Building a Science of Teaching

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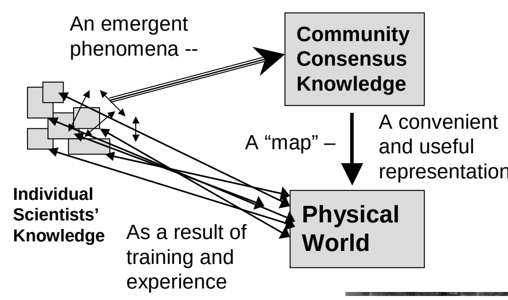
Why should physicists (and other non-education-college academics) be interested in finding out about (and doing) educational scholarship?

- The times they are a-changin':
  - new professions
  - shifting boundaries
  - new technology
- Who do we want to be in the 21st century?
  - What is our research role?
  - What is our educational role?

Figuring out education

- Scientists have a number of valuable insights about how to understand the workings of the real world reliably.
- Our knowledge comes from
  - careful observation
  - analysis and synthesis
- Community activity
  - confirming experiments
  - challenge and confrontation of ideas
  - peer review, publication, conferences and seminars

Building a community consensus



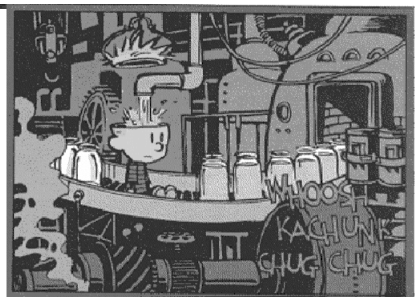
Why do disciplinary scholars need to study education?

- We need to improve the success of our instruction.
- The education schools have other fish to fry.
- Discipline independent results are interesting (when they exist) but too limited at the university level.
- No one else has the disciplinary expertise needed.
- The benefits accrue to the disciplines.
- It's intellectually extremely interesting!

Why begin with cognitive psychology?

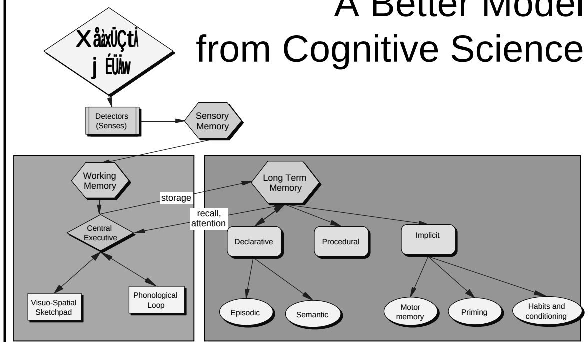
- If we want to understand a physical system (like a student), we better understand something about how that system functions!
- *"The whole of science is nothing more than a refinement of everyday thinking. It is for this reason that the critical thinking of the physicist cannot possibly be restricted 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).

A Model of Student Learning



Bill Watterson *Calvin & Hobbes*

A Better Model from Cognitive Science



Adapted from A. Baddeley, *Human Memory: Theory and Practice* (Allyn & Bacon, 1998). and L. R. Squire and E. R. Kandel, *Memory: From Mind to Molecules* (Scientific American Library, 1999).

A model of thinking relevant to instruction: Principles

- Long-term memory can exist in (at least) 3 stages of activation
  - inactive,
  - primed (ready for use),
  - active (immediately accessible)
- Memory is associative and productive
  - Activating one element leads (with some probability) to the activation of associated elements.
- Activation and association are context dependent
  - What is activated and subsequent activations depend on the context, both external and internal (other activated elements).

**Joaquin Fuster, Memory in the Cerebral Cortex: An Empirical Approach to Neural Networks in the Human and Nonhuman Primate (MIT Press, 1999).*

A Hierarchy of structures

- Patterns of association (the basic structure – viz. neural nets)
- Primitives / facets
- Schemas
- Mental models

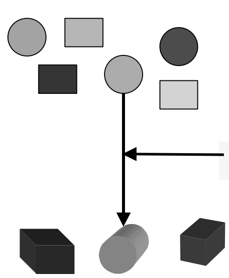
Physical reasoning maps primitive elements onto specific situations

Primitives

Irreducible functional pieces based on direct interpretation of experience

Facets

Inferred physical principles for specific situations



Context

Both internal and external

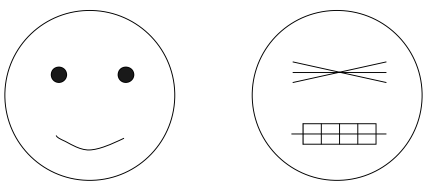
* *diSessa and Minstrell*

Examples

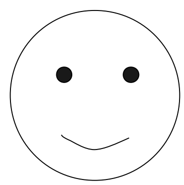
- Visual system
  - *Primitive:* a book is an object
  - *Facet:* interpreting a given visual pattern on the retina as a book
- Physics phenomenology
  - *Primitive:* bigger is stronger
  - *Facet:* larger objects sink (incorrect generalization)
  - *Facet:* when a truck hits a car, the truck exerts a bigger force on the car than the car exerts on the truck (wrong)

This is a …?

This is a…

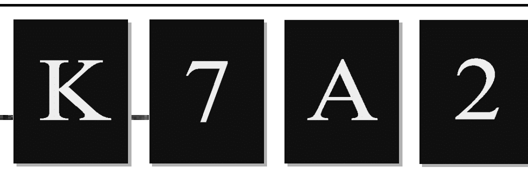


Which picture has more information? Which is easier to interpret?



Implications

- We interpret what we see by matching to templates and patterns that exist in our long-term memory.
- The pattern is not a recorded instance. We can interpret objects we have never exactly seen before.
- The closer the input is to an existing pattern, the easier it is to interpret.



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?

$$\frac{3\frac{1}{2}}{\frac{1}{4}} = \frac{\frac{7}{2}}{\frac{1}{4}} = \frac{\frac{7}{2}\times 4}{\frac{1}{4}\times 4} = \frac{7\times\frac{4}{2}}{1} = 7\times 2 = 14$$

A group of students have 3 ½ small pizzas. A small pizza is divided in 4 pieces. 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.

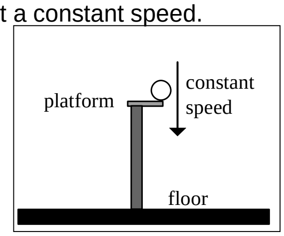
Implications

- Different contexts may trigger students to reach for different resources.
- Resources situated in students' everyday experiences are often much easier for them to use than formal ones.
- Transfer is non-trivial. Linking situated and formal methods may be particularly difficult for students.
- What may look simple to someone accustomed to a context may be hard for someone new to that context.

(A problem that looks like Gin and Coke to you may look like K2A7 to your students!)

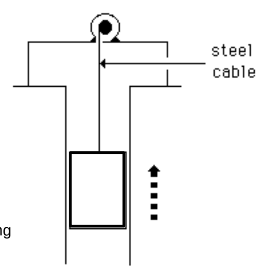
Student responses depend on context*

- Exam problem:
  A steel ball resting on a platform is being lowered at a constant speed.
  - **Draw a free body diagram of the ball.**
  - **Describe each type of force on the ball.**
  - **Compare the magnitudes of the forces you have drawn.**
  - **Explain your reasoning.**



*R. N. Steinberg and M. S. Sabella, *Phys. Teach.* 35, 150-155 (1997).

- FCI 18*: An elevator is being lifted up at a constant speed. (Ignore friction and air resistance)
  - A. The upward force on the elevator by the cable is greater than the downward force of gravity.
  - B. The amount of upward force on the elevator by the cable equals the downward force of gravity.
  - C. The upward force on the elevator by the cable is less than the downward force of gravity.
  - D. It goes up because the cable is being shortened, not because of the force being exerted by the cable on the elevator.
  - E. The upward force on the elevator by the cable is greater than the downward force due to the combined effects of air pressure and the force of gravity.



*D. Hestenes, M. Wells and G. Swackhamer, *Phys. Teach.* 30, 141-158 (1992).

Results

- Exam Problem
  - 90% give the correct answer
    - the normal force on the ball is equal to the downward force due to gravity
- FCI 18
  - 54% choose the correct answer:
    - the upward force on the elevator by the cables equals the downward force due to gravity
  - 36% choose a common misconception:
    - the upward force on the elevator by the cables is greater than the downward force due to gravity

*R. N. Steinberg and M. S. Sabella, *Phys. Teach.* 35, 150-155 (1997).

Implications

- Students' responses may depend on context.
- It not only matters that they "know" the physics, it matters when they naturally bring it up.
- "Physics problems" may cue different resources from "ordinary life situations".

Key Ideas

- **1. Knowledge is associative**
- **2. 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 built from old.*
- **3. Cognitive response is context dependent.**
  - The productive response depends on the context in which new input is presented, including the student's mental state.
- ➢ *Students can use multiple models*
  - -- *Confusion about appropriate context can make it appear as if students hold contradictory ideas at the same time*

Characteristics of Schemas

- Schemas are the basic associational patterns that activate or prime a chain of connections. (spreading activation)
- Schemas can be
  - context dependent
  - inconsistent
- School-based schemas may be less robust and effective than life-experience-based schemas (situated cognition)

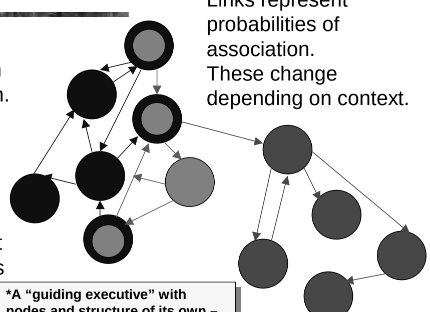
Organizing Long-Term Memory

- The fact that some bit of knowledge or know-how is "in there" doesn't help much if it doesn't come up when you need it.
- What's important is not just what knowledge you have but its functionality --
  - how appropriately you access it
  - how well you can use it.

I can't remember your name, but I never forget a face!

Organization of Long-Term Memory: Schemas

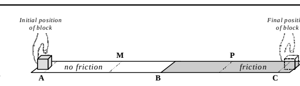
This picture is an oversimplification. "Nodes" have structure in multiple dimensions. There are "metanodes" that control what links appear when.*



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

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

A hand applies a force to a small 1 kg block from "A" to "C." The block starts at rest at point "A" and then come s to rest at point "C." The block moves along a frictionless surface from "A" to "B" and then travels an **equal** distance along a surface with friction from "B" to "C" with the force of the hand **remaining constant**. The force of the hand is 2 N to the right and the distance from "A" to "C" is 2 m. (See figure above.)



a) **Draw a free body diagram for the block when it is at "P."**

b) Is the magnitude of the net force acting on the block at "M" greater than, less than, or equal to the magnitude of the net force acting at "P"? Explain your reasoning.

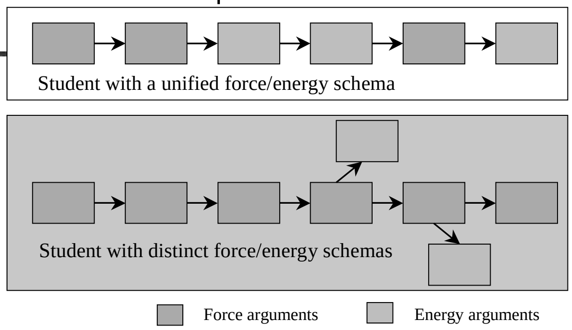
c) i. Draw a vector representing the acceleration of the block at "P." If the acceleration is zero state that explicitly.

ii. Does the magnitude of the acceleration increase, decrease, or remain the same as the block moves from "B" to "C"? Explain.

d) **Calculate the coefficient of kinetic friction μ.**

**Mel Sabella, Ph.D. Dissertation, U. of MD, August 1999.*

Interview Response of 2 "Grad Students"



Mel Sabella, Ph.D. Dissertation, U. of MD, August 1999.

Some guidelines for teaching

- Students' responses depend on context – including the state of their mind at the time.
  - Hands on activities are not enough. They have to be brains on, as well. (Learning environments need to be designed to prime the students' states of mind.)
- Connections count – not just the content.
  - Evaluations must focus on functional learning, not on the "presence" of the knowledge in a (presumed) unstructured box..
- Learning is a growth – not a transfer.
  - Students have to make connections many times before they "stick" (synapses grow).

Some cognitive goals

- In addition to having students master the physics content, our cognitive considerations suggest that we also want to consider
  - the extent to which students have a <u>conceptual understanding</u> of the physics (see the physics as "making sense")
  - the extent to which students can <u>access the correct knowledge appropriately</u>)
  - the way the students <u>organize their knowledge</u> (develop a coherent and consistent view of the physics they are learning).

Some research-based instructional environments in physics

- **<u>Lecture</u>**
  - **Interactive Lecture Demonstrations** (*Sokoloff & Thornton*)
  - **Peer Instruction** (*Mazur*)
  - **ActivPhysics** (*Van Heuvelen*)
- **<u>Recitation</u>**
  - **Tutorials** (*McDermott et al.*)
  - **Group Problem Solving** (*Heller & Heller*)
- **<u>Laboratory</u>**
  - **RealTime Physics** (*Laws, Thornton, & Sokoloff*)
  - **Problem Solving Labs** (*Heller & Heller*)
- **<u>Full Studio</u>**
  - **Physics by Inquiry** (*McDermott et al.*)
  - **Workshop Physics** (*Laws*)
  - **Studio Physics** (*Wilson & Cummings*)
  - **SCALE-UP** (*Beichner & Risley*)

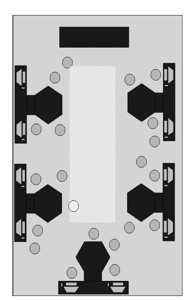
The UW Tutorial Model*

- Tutorials have a number of critical elements:
  - pretest
  - facilitator training session
  - tutorial with research-based worksheets and Socratic facilitators
  - tutorial homework
  - exams have a tutorial question
  - some tutorials (those developed at UMd) use computer-assisted data acquisition.
- Lectures (and labs) unchanged.

* L. C. McDermott, et al., <u>Tutorials In Introductory Physics</u> (Prentice Hall, NY, 1998)

Workshop Physics*

- In a WP room
  - Students use powerful computer tools for observation and modeling.
  - guided inquiry model of instruction.
  - can flexibly restructure groups.
  - instructor in the room's center can see all computer screens at once.
  - class can easily switch from small to large group discussion.



* Priscilla Laws, <u>Workshop Physics Activity Guide</u> (John Wiley & Sons, 1997)

Evaluating Concept Learning: The Force Concept Inventory (FCI)*

- 30 item multiple-choice probe of student's understanding of basic concepts in mechanics.
- The choice of topics is based on careful thought about the fundamental issues and concepts in Newtonian dynamics.
- The questions are framed in (semi-)real life contexts in common speech rather than physics jargon.
- The distractors (wrong answers) are malicious. They are based on research that probes the students' most common responses.

** D. Hestenes, M. Wells and G. Swackhammer, The Physics Teacher **30**:3, 141 (1992)*

Some preliminary results

- A study of 60 classes around the country by Dick Hake* shows that across a wide range of initial states the fraction of the possible gain is similar for classes of a similar structure.

$$h = \frac{(\,posttest\ average - pretest\ average)}{(100 - pretest\ average)}$$

- For traditional classes he finds

$$\boldsymbol{h \approx 0.20 \pm 0.05}$$

** R. R. Hake, Am. J. Phys. **66**:1, 64-74 (1998)*

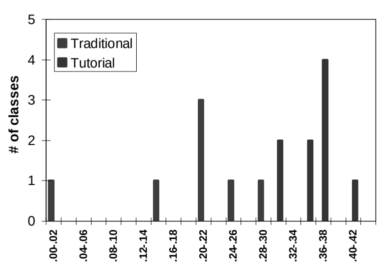
Can research-based instructional models produce better conceptual gains?

- We tested a change in our instruction* in calculus-based physics for engineers.
  - recitation is replaced by a group-learning concept-building activity (tutorial).
  - trained TA's help students learn qualitative reasoning with research-based worksheets.
- Half the lecture classes had recitations, half tutorials. Students were tested with pre- and post-FCI.

Research Context

- Introductory calculus-based physics
- ~90% of population are engineers
- Course occupies 3 semesters
  - 3 hrs of lecture/wk (100-200 students)
  - 1 hr small group (25-30 students)
  - 2 hrs lab/wk in semesters 2 & 3 (24 students)
- Small group sessions have 2 options
  - recitation (TA led problem solving)
  - tutorial (UW model)

Tutorials produced significantly higher gains than recitations

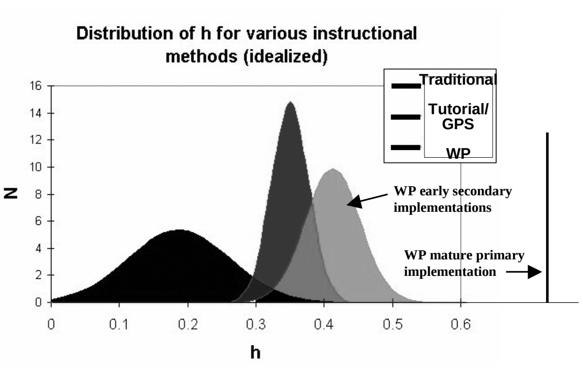


**E. F. Redish, J. M. Saul, and R. F. Steinberg, Am. J. Phys. 66, 212-224 (1998).*

Extension to many schools*

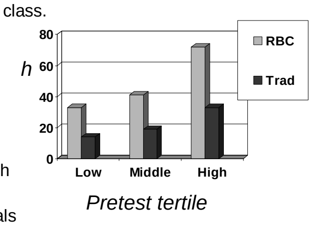
- This study was extended to 14 colleges and universities teaching calculus-based physics using 4 instructional models:
  - traditional with recitation
  - traditional with tutorial
  - traditional with group problem solving
  - workshop physics (a small class active-engagement model).
- Both primary and secondary implementations of the research-based curricula were observed.

**J. M. Saul, Ph.D. Dissertation, U. of MD, January 1998 and J. M. Saul and E. F. Redish, Evaluation of the Workshop Physics Dissemination Project, U. of MD preprint, April 1998.*



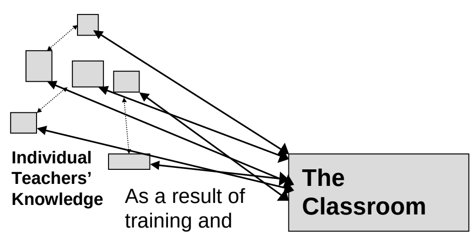
Interactive environments are not enough.

- RPI attempted to extend the Workshop Physics idea to a large class.
- The class is broken into groups of 50 in WP-like sessions.
- Materials are written by physics faculty.
- Cummings et al. gave pre-/post FCI to calculus-based students.
- The environment is technology rich and highly interactive.
- They compared traditional materials to research-based (ILD's) in random sections.



K. Cummings, J. Marx, R.Thornton, and D. Kuhl, PERS to Am. J. Phys.67 S38(1999)

Building a community consensus of education



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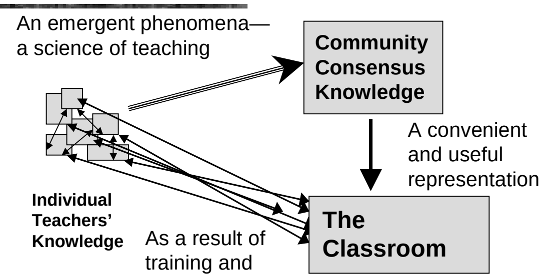

The research effort in university level PER has grown substantially over the past decade.

- Air Force Academy
- American U.
- Arizona State*
- Boise State
- Carnegie-Mellon
- CCNY
- Dickinson.
- Harvard
- Iowa State U.*
- IUPU Fort Wayne
- Kansas State U.*
- Montana St.*
- N. C. State*
- NE Louisiana U.
- Northwestern
- Ohio State*
- Oregon State
- RPI
- San Diego State U.
- Texas Tech
- Tufts U
- U. C. Berkeley
- U. of Central Fl.*
- U. Mass, Amherst*
- U. of Maryland*
- U. of Maine*
- U. of Minnesota*
- U. of Nebraska*
- U. of Oregon
- Utah State
- U. Washington*

In a physics department
In an education school
Joint physics/education
Special program

* has a physics grad program

http://www.physics.umd.edu/perg/

- **<u>Faculty</u>**
  E. F. (Joe) Redish
  David Hammer†
  John Layman† (*emeritus*)
  († joint with Education)
- **<u>Grad Students</u>**
  Rebecca Lippmann
  David May (visiting from OSU)
- **<u>Postdocs</u>**
  Laura Lising
  Andy Elby*
  Apriel Hodari**
  (*PFSMETE Fellow
  ** Congressional Fellow)
- **<u>Visitors</u>**
  Seth Rosenberg (CCNY)
- **<u>Recent Graduates, Associates and Visitors</u>**

  Jeff Saul, U. Cent. FL (Ph.D. 1998)
  Michael Wittmann, U. ME (Ph.D. 1998)
  Mel Sabella, UW (Ph.D. 1999)
  Bao Lei, OSU (Ph.D. 1999)

  Richard Steinberg§ (CCNY)
  Beth Hufnagel* (Anne Arundel CC)
  (§ NAE Spencer Fellow
  *PFSMETE Fellow)

  Pratibha Jolly (*India*)
  Gilli Shama (*Israel*)
  Jonte Bernhard (*Sweden*)
  ZuYuan Wang (*China*)