Astro 101: Rethinking the goals

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Some Astro 100 goals

- Structural goals
  - maintain a large enrollment
  - have high student satisfaction
  - not take too much faculty or staff time
  - engender support for funding of Astronomy research
- Learning goals
  - learn astronomy facts
  - understand the nature of scientific inquiry
  - develop a sense of scale and place in space and time
  - develop a habit of reading astronomy articles in the press and popular books

What has been learned: Extracting the core

- Developing effective instruction depends on our understanding
  - what students know when they come in
  - students' learning styles and expectations
- Both our <u>goals</u> and our <u>approaches</u> for instruction are strongly dependent on
  - the populations involved
  - our model of learning and knowing
  - the available instructional methods

A Model of Learning and Knowing

A Theoretical Frame

- *"The whole of science is nothing more than a refinement of everyday thinking. It is for this reason that the critical thinking of the physicist cannot possibly be restricted to the examination of concepts from his own specific field. He cannot proceed without considering critically a much more difficult problem, the problem of analyzing the nature of everyday thinking."*

  Albert Einstein, "Physics and Reality,"
  J. of the Franklin Institute 221 (1936).
- Triangulate on ideas and principles of learning developed in education research, cognitive psychology, neuroscience, and ethology.

Key results from cognitive education research

- 1. Learning is productive / constructive.
- 2. Knowledge is associative / linked
- 3. The cognitive response is context dependent
- 4. Most people require some social interactions in order to learn effectively.

1. Learning is productive / constructive.

- The brain tries to make sense of new input in terms of existing mental structures.
  - We learn by analogy / metaphor
  - New constructions tend to be based on the model of existing structures.
- The ideas and metaphors students bring into class are what they will use to learn with.
  - Understanding these learning resources can help us design more effective learning activities.

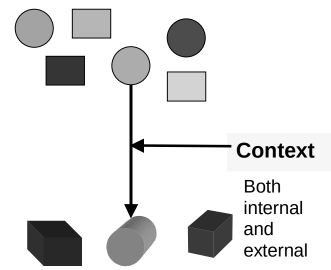
Physical reasoning maps primitive elements onto specific situations

Primitives

Irreducible functional pieces based on direct interpretation of experience

Facets

Inferred physical principles for specific situations



* *diSessa and Minstrell*

Example:

Primitive: Closer is stronger

Facet: You can get warmer by standing closer to the fire.

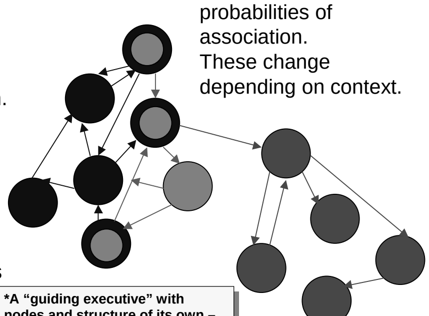
2. Knowledge is associative / linked

- One of the best established principles of cognitive science is the associative character of thinking.
- We have large amounts of information stored in our long term memory.
  - Most of it is not immediately accessible and needs to be activated by chains of association.
- What matters is not just what our students know, but how it's connected.

Organization of Long-Term Memory: Schemas

Links represent probabilities of association. These change depending on context.

This picture is an oversimplification. "Nodes" have structure in multiple dimensions. There are "metanodes" that control what links appear when.*



***A "guiding executive" with nodes and structure of its own – epistemology, control, affect, etc.**

3. The cognitive response is context dependent.

- The productive response depends on the context in which new input is presented, including the student's mental state (expectations).
  - Students can use multiple models
  - Confusion about appropriate context can make it appear as if students hold contradictory ideas at the same time

Resources, Links, and Context

- The context dependence of schema generation implies that <u>how a situation is presented may affect how an individual responds</u> — in particular, what resources they have access to.
- *Resource* = a cognitive knowledge element including data (facts), reasoning methods, metaphors, analogies, etc.

K 7 A 2

A set of four 3x5 cards is dealt on a table as shown above. Each card has a letter on one side and a number on the other.

The dealer proposes that these 4 cards satisfy the rule:

"If there is a vowel on one side of the card, then there is an odd number on the other."

What is the smallest number of cards you have to turn over to be sure the rule is satisfied? Which ones?

Coke 16 Gin & Tonic 50

You are acting as bouncer at the local pub. It is your job to check ID's for the servers.

One server has placed four 3x5 cards on the bar, describing the customers at a table in the back.

On one side of the card is his best guess of the patron's age, on the other, what they are drinking.

Should you go to the back to check some ID's? Whose?

A small problem: What is 3 ½ divided by ¼?

$$\frac{3\,{}^{1}\!/_{2}}{{}^{1}\!/_{4}} = \frac{{}^{7}\!/_{2}}{{}^{1}\!/_{4}} = \frac{{}^{7}\!/_{2}\times 4}{{}^{1}\!/_{4}\times 4} = \frac{7\times\frac{4}{2}}{1} = 7\times 2 = 14$$

A group of students have 3 ½ small pizzas, each divided into ¼-pizza parts. How many students can have a piece?

Each pie can serve 4 students, so the 3 pies can serve 12. The remaining ½ can serve 2, so a total of 14 can be served.

An example from astronomy

- The study summarized in the film "A Private Universe" demonstrated that both high school students and graduating Harvard seniors had confusions about why it was warmer in summer than in winter.
- Many thought that the sun was closer to the earth in summer than in winter.

Goal analysis

- If we we want to teach this, we could have many <u>distinct goals</u>, depending on what cognitive structures we want to help our students build.
  - learn an isolated fact
  - construct a model that coherently explains a number of distinct facts
  - construct a model that relates a mental model to students' personal and direct experience
  - construct a model that exemplifies the process of model building in science (combining multiple observations and seeking consistency)

Possible goals

- We could teach the isolated fact: “the tilt of the earth’s axis is responsible for the change of seasons.”
- We could teach that science is about the construction of models that coherently and consistently explain many facts (such as the fact that when it is summer in the northern hemisphere it is winter in the southern).
- We could teach that science is a refinement of everyday experience and get them to think about the implications of short winter and long summer days.

Resource analysis

- Why might students commonly suggest that the sun might be closer in summer than in winter?
  – Is it something they have been incorrectly told by an ignorant elementary school teacher? (possible but unlikely)
- Possible Explanations
  – They incorrectly (but plausibly) access a correct “closer is stronger” reasoning primitive and map it onto a “closer to the fire is warmer” analogy.
  – They recall the “tilt” picture but misinterpret the critical issue as “closeness” (the N. hemisphere is tilted towards the sun — “closer” in the summer daytime)

4. Most people require some social interactions in order to learn effectively.

- As a small child, most of our learning comes via interactions with parents and peers.
- The opportunity to ask questions or explain something to others
  – helps learners reflect on what they think they know
  – fills in gaps they might have missed
  – provides feedback to refine and correct their knowledge.
- Social exchange on a subject helps focus the student’s mind on the topic and engage it intellectually.

Tying it all together: Expectations and Frames

- Most learning is done in a social context:*
  – a lecture, laboratory, or recitation
  – doing homework with others
  – getting feedback from an instructor
- Students bring to each social context a set of expectations or “frame”.
  – These expectations set the “rules of the game”.
  – They determine what the students feel is appropriate for them to do.

** A few people learn to become independent learners, in part by internalized an “other” — learning how to question and argue with themselves. This is rare.*

Implications: Expectations and Frames

- When students have the wrong idea about what is supposed to take place in an educational activity, it can lead to major miscommunications and undermine our best efforts.
- Students in engineering physics
  – think that derivations are only to show that it’s OK to use an equation (>50%)
  – think the point of laboratory is only to collect data and confirm a result presented in lecture or the book

Beyond Content: Expectations and Attitudes

- Students select only a small part of what is offered in a typical firehose physics course.
- Their “filters” depend on their ideas about the nature of physics and the course.
- If some of our goals are to improve their attitudes and understanding as well as their content knowledge, we have to understand where they are starting from and what causes change.

Expectation barriers to learning

- Some students believe that physics consists of unrelated “facts”.
- Some students believe that they don’t need to understand why we believe something in physics is true — just that it is.
- Some students believe that they don’t need to understand the meaning behind an equation — just to use it to calculate the “right” number.
- Some students believe their real-world experience is irrelevant to their physics class — and vice versa.

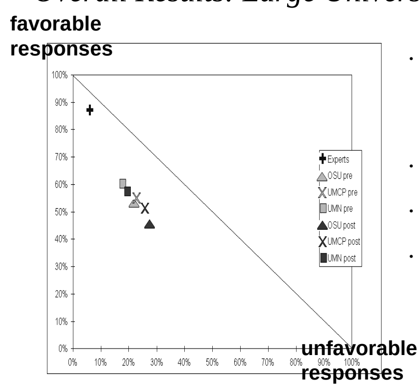
The MPEX Survey

- Contains 34 statements with which students are asked to agree or disagree on a 5 point scale
- Delivered at more than 20 colleges and universities to more than 6000 students.
- Translated into many languages including Chinese, Flemish, Turkish, Italian, Finnish, and Computer Science.

MPEX Clusters

Favorable		Unfavorable
– Independence	⟷	– Authority
– Concepts	⟷	– Formulas
– Coherence	⟷	– Pieces
– Reality linked	⟷	– Reality separation
– Integrated math	⟷	– Math as calculation

Overall Results: Large Universities (M)

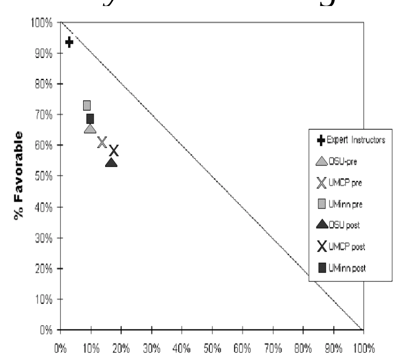


- Introductory mechanics (C) at 3 large research universities: ~500 each
- Initial distribution far from ideal.
- Result of instruction is a loss.
- This result has been often confirmed for large-lecture traditional instruction.

Items of the Reality Cluster:

- Physical laws have little relation to what I experience in the real world.
- To understand physics, I sometimes think about my personal experiences and relate them to the topic being analyzed.
- Physics is related to the real world and it sometimes helps to think about the connection, but it is rarely essential for what I have to do in this course.
- Learning physics helps me understand situations in my everyday life.

Reality Cluster: Large Universities



- The reality cluster shows a significant loss not only in traditional but in concept-oriented reform classes.
- This result is very hard to change.
- A few “real-world” homework problems do not suffice.

Available Research-Based Instructional Methods

Some instructional implications

- Seeing is not believing. Because they are using what they know to interpret what we tell them, students often misinterpret even a clear and compelling lecture or demonstration. More mentally engaging activities are required to have a more reliable effect.
- Students are not blank slates. We can use what we learn about students' knowledge to create lessons that build from appropriate starting points. (e.g., cognitive conflict, bridging, etc.)
- There's more to a course than content. Students use their learning to build (and confirm existing) expectations and understanding of what science is about and how to do it. To affect these components, we have to pay explicit attention to these issues in how we teach content.

New Instructional Methods

- Lecture
  - Peer instruction
  - Interactive lecture demonstration
  - In-seat experiments
- Recitation
  - Tutorial
  - Group problem solving
- Laboratory
  - Guided inquiry labs
  - Concept labs
  - Problem-based labs
  - Exploratory labs
- Full studio / workshop

Elements in Research-Based Curricula

- Although research-based reforms differ in many ways, they have a number of elements in common.
  - an awareness of specific difficulties students have in interpreting or understanding specific material
  - a focus on creating learning environments in which the students are actively engaging the issues — not just "hands-on" but "minds-on"
  - the use of problems and situations that challenge common spontaneously generated errors ("cognitive conflict")
  - a social or group-learning component
  - a reflective or resolving component

An Example: The UW Tutorial Model

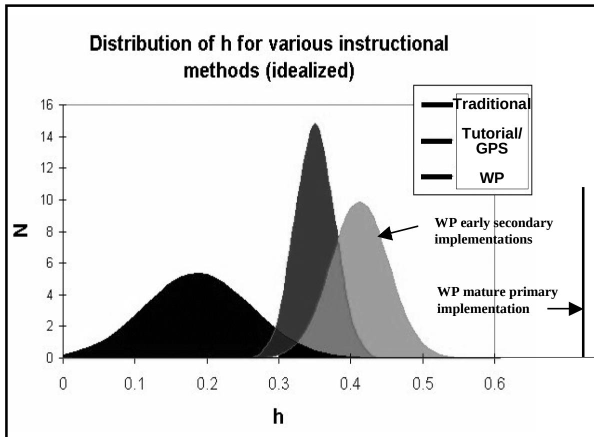
- Tutorials replace recitations. They have:
  - a focus on concepts and qualitative reasoning
  - a TA training session
  - research-based worksheets with facilitators
  - homework
  - exams have a tutorial question

Do they work?

- It depends on what you mean by "work".
- For specific goals, new learning environments can be effective.
- We compared traditional and 3 RB-reform curricula in calculus-based physics (UWTs, GPS, WP) at 14 colleges and universities.
- We evaluated them using a standardized multiple-choice test (the Force Concept Inventory) pre-post and problem solving on exams.
- The FCI probes understanding of fundamental concepts in Newtonian mechanics.

Results

- We took the fraction of the class's possible gain on the FCI as a measure
  h = (post – pre)/(100 – pre)
- Reform curricula showed significantly better gains than traditional classes, in both primary and secondary implementations.
- A detailed analysis of the results show that the gains for this population occur primarily for two issues:
  – understanding that force is associated with acceleration rather than velocity
  – Newton's 3rd law.
- Problem solving also showed some improvement.



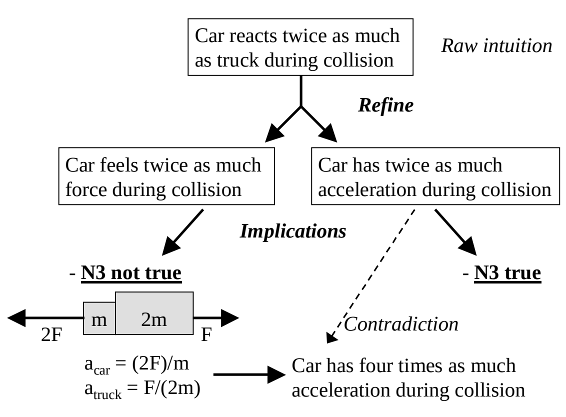
Teaching for growth: Using student resources effectively

- MPEX results indicate that even reform curricula built for concept learning do not improve expectations.
- Can explicit instruction change attitudes ?
- Apply our guidelines by
  – explicitly preparing the student mental state to think about their own thinking
  – repeating the lesson in a variety of contexts
  – explicitly evaluating student gains along these dimensions (testing)
  – using what we know about student thinking as resources to help them build correct new knowledge.

*Learning to Learn**

- In order to get students to become more aware of scientific thinking, Elby has developed some new teaching techniques by adding to the tutorial model.
  – Have students explicitly think about their own intuitions about the physical world and
  – Have students compare their intuitions to what they've learned in physics class
  – Have students build refinements of their thinking so that they match the science better.

** A. Elby, PERS to Am. J. Phys. to be published (2001).*

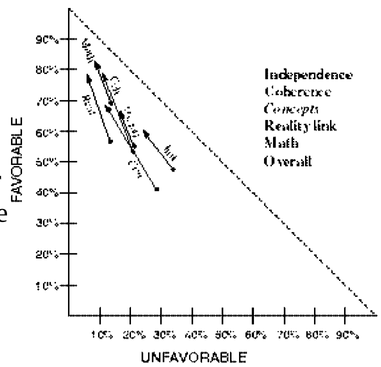


Additional Elements

- Besides the enhanced tutorials, Elby's class includes
  – conceptual homework and exam questions
  – explicit discussions of intuition in lab and class
  – reflective homework, e.g.
    - Think about the material you learned for last week's quiz.
      – (a) What role did memorization play in your learning the material?
      – (b) What makes the material "hard"?
      – (c) What advice about how to study would you give to a student taking this course next year?

Results

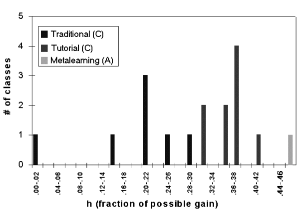
- Elby's students gained substantially on every cluster as well as on the overall MPEX.

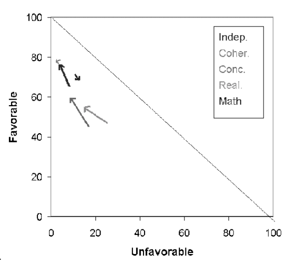


Preliminary Results in a Large Class

- Introducing some of these elements in algebra-based physics in Fall 2000
  - We obtained the largest percentage gains we have ever recorded on a standard mechanics conceptual test.
  - We recorded the first improvement on the MPEX that we have ever obtained in a large lecture class.

Conceptual and attitudinal gains using "learning-to-learn" techniques





What about implementation? What's easy?

- Many of the new learning environments are hard to develop
  - a research and refinement cycle is required.
- But they are relatively easy to implement — in principle.
  - peer learning questions can be shared and easily delivered in lecture
  - ILD and tutorial worksheets are easily shared.

What about implementation? What's hard?

- No learning environment is teacher independent.
- To implement these new environments, instructors (both faculty and GAs) must modify their traditional orientation.
  - Increase in awareness of a course as providing more than content.
  - Shift in responsibility for student learning
  - Increase in ability to listen to students and diagnose their current states
  - Willingness to respond flexibly

Building a community

- The critical element in effective educational reform is *community*:
  - having a (possibly small) subgroup working hard (possibly full time) on research and curriculum development
  - having a (much larger) community that interacts with the first group, using their results and materials and providing feedback
  - having a local community that spends (at least some) time sharing experiences and discussing both their own classroom experience and new research results.