such a "normalized gain" allows comparing students at different schools that have different entering populations.)
3. "Learned" means learned deeply = learned well enough to apply a concept to a new situation, not just memorized.

Superimposed on the national results are those from the author's university, showing that the results are extremely repeatable. *No course in the United States that is purely based on lecture has ever shown learning gains over 30%.*

Force Concept Inventory at Univ. of Colorado



R. Hake, "...A six-thousand-student survey..." AJP **66**, 64-74 ('98).

The arrows labeled F01, S05... represent classes taught at the Univ. of Colorado in Fall 2001, Spring, 2005, etc. F01 was taught by a famous and excellent lecturer.

The problem is not the faculty; the problem is that learning takes place in the mind of the student. *For significant, lasting learning to take place, students' minds must be active.*

After instruments such as the FCI pinpointed student difficulties, years of work resulted in methods such as **peer instruction** (Mazur 1997; Crouch et al. 2007) and **tutorials** expressly targeted at student difficulties. Use of these (labeled “clickers” and “clickers + tutorials in the Figure) produces dramatic improvements in learning.

Astronomy has begun producing instruments such as the Astronomy Diagnostic Test and the Light and Concept Inventory (Deeming 2002; Barder et al. 2007). The results of these tests are consistent with what was found in physics – classes that incorporate active engagement of students were systematically higher than those taught in traditional lecture style. This is on the basis of 34 course sections at 26 colleges and universities (Barder 2008).

It is essential that more research like this be supported. Topics that we know are important to astronomers, such as planets, cosmology; and the ability to understand science and think scientifically have no appropriate instruments. They need to be tested for rigorously, not speculated on. A single set of *Lecture Tutorials for Introductory Astronomy* is available (Prather et al. 2007). More are needed. Good peer instruction questions need to be developed, tested, and shared. Although this represents significant work, once done it will benefit the entire community for many years.

What astronomers *think* is happening in their own classrooms has proven to be a poor measure of what actually happens. In the major study of astronomy teachers predictions vs. actual student gains, Lightman and Sadler at Harvard found the teachers vastly overpredicted how much students were learning. (Remember this is deep, not superficial learning. Lightman and Sadler questioned students more deeply than most faculty do.)

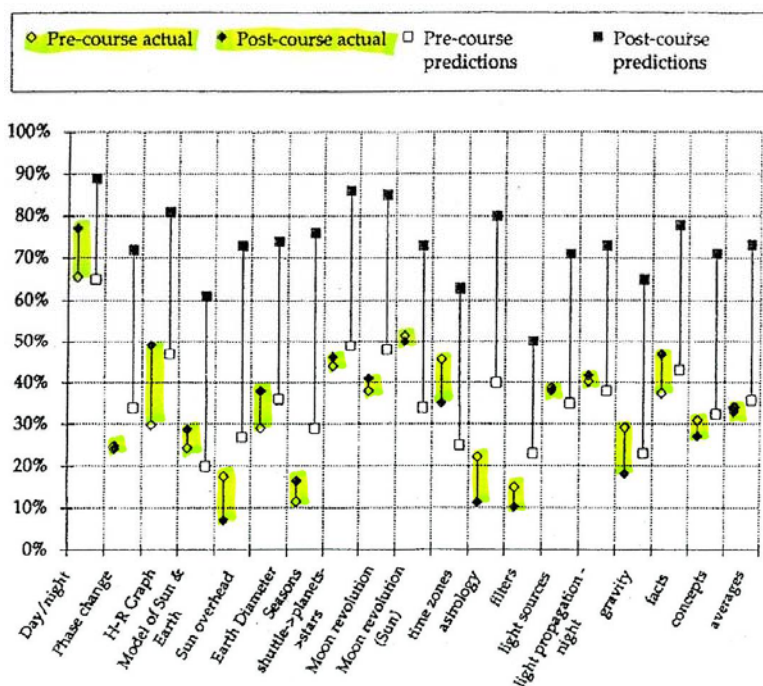


Figure 2. Learning gains are much less than those who teach astronomy predict. (Lightman and Sadler 1993)

II. Encourage those who teach astronomy, and department chairs, to make use of these instruments, so that significant national data are collected.

Effective instruments aren't useful unless they are used. It is important that instruments such as the Astronomy Diagnostic Test and the Light and Concept Inventory have been widely tested and shown to produce clear results. Now they should be used in every class, to build up a true national database.

We can get more faculty members to use good diagnostic tests with both “top down and bottom up” strategy. Bottom up is already happening. A remarkable 680 faculty members who teach astronomy now belong to a listserve (astrolrner on Yahoo groups). It is run by Gina Brissenden, who formerly worked in the American Astronomical Society Education Office. These teachers already are using what is available and asking for more. **The American Astronomical Society, NASA, and NSF** can make a difference by adopting clear and visible policies that call for good assessment of learning in all classes, and for student-centered teaching (teaching approaches designed to get students minds active).

We live and teach during a time of rapid technological change. It is ineffective and unprofessional to adopt new technology (videos, applets, DVDs, clickers, laptops) on any other basis than whether it achieves the class goals. (And any faculty member who has taken even a little training – recommendation III below – knows to spell out their goals before teaching.) It is especially important to have effective assessment when changes in astronomy teaching are made.

A good example is wireless student response systems, commonly called “clickers.” They were not widely adopted at the University of Colorado until extensive research showed they achieved desired goals such as getting students more actively engaged in learning. Now we can predict with nearly 100% certainty which uses by faculty will succeed and which will lead to failure. In fact, these can be listed on a single piece of paper: <http://www.colorado.edu/its/cuclickers/instructors/Tips.pdf> . Around 80% of faculty read the “Tips” or take a seminar on effective peer instruction and essentially all succeed. Around 20% take no instruction and most of these fail. Knowing what a difference relatively simple faculty preparation makes stresses even more the importance of Section III .

III. Adopt a policy statement that anyone who teaches astronomy should have received at least some training in how to teach effectively, including an introduction to the scientific literature that describes the strengths and weaknesses of different teaching methods.

No astronomer would ever design a telescope or satellite, or expect to publish a paper, without being familiar with the literature of what has been done previously. No one should expect to teach without preparation, either. It is malpractice to put a faculty member or graduate student in front of students with no training whatsoever in teaching.

We ask the Decadal Commission to call on the American Astronomical Society to adopt and promulgate the policy that part of preparation for the profession includes preparation for teaching, and that departments have a responsibility to play a role in this. The author was trained in such a program developed by U.C. Berkeley 30 years ago, and Berkeley offers a program today. Every department should do so.

Workshops such as those conducted by the Center for Astronomy Education (and supported by NASA) have an important role to play as well.

A small amount of preparation makes a large difference in how well most faculty members and graduate students teach. It is wrong to send them unprepared to teach large groups of students.

In closing it is worth noting that over 250,000 students take an Introductory Astronomy course each year (Fraknoi 1996). Many of these introductory students are convinced that they are “not good” in

science and therefore are challenging to teach. More than half are female, and many will be future K-12 teachers. Unless we teach them well the U.S. is unlikely to be as competitive as we would like it to be in the future, and science is unlikely to have the public understanding and support most of us would like to see. The National Academy has called on us (among others) in “Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future (2007).” Our profession is called upon to provide better science teaching. The Decadal Survey should respond officially.

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