

# The Future of Physics Education: Building an applied science?

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## What have we learned?

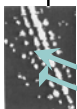
- Over the past two decades, physics education research has studied how students learn – and don't.
- Much has been learned about specific student difficulties with particular topics ranging from mechanics to quantum physics.
- In the past decade a variety of instructional techniques have been developed and tested.

- Traditional instruction leaves most students with little understanding.
- Students bring knowledge of the world into the classroom and interpret what we offer them using what they know.
- Students can often learn to do traditional physics problems without understanding what the solution means and without changing their naïve beliefs about how things behave.
- Reforms based on active learning can help develop conceptual understanding.

## What's next?

- From creating applied sciences we have learned that it is not enough to create a "wizard's book" of what happens.
- We need to develop a deeper understanding of student learning.
- We need a model of student thinking and learning that can be tested, refined, and used to predict and interpret.

## Physics is an interaction between the real world and the mind of physicists

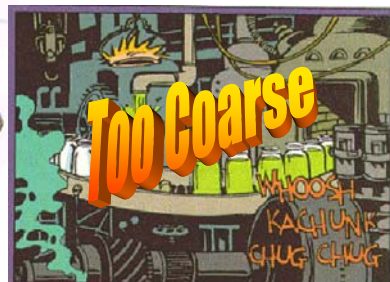


$$\frac{\hbar^2}{2m} \nabla^2 \psi + V\psi = i\hbar \frac{\partial \psi}{\partial t}$$

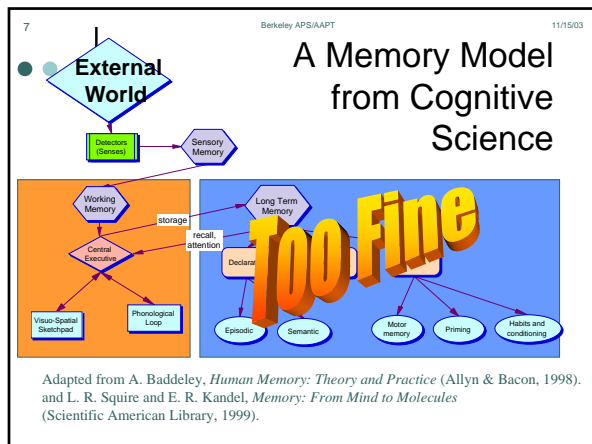
- When we only study one side of the interaction, we miss a critical part of the phenomenon of physics.



## A Model of Student Learning



Bill Watterson Calvin & Hobbes



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## Two Current Models of Student Learning

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

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## Build a Theoretical Framework

- o Seek general principles to help us understand what we see in our classes and research.
- o 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*)

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## Some Components of a Model of Thinking: Level 1— Knowledge

- o 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.
- o 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).

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## Implications: Some heuristic principles

- o 1. Resources:
  - *Pay attention to what the students will use to build their knowledge.*
- o 2. Association / Linking:
  - *Help students build coherence*
- o 3. Making sense:
  - *Help students build strong conceptual understanding.*
- o 4. Context dependence:
  - *Help students understand when physics knowledge is relevant.*

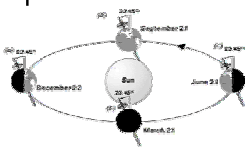
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## 1. Resources: Physical reasoning maps primitive elements onto specific situations\*

\* diSessa and Minstrell

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## 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)


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## Using this idea in class

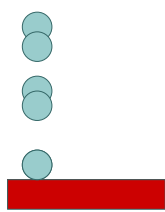
- How the students interpret what we give them in class depends on
  - what they have (the resources) and
  - what they use (the mappings) to interpret it.
- Often, finding the appropriate resource to activate can help students a lot.
  - metaphors
  - analogies
  - ...

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## Example: Finding appropriate analogies

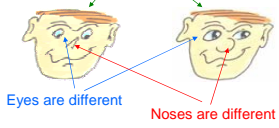



- Students often activate inappropriate resources when thinking about physics.
- In thinking about energy, some students activate *feature analysis* rather than *compensation*.



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

## Two resources

- Feature analysis:** "Different plus different is more different."
 
- Compensation:** "Robbing Peter to pay Paul."
 

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## 2. Associations / Linking

- 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.

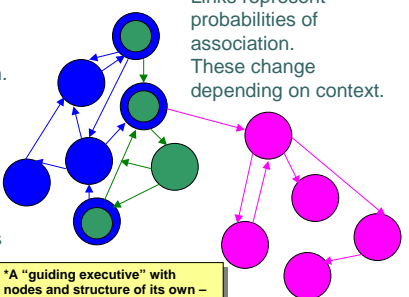
I recognize the face, but just can't bring up the name!

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

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.

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## Memorize these numbers!

3 5 2 9 7 4 3 1 0 4 8 5

1 7 7 6 1 8 6 5 1 9 4 1

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## 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.

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## Example: Link to personal experience

- In a resources / linkages picture, it is natural to suggest that a valuable resource to link to for physics is students' personal experiences with their own physical world.
- We make a strong effort to do this
  - when we introduce new topics in lecture
  - in homework (estimation and context rich problems)
  - in examination questions.

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## Sample Homework Problem


- One day I stopped to pick up a pizza. I put the box on the dashboard and pushed it against the windshield and left against the steering wheel to keep it from falling. I realized that it could still slide to the right or back towards the seat. Do I have to worry about it sliding more when I turn left or when I turn right? when I speed up or when I slow down? Explain your answer in terms of the physics you have learned.



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## 3. Making sense

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



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## 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.



## Example: Making sense, not memorizing equations.

- Even for the algebra-based students, I minimize applying many equations without thinking.
- Rather, I focus on using a few equations that have clear conceptual content and ask them to derive results and interpret their meaning.
- It sends a non-traditional message
  - not that: "physics (and science) is about lots of independent facts and reasoning can be automated."
  - rather, "physics is about making coherent sense of the physical world."

## Conceptual Equations

- Kinematics are handled with only two equations.
- These equations are related directly to the conceptual ideas.
- Other equations are (in lecture) obtained from processing these equations.
- If students put in numbers early, intermediate variables appear, but not the traditional equations (e.g.,  $s = \frac{1}{2} at^2$ )

$$\langle v \rangle = \frac{\Delta x}{\Delta t}$$

$$\langle a \rangle = \frac{\Delta v}{\Delta t}$$

## 4. The cognitive response is context dependent.

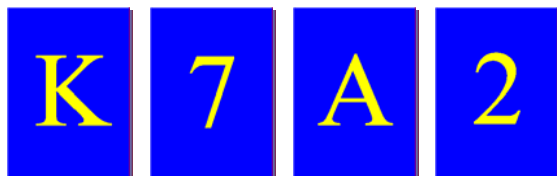
- The productive response depends on the context in which new input is presented, including the student's entire mental state.
  - Students can use multiple models
  - Confusion about appropriate context / lack of coherence in the student's reasoning can make it appear as if students hold contradictory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

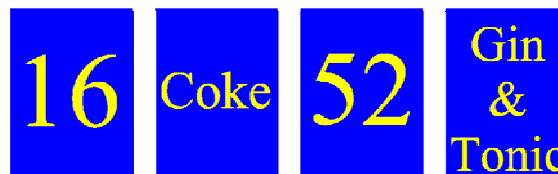


You are acting as bouncer at the Vons.

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?



## Using this idea in class

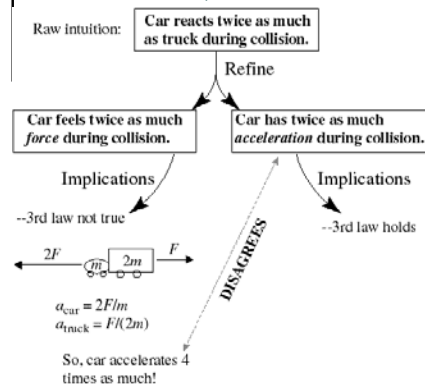
- Don't expect lots of buffering.
- "Given-new" principle
  - Give new information in the context of what is needed to interpret that information.
- Set context first
  - Find out what students know (The more you know about this, the better.)
- Help students build coherence.

## Example: Building coherence

- We create paired questions ("Elby pairs"),
  - one which most students are likely to answer correctly,
  - one which students are likely to answer with a common misconception.
- We then help them to see there is a contradiction in their thinking and help them resolve it.
- It sends a different message
  - not that "physics is right, your intuition wrong"
  - rather, that "physics helps you resolve contradictions in your intuitions."

## ILD and Tutorial

1. A truck rams into a parked car.
  - (a) Intuitively, which is larger during the collision: the force exerted by the truck on the car, or the force exerted by the car on the truck?
  - (b) Suppose the truck has mass 1000 kg and the car has mass 500 kg. During the collision, suppose the truck loses 5 m/s of speed. Keeping in mind that the car is half as heavy as the truck, how much speed does the car gain during the collision? Visualize the situation, and trust your instincts.
2. To simulate this scenario, make the "truck" (a cart with extra weight) crash into the "car" (a regular cart). The truck and car both have force sensors attached. Do whatever experiments you want, to see when Newton's 3rd law applies.



## Which model?

- Notice that our framework is consistent both with a misconceptions and with the more fine-grained modular description.
- "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.



"The moles might build a castle!"

## Some Components of a model of thinking: Level 2 — Framing

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.



## It's not just knowledge

- Students' understanding of the nature of scientific knowledge in general and what is happening in a physics course in particular may not agree with what we want and expect.
- "Science is not supposed to make sense."
  - Students in a laboratory in which they tried to create ways of thinking about electric current using models such as traffic flow and water.

- S: Are you going to tell us at some point what electricity really does?... I still have no idea how electricity ... works
- TA: OK. So this is what we're going to learn about physics. What stuff "really" does is sort of irrelevant, right? Cause it doesn't matter... [if it] always works to tell you whether or not a light bulb's going to light, that's good enough....
- S: You aren't interested in what really is though?
- TA: No. The philosophy majors can do that.... I mean, would you guys feel better if I used words you didn't understand?
- S: That's what I'm used to!

## 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)

## Frame Components

- The way a student frames a learning situation has many components.
  - *social* (Who will I interact with?)
  - *material* (What materials will I use?)
  - *skills* (What will I actually 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.

## Examples of E-Framing

- 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.

## 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")



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## Using this idea in class: Each of our examples sent carefully designed meta-messages

- Example 1:**  
Energy conservation
- Example 2:**  
The pizza box
- Example 3:**  
Kinematics equations
- Example 4:**  
Elby pairs


- Find a way of thinking about physics that makes sense to you.
- Reinterpret your everyday experience in terms of the physics you are learning.
- Don't memorize equations, use them to represent conceptual ideas.
- Make your physics knowledge coherent over many ways of looking at things.

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## How do students respond?



**Second term:**  
Tutorial in the third week.  
Student 1 had my course in the first term.  
The others had a traditional class.

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## Where can adding theory take us?

- A more complex and complete understanding of student thinking can help us
  - understand our students' errors
  - design more effective curriculum
  - better understand the true goals of our instruction ("The Hidden Curriculum")
  - adapt the goals of our instruction appropriately to the population
    - Biologists
    - Physics majors

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## The UMd PERG:

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- Postdocs**
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