Our model of how a student "works": Does it matter for teaching science?

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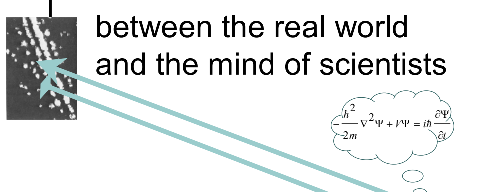
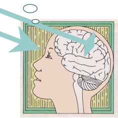
Supported in part by NSF grant REC-008 7519

Outline

- Why should a science teacher worry about how people think?
  - A model of science
  - A model of thinking
- Level 1: Basic Elements – Concepts
- Level 2: Executive Function – Frames
- How does it matter?

Science is an interaction between the real world and the mind of scientists

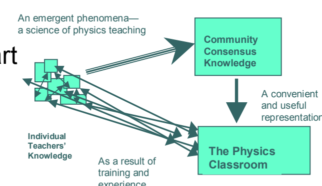




- When we only study one side of the interaction, we miss a critical part of the phenomenon of physics.

Science is an interaction among scientists, and the minds of scientists

- When we ignore the social character of science, we miss a critical part of the phenomenon of science.

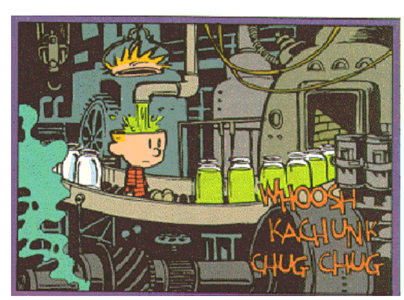


Science is not only about the real world, it's about how to <u>think</u> about the real world.

- *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, J. of the Franklin Institute (1936)

A Model of Student Learning



Bill Watterson *Calvin & Hobbes*

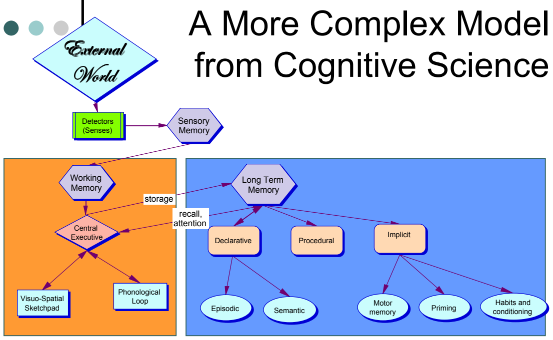
Two Phenomenological Models of Student Learning

- The Misconceptions Model
  - Students hold well-formed "alternative" (non-scientific) theories.
- The Resources Model
  - Students have a (largely disconnected) collection of ideas and principles that apply to specific situations.

Build a "Soft Paradigm" — An evolvable heuristic

- Seek general principles (heuristics) to help us understand what we see in our classes and research.
- Triangulate:
  Look for ideas consistent with data from
  - *Phenomenological observations* – real people in real environments: classrooms (*Education research / Social science*)
  - *Idealized ("zero friction") experiments* to probe fundamental mechanisms (*Cognitive science*)
  - *Studies of mechanisms* in the brain for plausibility (*Neuroscience*)

A More Complex 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).

Some Components of a Model of Thinking: Level 1— Concepts

- 1. Memory is productive and associative
  - Coherent memories are reconstructed and interpreted out of smaller components (primitives, resources, templates).
  - Activating one element leads (with some probability) to the activation of associated elements.
- 2. 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).*

Making sense

- What's this?
- Hint: It's an animal.

Making sense

- Does this help?

Using this idea in class

- If students don't have a template for using an equation for "sense making" they won't be able to do it.
- The process needs to be modeled.
- They need to be given practice in doing it.
- They need to be tested on whether they've learned to do it.

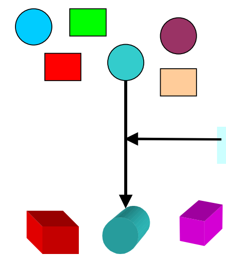
Resources: Physical reasoning maps primitive elements onto specific situations*

Primitives

Irreducible functional pieces based on direct interpretation of experience

Facets

Inferred physical principles for specific situations

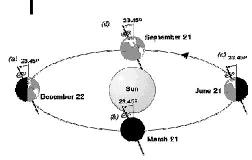


Context

Both internal and external

** diSessa and Minstrell*

Why do we have seasons?



- Essentially every elementary school student in the USA has been given the explanation.
- Then why do Harvard graduates give the wrong answer when asked?

Primitive: Closer is stronger / more effective (neither right nor wrong)

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

Facet: It's warmer in the summer, so we must be closer to the fire.(wrong)

Using this idea in class

- How the students interpret what we give them in class depends on
  - what they have (the resources) and
  - what they use (the mappings)

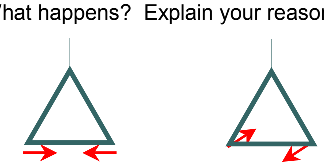
  to interpret it.
- Often, finding the appropriate resource to activate can help students a lot.
  - metaphors
  - analogies
  - …

Using this idea in research

- Often, when researching a topic we ask students to provide an explanation of their reasoning.
- We assume this will give us an insight into their thought processes.
- But the answer might come first (a spontaneously mapped primitive), the reasoning second.

Example

- A triangle is hung from one of its points.
- Equal and opposite forces are exerted on the bottom points of the triangle. What happens?
- Now the forces are tilted as shown in the figure. What happens? Explain your reasoning.



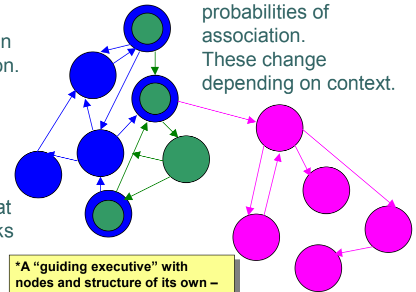
Knowledge is associative / linked

- 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.

I recognize the face, but just can't bring up the name!

Organization of Long-Term Memory: Schemas, Coordination Classes, etc.

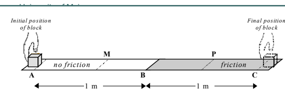
This picture is an oversimplification. "Nodes" have structure in multiple dimensions. There are "metanodes" that control what links appear when.*



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.

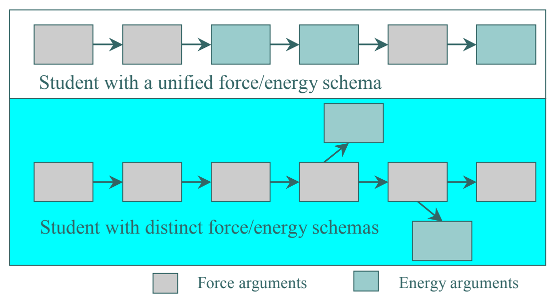
c) i. Draw a vector representing the acceleration of the block at "P." If the acceleration is zero state that explicitly.

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.**

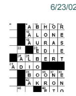
**Mel Sabella, Ph.D. Dissertation, U. of MD, August 1999.*

Interview Response of 2 "Grad Students"



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

Using this idea in class



- The organization principle has serious implications for our testing.
- It's not enough to assume "If it's in their heads, they know it."
- We have to consider functionality: When do they activate their knowledge?
- Often, our testing provides enough cues to activate an answer, showing that it's "in the student's head", but doesn't tell us how functional that knowledge is.

The cognitive response is context dependent.

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

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

The dealer of the cards proposes that they satisfy the rule:

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

Which cards you have to turn over to see if the rule is satisfied for this set of four cards?

K	7	A	2

You are acting as bouncer at the Vous.

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

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

What is the smallest number of cards you have to turn over to see if you should evict any of the customers?

16	Coke	52	Gin & Tonic

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.

Long-Term Memory: Organization

- 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
  - whether you choose to use it.

Using this idea in class

- Don't expect lots of buffering.
- "Given-new" principle
  - Give new information in the context of what is needed to interpret that information.
- Set context first
  - Find out what students know (The more you know about this, the better.)

A Global Theory or a Soft Paradigm?

"The moles might build a castle!"

- Notice that this framework is consistent both with a misconceptions and with a more fine-grained framework.
- "Misconceptions" can arise as robust linkages of primitive elements to particular classes of situations.
- The question how a bit of student knowledge should be handled becomes an empirical question, not a matter of theoretical dogma.

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Some Components of a model of thinking: Level 2 — Frames

- 1. In addition to the cognitive mechanism discussed before, there are mechanisms of "executive function" that manage and select their knowledge structures.
- 2. People have a variety of resources that they use to decide they know something.
- 3. People have "meta-schemas" or "frames" that determine what resources they feel are appropriate to use in what context.

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Frames

- For each activity we give them, students bring not only general expectations about physics, but specific expectations about "What is it we're doing here?"
- These context-dependent expectations have cognates in different fields.
  - Frames (rhetoric)
  - Scripts (cognitive psychology)
  - Registers (sociolinguistics)
  - Epistemic games (education)

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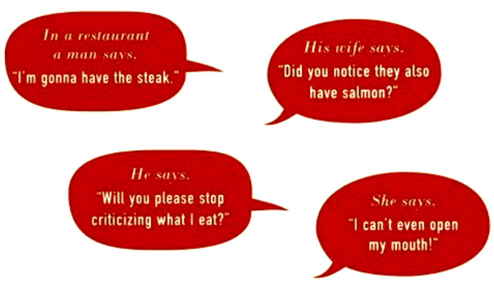
Example



Deborah Tannen, *I Only Say This Because I Love You*

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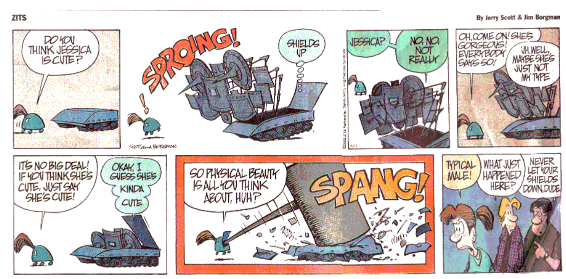
Another Example



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Frame Components

- A student's learning frame has many components.
  - social (Who will I interact with?)
  - material (What materials will I use?)
  - skills (What will I be doing here?)
  - affect (How will I feel about what I'm doing?)
- The student's frame may shift from class to class and even from task to task within a class.
- One of the most important components of learning frames is epistemological:
  - specific expectations about what sort of knowledge production / creation is appropriate for a particular activity.

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Examples of E-Frames

- Students trained in traditional / WP environments took different approaches to solving a problem. (Saul)
- Students new to a UW-tutorial environment assume the worksheets should be filled out in detail with every statement correct.
- Students in a traditional lab assume that getting the data is what's important, not making sense of what is happening in physical terms.
- African-American and Hispanic students at Berkeley felt it was "cheating" to collaborate with other students on science and math homework. Their grades suffered with respect to European- and Asian-American students. (Treismann)

Messages and meta-messages

- Our two-level cognitive paradigm leads us to focus not only on
  - what our instruction presents about content (the "overt message")

  but also on
  - what our instruction is saying to the students about how it's appropriate to work with and think about the content (the "covert message")

Using this idea in class

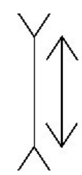
- If we say in lecture
  - "It's really important for you to learn the concepts and to make sense of the science you are learning."
- If we give homework that only require finding the right equation, plugging in numbers, and getting an answer
  - "What really matters is knowing the equation. Making sense of it doesn't matter."

How does having a theoretical frame (soft paradigm) affect instruction?

- Putting student learning into a two-level resources paradigm affects many aspects of instruction.
  - Choice of goals
  - Method of delivery
  - Choice of evaluation tools
  - Paying attention to the covert messages as well as the overt messages

Example: Making the covert messages overt

- Giving voice to epistemology
- Handout



Conclusion: How does having a theoretical frame (soft paradigm) affect instruction?

- Having a model of how students think changes the way we listen to students.
- Putting student learning into a two-level resources paradigm affects many aspects of instruction.
  - Choice of goals
  - Method of delivery
  - Choice of evaluation tools