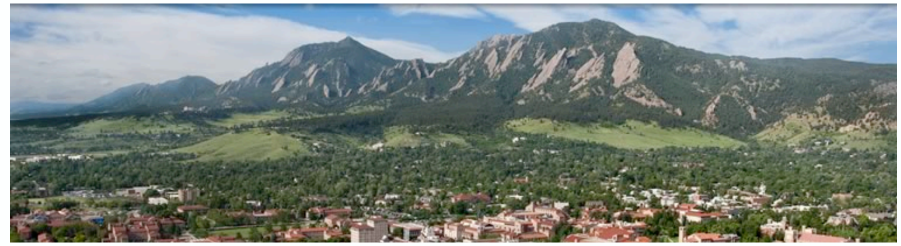

Changing the way we teach:

why we should and how we can

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Albuquerque, 9/12/13

Outline

- Why we should:
  - What students are learning, and how we're teaching them
  - Alternative teaching approaches: tutoring to clickers
  - Evidence that alternatives work better ("scientific teaching")
- How we can:
  - Barriers to change
  - A case study of change at U. of Colorado

Changing: why we should

In general, we are not doing a good job at teaching science to (most) undergraduates, particularly in large courses at the introductory level.

Problems and consequences:

- Too much emphasis on factual knowledge; too little on conceptual understanding, science skills, and the nature of science
- Many talented students opt out*
- Many survivors have low retention, persistent misconceptions, shallow understanding

At least partly because of the way we teach

* e.g. Seymour & Hewitt (1997), Talking About Leaving: Why Undergraduates Leave the Sciences, Westview

There are problems with

- what we are asking students to learn
- and how we are teaching them

What are we asking students to learn?

Bloom's Levels of Understanding

6. **Evaluation:** think critically about and defend a position

5. **Synthesis:** transform, combine ideas to create something new

4. **Analysis:** break down concepts into parts

3. **Application:** apply comprehension to unfamiliar situations

2. **Comprehension:** demonstrate understanding of ideas, concepts

1. **Factual Knowledge:** remember and recall factual information

Bloom, B, Ed. (1956) Taxonomy of Educational Objectives: Cognitive Domain, Longman, Chicago

Bloom's Levels of Understanding – Action Verbs

6. Evaluation: think critically about and defend a position
   Judge, Justify, Defend, Criticize, Evaluate
5. Synthesis: transform, combine ideas to create something new
   Develop, Create, Propose, Design, Invent
4. Analysis: break down concepts into parts
   Compare, Contrast, Distinguish
3. Application: apply comprehension to unfamiliar situations
   Apply, Use, Compute, Solve, Predict
2. Comprehension: demonstrate understanding of ideas, concepts
   Restate, Explain, Summarize, Interpret, Describe
1. Factual Knowledge: remember and recall factual information
   Define, List, State, Name, Cite

Adapted from Allen, D. and Tanner, K., Cell Biol. Educ. 1: 63-67 (2002)

Bloom's Levels of Understanding

6. **Evaluation:** think critically about and defend a position

What students really need to learn how to do!

5. **Synthesis:** transform, combine ideas to create something new

4. **Analysis:** break down concepts into parts

***A few* questions on MCAT, GRE, AP Biology exams**

3. **Application:** apply comprehension to unfamiliar situations

2. **Comprehension:** demonstrate understanding of ideas, concepts

~95% of questions on introductory level biology exams!

1. **Factual Knowledge:** remember and recall factual information

What are we asking students to learn?

Mostly factual information

We're not challenging them to think conceptually, or giving them enough practice in developing higher level thinking skills.

And part of the reason why is how we teach them

The “transmissionist” view

vs. the **constructivist view** of learning

Jean Piaget, John Dewey, D. Ausubel, et al.

Transmissionist vs Constructivist

views imply different roles for the instructor

Lecturer: I know a lot about this topic, so I will transmit my knowledge to you by telling you about it.

Facilitator: I know a lot about this topic, so I will create situations and present challenges for you that will make it easier for you to efficiently construct your own knowledge and understanding.

Compelling evidence supports the constructivist view of how learning works.

Yet most instructors in large classes teach mostly by lecturing.

Facts can be transmitted by lecturing

(though not necessarily retained by students)

Lasting conceptual understanding and science skills cannot;

they require active engagement through practice.

(Note the futility of this seminar)

Argument from experience

What should students be learning ?

(Content)

Critical thinking skills

Problem solving

Data analysis

Experimental design

Application of knowledge to new situations

How to learn on their own

What do they need in order to learn these skills ?

Practice - constructivist learning

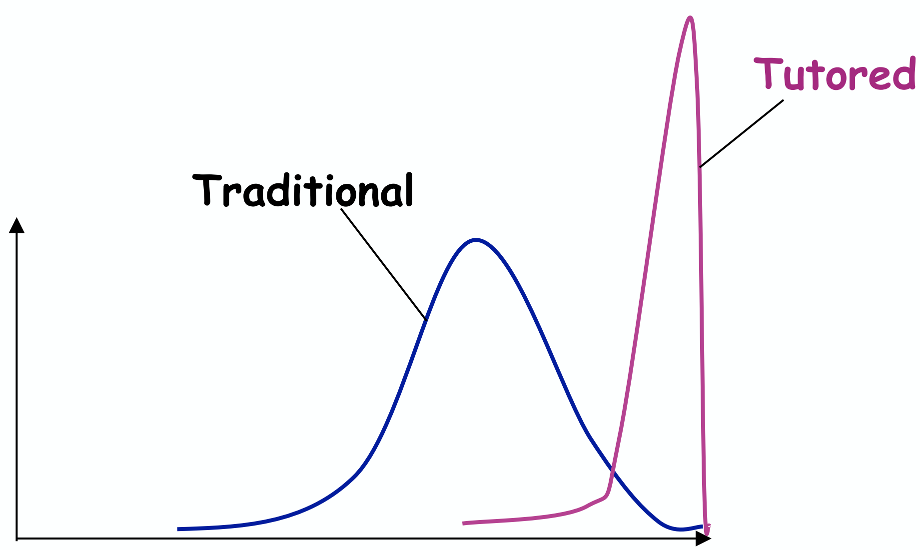
Coaching – not transmission of information

How much difference can good instruction make?

Bloom's experiment: Compare results of standard instruction to individual instruction with an expert tutor

Large increases in learning for all students compared to standard instruction.

Average for group with expert individual tutors was better than 98% of students in class with standard instruction!



* Bloom, *Educational Researcher*, 13: 4 (1984)

What do expert tutors do?

- Motivate students (real-world context, pique curiosity,...), and encourage them.
- Almost never tell students anything! Pose questions; students spend most of the time answering and explaining (formative assessment).
- Understand clearly what students do and don't know.
- Give timely, specific, interactive feedback.
- Ask questions that students are challenged by but can figure out. Progress systematically toward increasing difficulty.
- Let students make mistakes, then discover and fix by themselves.
- Require students to reflect: how solved, explain, generalize (metacognition).

Lepper and Woolverton, in Improving Academic Achievement, Elsevier 2002, p. 135

What does this have to do with teaching large science courses??

The same principles are applicable!

Expert tutors facilitate constructivist learning, and we can too, even in large classes!

Moreover, we can exploit an additional resource: group work and peer instruction.

WB Wood and KD Tanner (2012). The Role of the Lecturer as Tutor: doing what effective tutors do in a large lecture class,, CBE-Life Sciences Education 11: 3–9, Spring 2012

What are practical "constructivist" alternatives to lecturing in large classes?

- Clicker questions (challenging, with discussion)
- Problem solving (in groups)
- Analysis of data from a research paper, etc.

Any activity, **preferably cooperative and with timely feedback**, that requires students to recall, think about, apply, and verbalize concepts in the course, rather than simply record facts for later memorization.

I.e. active-learning activities rather than, or in addition to lecturing.

What's the evidence: Does introduction of active learning exercises increase student learning?

To answer this, we must approach teaching as scientists:

1) Define specific learning objectives for the course.

2) Design an assessment (assay) to measure student progress toward those objectives.

(Two simple additions to course design)

3) Compare different teaching methods and determine what works better

1) Replacing syllabi with learning objectives

(backward design, student-centered teaching)

Genetics example - the syllabus

Part of the syllabus for an introductory level genetics course

DNA replication and the Central Dogma (Review)
- DNA replication
- → Transcription
- Translation

Principles of heredity: how traits are transmitted
- Alleles
- Dominant and recessive traits

The chromosome theory of inheritance
- Meiosis

Linkage and recombination

Etc.

Syllabus	Broad Learning Goals:
Transcription	Understand the process by which DNA sequences are transcribed into mRNA. Understand that transcription provides DNA sequence information to the cytoplasm where it can direct the synthesis of specific proteins. Be aware that transcription can be regulated so that different cells in an organism produce different proteins.

Syllabus	Specific Learning Objectives - be able to:	
Transcription	Define transcription.	1
	Describe the process by which nucleotides are added to the RNA.	2
	Diagram a DNA duplex in the process of transcription showing base-pairing and strand polarity for all polynucleotides.	2-3
	Predict, for example, the possible effects of adding 3'-deoxyribonucleoside triphosphates to an *in vitro* transcription reaction in addition to the four normally occurring ribonucleoside triphosphates.	3
	Compare the mechanisms for regulating transcription in bacteria and eukaryotes.	4
	Design an experiment to determine whether all of an organism's mRNA sequences are encoded in its DNA.	5

Notice different Bloom's levels!

Bloom's Levels of Understanding – Action verbs

6. **Evaluation**: think critically about and defend a position
   Judge, Justify, Defend, Criticize, Evaluate
5. **Synthesis**: transform, combine ideas to create something new
   Develop, Create, Propose, Design, Invent
4. **Analysis**: break down concepts into parts
   Compare, Contrast, Distinguish
3. **Application**: apply comprehension to unfamiliar situations
   Apply, Use, Compute, Solve, Predict
2. **Comprehension**: demonstrate understanding of ideas, concepts
   Explain, Summarize, Interpret, Describe, Diagram
1. **Factual Knowledge**: remember and recall factual information
   Define, List, State, Name, Cite

Adapted from Allen, D. and Tanner, K., Cell Biol. Educ. 1: 63-67 (2002)

2) Designing and using concept assessments

Must be aligned with learning objectives

Should be jargon-free to allow pre-testing

Should be validated
(appropriately difficult,
actually testing what it purports to,
consistently distinguishing between
stronger and weaker students, etc.)

Bad news and good news: construction and validation of such a test takes time and effort, but several are already published with more on the way.

Validated concept assessments (inventories)

Conceptual Inventory of Natural Selection (CINS)

Measure of Understanding of Macroevolution (MUM)

Basic Tree Thinking Assessment

Genetics Literacy Assessment Instrument (GLAI)

Genetics Concept Assessment (GCA)

Introductory Molecular and Cell Biology Assessment (IMCA)

Molecular Life Sciences (MLS) Concept Inventory

Diagnostic Question Clusters on Energy and Matter (DQCs)

Internal Transport in Plants and the Human Circulatory Systems

Flowering Plant Growth and Development

Host-Pathogen Interactions (HPI)

Diffusion and Osmosis Diagnostic Test (DODT)

From Fisher, K.M. and K.S. Williams. 2011. Concept Inventories and Conceptual Assessments in Biology (CABs): An annotated list. http://www.sci.sdsu.edu/CRMSE/files/Concept_Inventories_in_Biology_20110325.pdf

Given such an assessment to measure achievement of learning objectives

Administer it:

as a pre-test, before the start of a course,

and again as a post-test, perhaps embedded in the final exam.

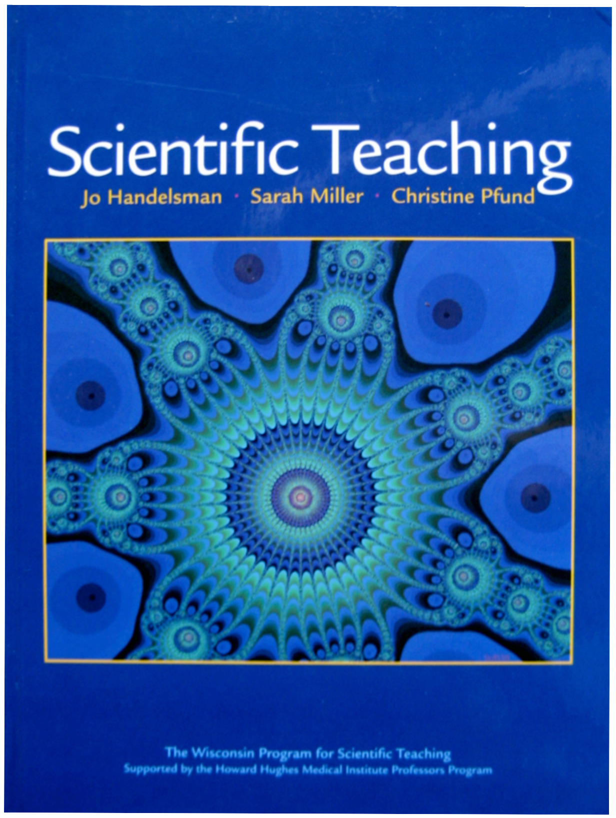
Then calculate a normalized learning gain for each student:

Normalized % Learning Gain =

$$\frac{\text{(post-test minus pre-test)} \times 100}{\text{(100 minus pre-test)}}$$

Now you're in a position to do . . .

Scientific Teaching!



Jo Handelsman
Sarah Miller,
Christine Pfund
W.H. Freeman,
ST Books, 2007

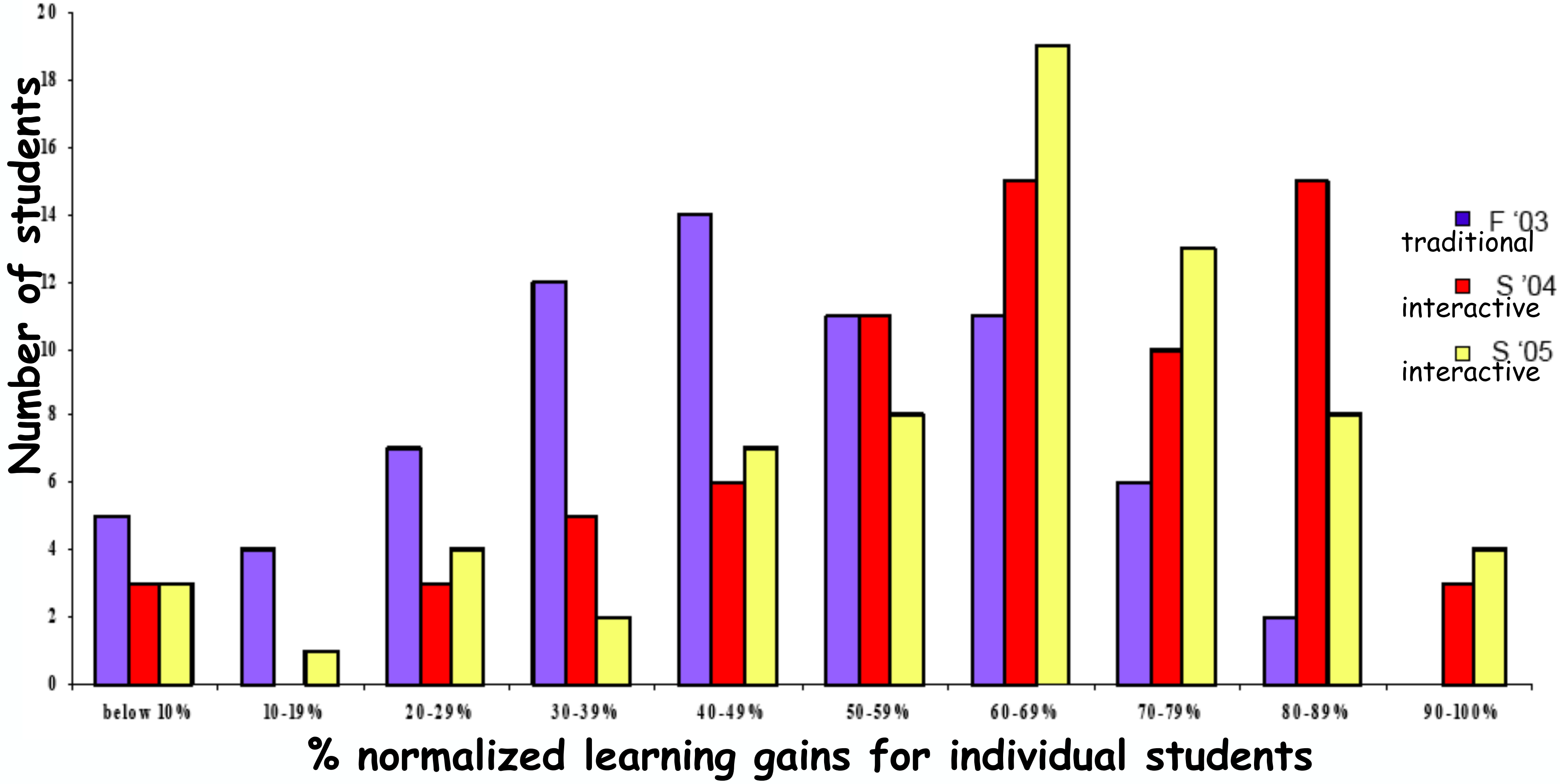
Make course changes, introduce innovative approaches, and measure the effects on learning.

Summary: Promising practices for "transformed" student-centered courses

- Pedagogy and course design based on relevant educational research.
- Course content designed to achieve specific **learning objectives**, which are explicitly communicated to students and appropriately assessed, aiming for higher Bloom's levels.
- ***Active-learning exercises, group work, formative assessments***, included in all classes; **homework** outside of class.
- **Pre-test** to gauge students' knowledge and skills when the course begins.
- **Post-test**: repeat of pre-test at end of course to measure student learning gains.
- **Outcomes data from course used to design improvements in subsequent semesters.**

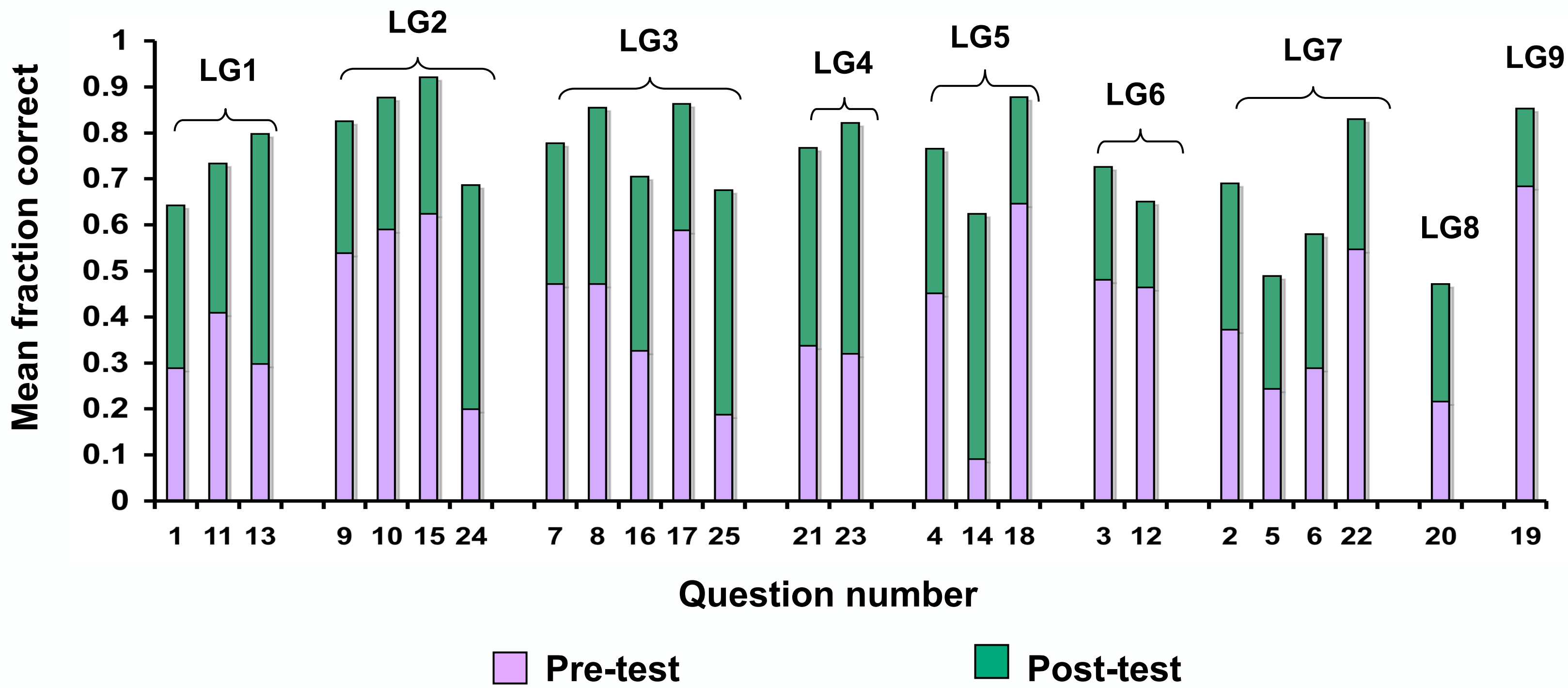
Comparison of student normalized learning gains in traditional and interactive-engagement courses

("Teaching more by lecturing less")



Developmental biology, a required course for majors, ~70 junior and senior undergraduates, taught in Fall '03, Spr. 04,and Spr. 05 by Jennifer Knight and Bill Wood (Cell Biol Educ 4: 298-310, 2005).

Mean fraction correct answers on each of the 25 GCA questions, pre- and post-tests, grouped by learning goal



n = 607 students

Smith, MK, Wood, WB, Knight, JK (2008) The Genetics Concept Assessment: a New Concept Inventory for Gauging Student Understanding of Genetics. CBE-Life Sci. Educ. 7: 422-430.

Freeman et al. meta-analysis, 2013

229 studies comparing active-learning vs. traditional lecture STEM courses.

Finding: Student performance on exams and concept assessments was on average 0.52 standard deviations higher in the active-learning courses.

Inference: adoption of active-learning techniques will, on average, increase performance by about 0.3 grade points and reduce failure rates (DFW) by 12% across the STEM disciplines.

How we can

What are the barriers to change and how can we surmount them?

- Results of science education research provide clear evidence that transformation to student-centered instruction emphasizing active learning can lead to substantial increases in student performance.

- Yet surveys show that very few instructors are changing the way they teach.

Why?

Some barriers to change

1. Lack of awareness that there's a better way
2. Lack of appropriate classrooms
3. Coverage anxiety
4. Student resistance

In order of increasing difficulty (?)

Student resistance - how to deal with it

- Give students a stake in the reform process:

  Explain why you are teaching this way and how it will benefit them in terms of their goals for the future. (Not once, but frequently!)

- Acknowledge that the transition is not easy.

  Dee Silverthorn and the Kübler-Ross stages:

  1. Denial, disbelief
  2. Shock, panic
  3. Anger, resistance
  4. Depression, despair
  5. Acceptance, adjustment
  6. Empowerment

Silverthorn, D. U. (2006). Teaching and learning in the interactive classroom. Adv. Physiol. Educ. 30: 135-140.

What stage are you in this week?

A) Denial, disbelief

B) Shock, panic

C) Anger, resistance

D) Depression, despair

E) Acceptance, adjustment

Some barriers to change

1. Lack of awareness that there's a better way
2. Lack of appropriate classrooms
3. Coverage anxiety
4. Student resistance
5. It's too much work – faculty don't have the time
6. The current faculty reward system (and lack of reliable measures of teaching effectiveness)
7. It may require a change of professional identity

In order of increasing difficulty (?)

Barriers to Faculty Pedagogical Change: Lack of Training, Time, Incentives, and. . .Tensions with Professional Identity?

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Case Study of departmental change:

The Science Education Initiative at CU Boulder

Brainchild of Carl Wieman

Funding from the University:

- 5-year project, 2006-2011, ~$4M
- Competitive applications from departments to participate in the program

Five participating science departments:

Chemistry and Biochemistry

Earth Sciences

Integrative Physiology

MCD Biology

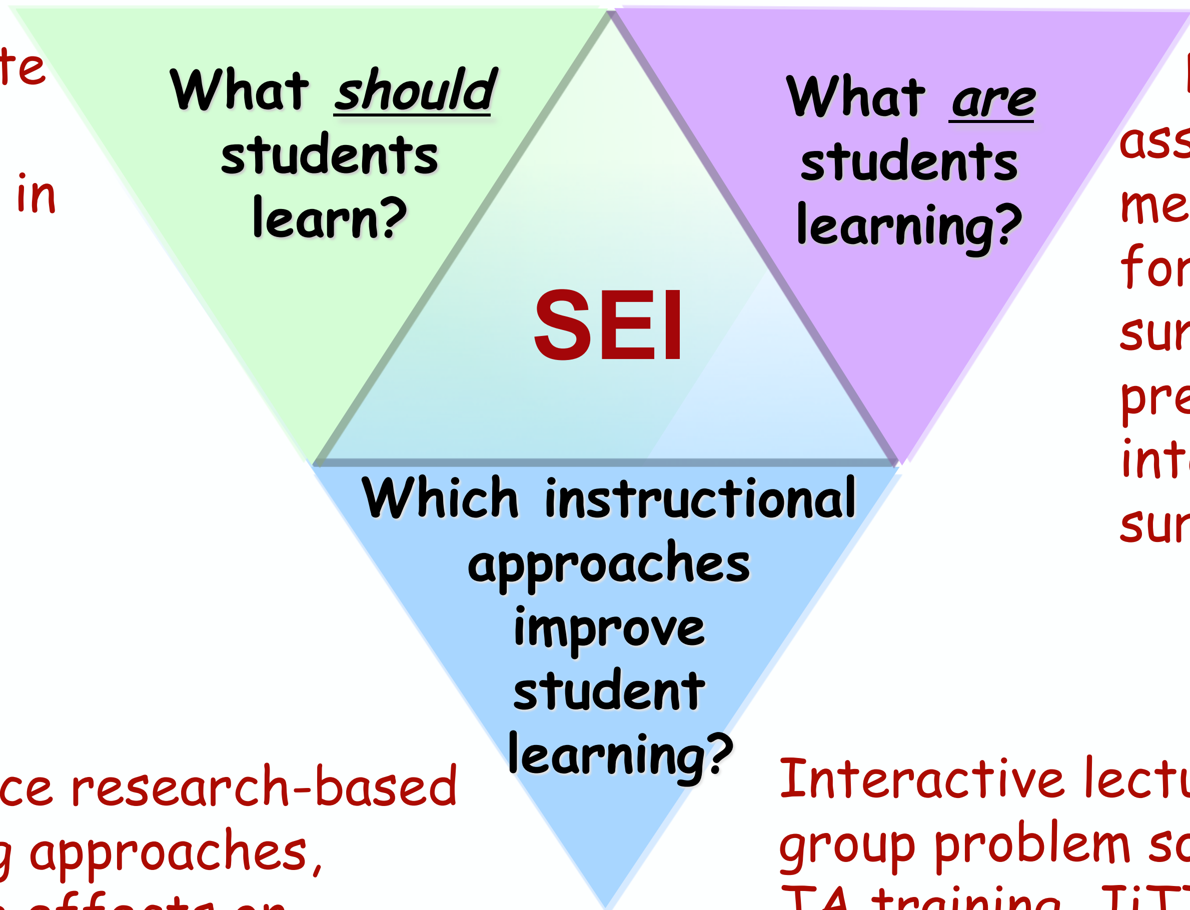
Physics (funded in 2008)

All strongly research-oriented

All teaching many undergraduates

The Science Education Initiative (SEI)

Reformulate majors curriculum in terms of specific learning objectives



Develop assessments to measure learning: formative, summative, pre-/post CI's, interviews, surveys.

Introduce research-based teaching approaches, measure effects on student learning

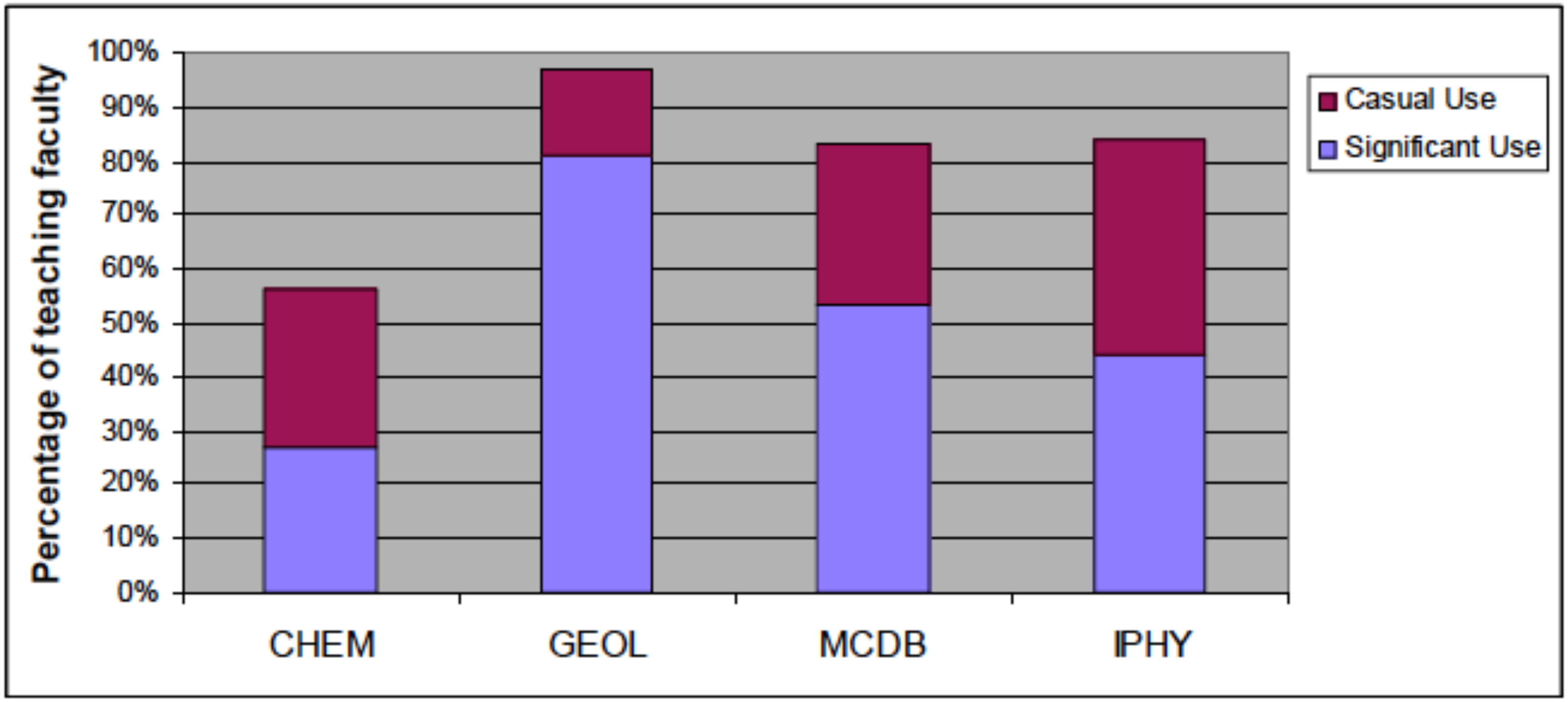
Interactive lectures (clickers) group problem solving, TA training, JiTT, tutorials, etc.

Improve each year based on assessment results

One key to success - Science Teaching Fellows (STFs):

- have Ph.D.'s in the discipline
- have elected to pursue careers in science education
- receive pedagogical training as a group from SEI faculty and staff and occasionally education faculty
- do little actual teaching
- **assist faculty in developing learning goals, assessments, and classroom activities**
- spearhead research to evaluate effectiveness of materials and activities developed for each course, in collaboration with faculty

Departmental buy-in as of 2009-10



Use of SEI resources (primarily STFs) by faculty who teach undergraduates in four departments

Outcomes: SEI Impact

- Impact at CU
  - >100 faculty involved
  - >55 courses incorporating more research-based teaching practices (>10,000 students/yr)
  - Faculty involved in research & publications

- Impact beyond CU
  - 30 peer-reviewed publications
  - Sister program at UBC, Vancouver
  - Assessments and curricular materials are publicly available, being used by others

Outcomes: Faculty and departmental change

2010 Survey: 114 faculty responding (70%)

75% faculty report increased conversations about teaching, less lecture, more active learning in class

62% developed/used learning objectives

47% used pre-post measures of learning

56% used information on student thinking/ attitudes

Are students learning more as a result of the SEI?

Yes, based on STF research results from several individual courses

(overall evaluation of the program is still in progress)

Sustainability?

- Wieman postulated that the cultural change with regard to teaching would persist beyond the 5-year project.
- Learning goals, assessments, and learning activities have been archived and made publically available online.
- New instructors can be assimilated into the culture and provided with all the materials they need to propagate these courses.

What SEI features helped it work?

- Department-based (with strong central leadership)
- Competitive funding (departments must commit to participate)
- One course at a time (in framework of departmentally established learning objectives)
- Faculty-STF relationship (post-doctoral level STFs are stimulating and non-threatening to faculty)
- Synergy between STFs (fostering interdisciplinary interaction and collaboration)

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Carl Wieman, SEI initiator, First Director

Kathy Perkins, Second Director

The University of Colorado, Boulder

Science Education Initiative