Carl Wieman Science Education Initiative
at the University of British Columbia

Transforming science education at a large research university

progress report from the Carl Wieman Science Education Initiative (CWSEI) at UBC

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1. **Background/Motivation**
2. **Goals and brief description**
3. **Underlying ideas/rationale for design**
4. **Some highlights and observations**

Traditional Science teaching Model

think hard, figure out subject

tell students how to understand it

give problem to solve

yes

done

no

students lazy or poorly prepared

tell again

Louder

Basic Assumptions of Traditional Lecture Approach

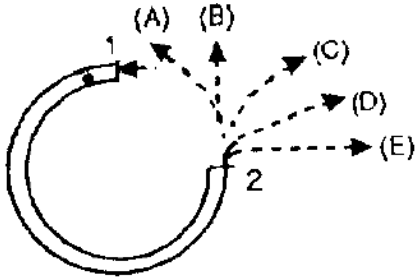
- If you TELL the students something, they will learn it (and they cannot learn it if you do not tell them)
- If the students can do the problems (homework, test), they understand the underlying structure and concepts

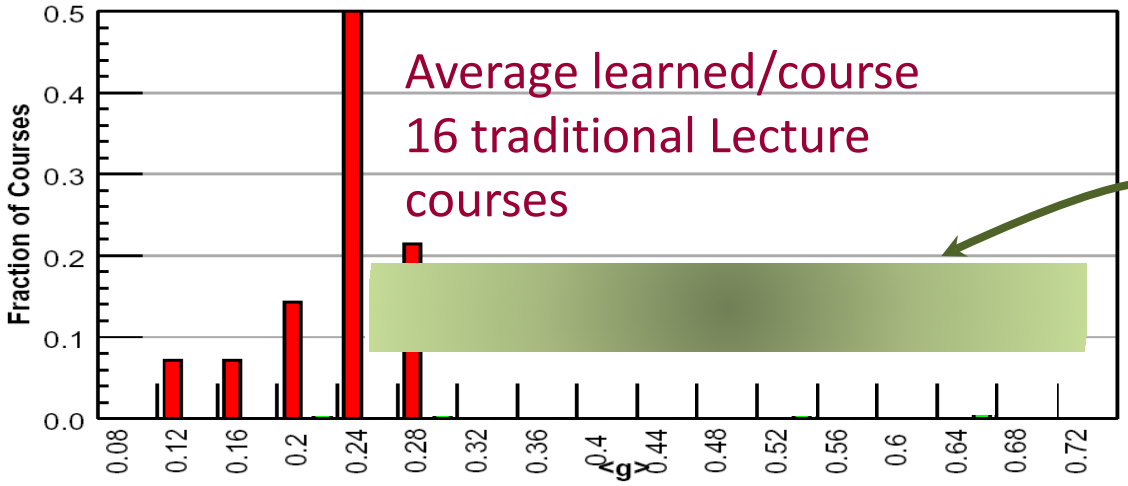
Measuring conceptual mastery – Physics example

Force Concept Inventory – basic concepts of force & motion

1st semester physics

Pre-post test – what % learned? (100's of courses)



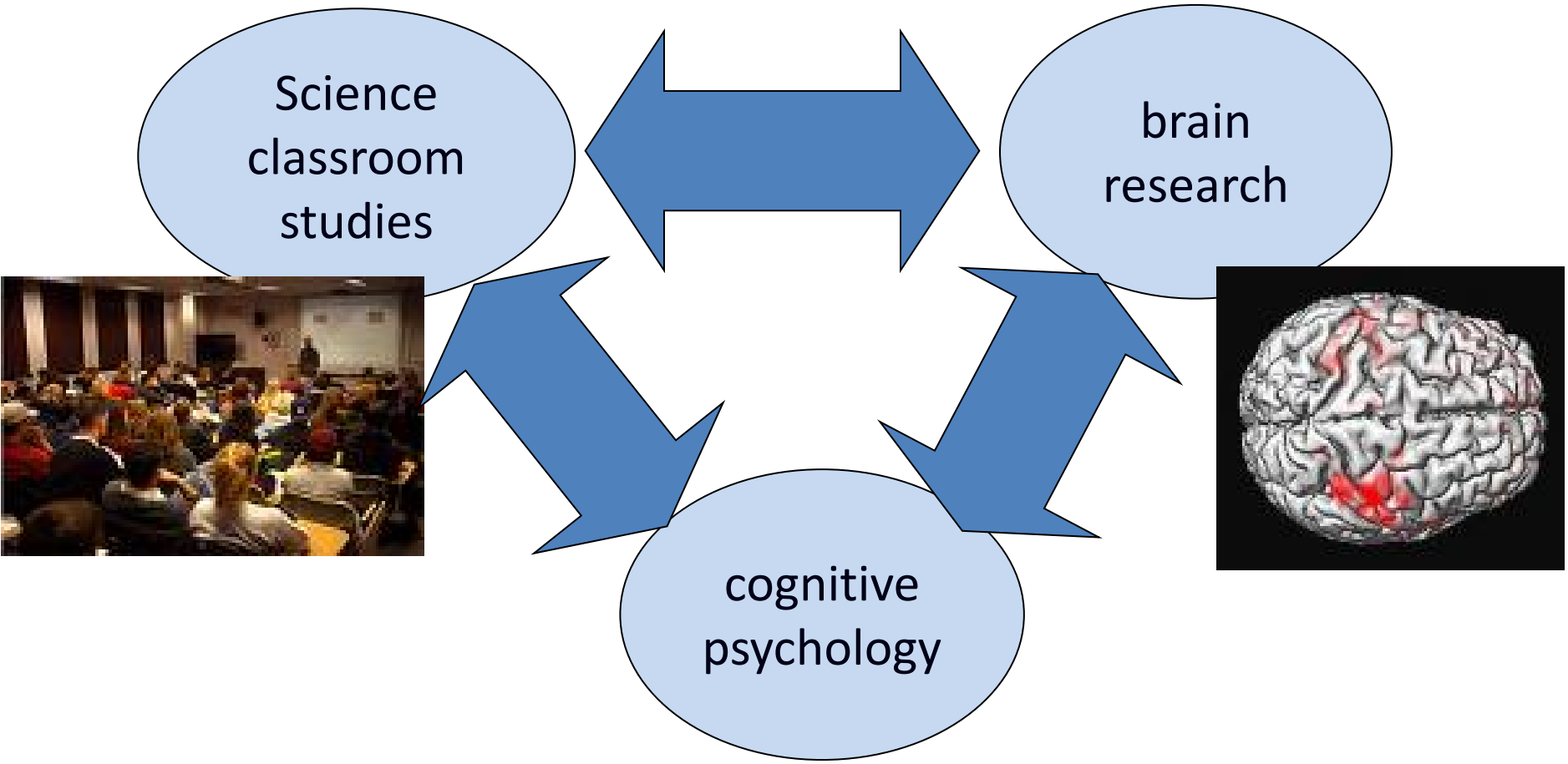


improved methods

On average learn <30% of concepts did not already know.
Lecturer quality, class size, institution,...doesn't matter!
Similar data for conceptual learning in other courses.

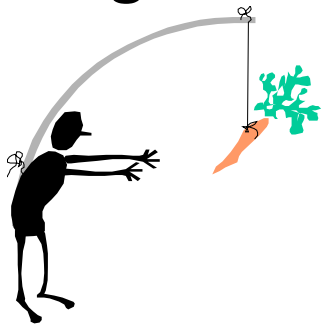
R. Hake, "…A six-thousand-student survey…" AJP 66, 64-74 ('98).

Major advances past 1-2 decades
Consistent picture of How People Learn



Research on Learning

Components of effective teaching/learning



1. Motivation
   - relevant/useful/interesting to learner
   - sense that can master subject
2. Connect with prior thinking
3. Apply what is known about memory
   - short term limitations
   - achieving long term retention
4. Explicit authentic practice of expert thinking
   - interactive engagement focused on developing expert thinking skills (scientific reasoning, sense-making, ….)
5. Timely & specific feedback

Carl Wieman Science Education Initiative

Started in 2007, also CU-SEI started at the University of Colorado in 2006

Goals:

- **Widespread improvement in science education at UBC & CU**
- **Develop successful demonstration model(s) to help inform change efforts elsewhere**
- **Ultimately: change the World**

Lessons from history:

- A few faculty employing effective teaching practices in a department does not result in widespread change in dept. (spreading a few seeds approach doesn't work)
- Most science faculty are unaware of the findings of relevant science education and cognitive psychology research.
- People, in general, resist change.

“There is nothing more difficult to take in hand, more perilous to conduct, or more uncertain in its success, than to take the lead in the introduction of a new order of things. For the reformer has enemies in all those who profit by the old order, and only lukewarm defenders in all those who would profit by the new order, this lukewarmness arising partly from fear of their adversaries … and partly from the incredulity of mankind, who do not truly believe in anything new until they have had actual experience of it.”

– Machiavelli

Discussion Question

For a University Science course, who should decide what the students should learn?

The instructor? The department? The Dean? The Government? ….

Bonus question (in case the first one was too easy):

Is the answer the same if the course is:

- A prerequisite for another course in that department
- A prerequisite for another course in a different department
- An elective for majors in that department
- One section of a multi-section course
- For non-science students
- fulfills a general university requirement

CWSEI Underlying Reasoning

Logical unit of change is the Department – it is the cultural unit.

Change must be driven by department – Faculty are experts in their science fields. The faculty & department as a whole need to decide what students should learn (in consultation with relevant depts. for service courses), adopt or develop good measures of relevant learning, and change instructional approaches.

Evidence is key – Most faculty will feel that change is necessary if there is good data showing students aren't getting important ideas/concepts.

Effective teaching can be more efficient than current practices (and more fun) – Re-use of materials, less repetition/overlap of material, team teaching large courses, effective use of technology, etc. can result in lower resource requirements in long-term.

Approach

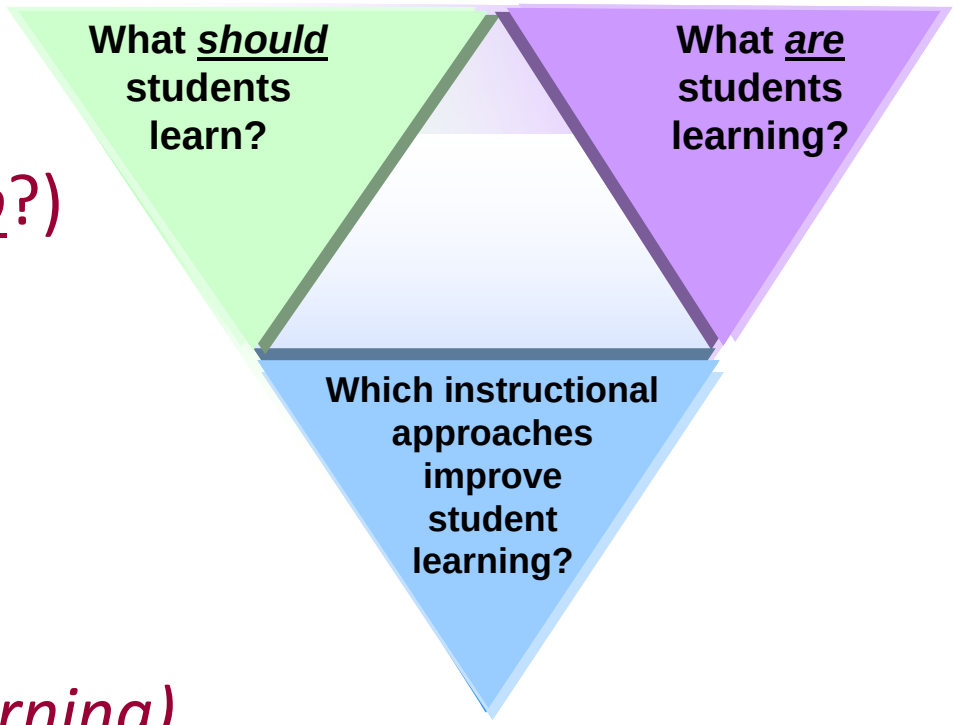
Significant 1-time investment of resources – Concentrated (~1-2 M$/dept. over 6 years) to fund change activities; maintenance of change should not require extra resources.

Departments compete for funding – Criteria: commitment and readiness to undertake widespread sustained effort to improve undergrad education

Science Teaching & Learning Fellows (STLF) – Temporary positions funded by CWSEI; content and pedagogy expertise (typically Masters or PhD in discipline) work with faculty to measure student thinking & learning, develop learning goals & activities, …

Archive, Re-use, Improve materials – SEI course materials archival system (sei.ubc.ca)

CWSEI "Trinity" for each course



Learning goals. (what should students be able to *do*?)

Good assessment (validated tests)

Improved teaching methods *(research based, improve learning)*

Materials, assessment tools, homework, notes … saved, reused, improved.

Making teaching more effective, and more rewarding for faculty and students

Typical new aspects incorporated in courses:

- **Clearly articulated learning goals (not just a list of topics)**
  - What the students should be able to *do*
- **Pre-reading assignments & quizzes**
- **Efforts to increase student interest & motivation to learn subject (context, relevance, why useful/interesting, …)**
- **Interactive engagement targeted at learning goals**
  - Clicker questions and peer discussion – especially in large classes (challenging questions involving scientific reasoning best)
  - In-class group activities – effective even in large (250 student) classes
  - 2-stage exams (individual + group)
- **Homework problems targeted at learning goals**
- **Pre-post testing to measure learning, surveys to gauge perceptions about science ...**

CWSEI Programs at various scales and stages:

Large scale & in later stage – **Earth & Ocean Sciences**

Large scale at earlier stages:

Physics & Astronomy
Mathematics
Computer Science
Life Sciences

Smaller scale programs – **Chemistry, Statistics**

Funded by donations to UBC; total budget $10 M including $2 M gift from David Cheriton for Math and Computer Sci.

Some Highlights (More details in talks & posters)

Earth & Ocean Sciences

STLFs: Francis Jones, Brett Gilley, Erin Lane, & Josh Caulkins; CWSEI Dept. Director: Sara Harris

- About 60% of faculty have made significant changes to teaching.
- 20 courses undergoing or completed transformation plus another 10 improved with SEI help

cwsei.ubc.ca/departments/earth-ocean_courses.htm

COURSE	LEARNING GOALS	NEW ASSESSMENTS	IMPROVED METHODS
EOSC 111: Laboratory Exploration of Planet Earth (Sept '07 start) Faculty: S. Harris STLF: Brett Gilley Transformation completed in Fall '08 w/ ongoing updates to pre-post assessment, lab activities, and quizzes To view course materials, click HERE.	Course-level goals: complete Lab-level goals: complete	Individual and group quizzes 3rd draft of Pre/Post assessment complete for all topics Post-lab surveys for each lab End-of-term survey	Invention activities (Introduction, Plankton & Marine Ecosystems) Student-derived methods (Earthquakes, Groundwater, Dinosaurs, Waves, Estuaries) Contrasting cases (Sediments & Sedimentary Rocks)
EOSC 112: The Fluid Earth: Atmosphere and Ocean (Jan '08 start) Faculty: R. Francois, S. Harris, W. Hsieh STLF: Erin Lane Poster: Climate Science/Oceanography Misconceptions	Course-level goals: complete Lecture-level goals: complete	Midterm & end-of-term surveys Online quizzes Validated pre-post survey Student engagement observations Student workloads questions	Widespread use of thought-provoking clicker questions Relevance slide added to each lecture, relevance added throughout class.

Materials archived when transformation complete: sei.ubc.ca

cwsei.ubc.ca/departments/earth-ocean_courses.htm

COURSE	LEARNING GOALS	NEW ASSESSMENTS	IMPROVED METHODS
EOSC 211: Computer Methods in Earth, Ocean & Atmosph. Sciences (Jan '09 start) Faculty: R. Pawlowicz, C. Johnson STLF: Josh Caulkins Poster: Investigation of student perspectives: focus group set up & findings from EOSC 211 Poster: Transformations and results	Course-level goals: complete Lecture-level goals: complete Learning goals for Labs/Assignments: draft	Pre-post assessment: Administered in Teach 1 and edited for Teach 2, can be used "as is" for all future terms Midterm and end-of-term surveys New types of exam questions based on computer science concepts	In-class worksheets for every lecture Pair-programming used in all labs and assignments. Name-sticks used to call on students during lectures and in-class discussions Post-lecture Interviews Lab interviews
EOSC 212: Topics in the Earth & Planetary Sciences (Jan '08 start) Faculty: M. Jellinek, M. Bostock STLF: Francis Jones Final transformation term was Fall'09, but further refinements of generic science thinking activities and assessments were	Course-level goals: complete Focus is on science thinking skills rather than content	End-of-term survey for project evaluation Quizzes on readings for both individual and teams, using Team Based Learning strategies Two projects (presentation and poster), including feedback at multiple stages of delivery Pre-post test related to model-based reasoning	Vista Course Management System used extensively for content delivery, quizzing, surveying, logistics. Team Based Learning elements: permanent teams, individual/team quiz protocols & in-class team activities Content from Scientific American and other articles and lectures Three modules chosen to highlight Departmental research strengths

Session D2 this morning, Francis Jones talk: Teaching, learning & assessing generic scientific skills early in an undergraduate degree.

Physics & Astronomy

STLFs: Louis Deslauriers, James Day, Jim Carolan, Cynthia Heiner, Peter Newbury, & Ido Roll; CWSEI Dept. Director: Mona Berciu

- Astronomy courses – *Exploring the Universe I & II*
- 6 Intro Physics courses
- Higher level Physics courses: *Quantum Mechanics, 4th year optics, …*
- Some courses have no lectures anymore (100% interactive)

Mini-transformation in Intro Physics course

Louis Deslauriers (STLF) and Ellen Schelew (grad student)

Comparison of effect of teaching methods:

nearly identical sections (~270 students each), intro phys, same material & time

I

Experienced highly rated instructor
traditional lecture & ~2 clicker Qs

week 1-11

II

Experienced highly rated instructor
traditional lecture & ~2 clicker Qs

week 1-11

same preparation
same attendance
same engagement
same midterm 1 & 2 grades

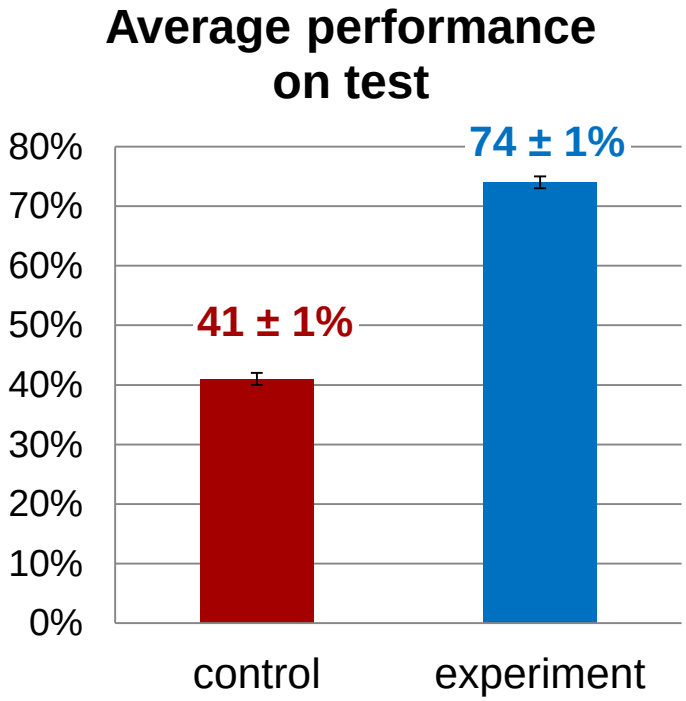
Week 12 - comparison – mutually agreed upon learning goals

electro-magnetic waves
regular instructor
intently prepared lecture

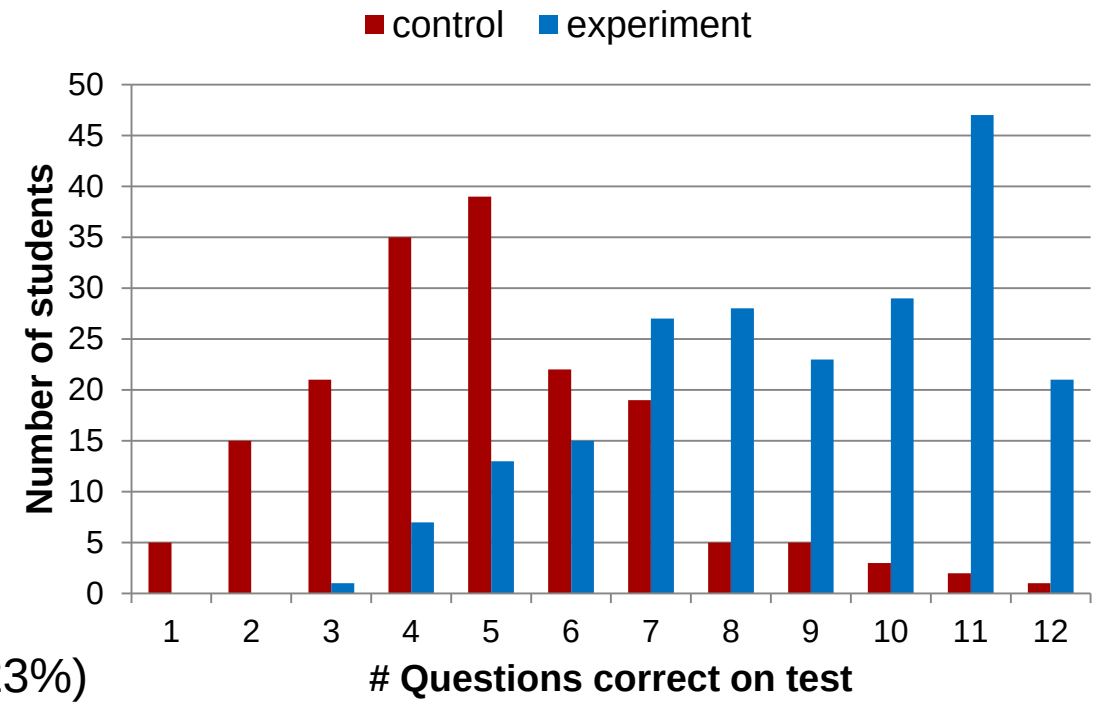
electro-magnetic waves
Louis and Ellen (inexperienced)
research based teaching

Common test on EM waves (mutually agreed upon)

Mini-transformation in Intro Physics course Results



(Random guessing gives score of 23%)



Published in Science, May 2011

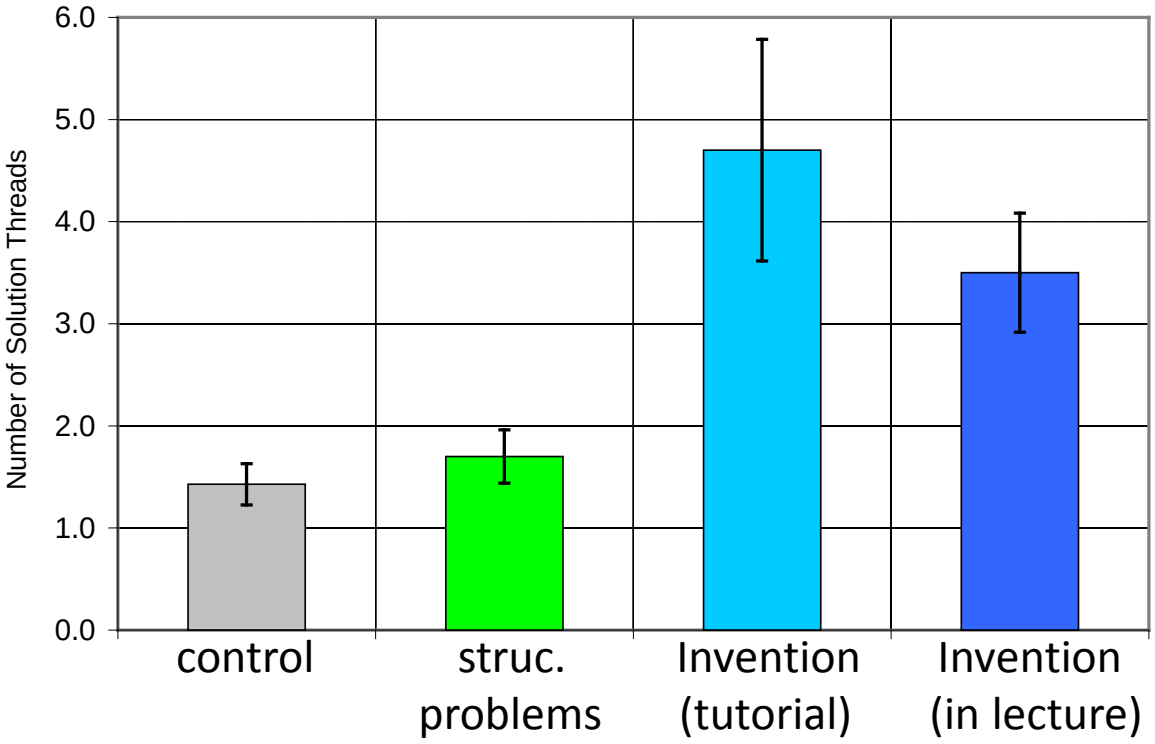
Results inspired department to start a full transformation of course and another intro physics course

Life Sciences

STLFs: Jared Taylor & Malin Hansen; Dept. Director: George Spiegelman

- **1st year Cell Biology**
  Clicker questions & peer discussion, Invention activities, structured problem solving activities, In-class writing assignments, …

Coming up with plausible mechanisms for biological process student never encountered before:



Published in CBE-Life Sciences Education

Jared Taylor, Karen Smith, Adrian van Stolk, & George Spiegelman

Selected for inclusion in the 2010 Highlights issue

Ecology courses

Fundamentals of Ecology and Advanced Ecology redesigned around the questions:

- Why do species differ in their population dynamics?
- How do species coexist?
- Are communities stable?
- Are humans reducing the ecosystem services on which we depend?

Malin Hansen poster yesterday: The use of everyday life analogies in scientific teaching

Mathematics

STLFs: Warren Code, Joseph Lo, KatyaYurasovskaya, & Sandi Merchant; CWSEI Dept. Director: Costanza Piccolo

- Calculus courses
  - Major effort in Differential Calculus with Applications to Commerce and Social Sciences
- Mathematical Proof – *Math 220*
  - Developed pre-post test for basic proof skills, conducting student interviews, discovering interesting student thinking about proofs
- Mathematics Attitudes & Perceptions Survey *under development*
  - Ask if agree or disagree with statements like:
  - *"In math, it is important for me to make sense out of formulas and procedures before I can use them correctly."*
  - *"If I get stuck on a math problem, there is no chance that I will figure it out on my own."*
  - Warren Code talk Friday morning (Session F2): Measurement of student perceptions and attitudes in mathematics

Conclusions

Succeeding in a number of departments

Over 50% of faculty have changed teaching 1 UBC and 3 Colorado depts., impacting about 80% of student credit hours taught. Several other depts. making very good progress.

Factors that help:

- Actively supportive dept. head/chair
- Broad faculty support & involvement within dept.
- Reward structure for SEI-related activities
- Faculty dissatisfied with student learning
- Respected faculty who support SEI goals

Factors that hinder:

- Departmental culture that
  - does not respect education research
  - expects total individual freedom in teaching
  - blames lack of learning on students
- Last minute teaching assignments
- Many faculty teaching multiple sections of same course

Discussion Question

How can this be done elsewhere without lots of extra resources?

Some ideas:

1. Incentives similar to those driving science research
2. Metrics for effective teaching
   - Use of research-based methods
   - Validated pre-post tests of learning
3. Strategic approaches (e.g., team teaching)
4. Use materials produced by others (e.g. SEI materials: sei.ubc.ca)
5. Consultant(s) within dept. (faculty member or STLF with content and pedagogy expertise)
6. Professional societies conduct workshops on effective teaching (e.g. American Association of Physics Teachers/ American Physical Society New Faculty Workshops)

Session E4, Workshop: How to develop and use concept inventories in Biology, *Carol Pollock, Joan Sharp, Angie O'Neill, Greg Bole*

Malin Hansen (Ecology STLF) poster yesterday: The use of everyday life analogies in scientific teaching

Session D2 Thurs AM - Francis Jones (Earth/Ocean Sciences STLF): Teaching, learning & assessing generic scientific skills early in an undergraduate degree.

Session D3, Thurs AM – Ashley Welsh: Considering the student perspective: Factors that undergraduates perceive as influential to their academic performance in science.

Session E1, Thurs PM - Jackie Stewart: An instructional method for engaging students in correcting their problem solving errors **(New title)**

Jackie Stewart poster yesterday: Development, implementation, and evaluation of a Chemistry Integrated Resource Package (ChIRP) for first year chemistry at UBC

Session F2, Friday AM - Warren Code (Math STLF): Measurement of student perceptions and attitudes in mathematics

Tamara Kelly, former STLF (Biology)
Sarah Wise, STF (Biology Colorado CU-SEI)