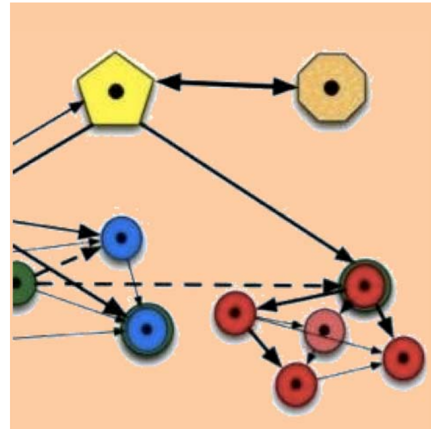
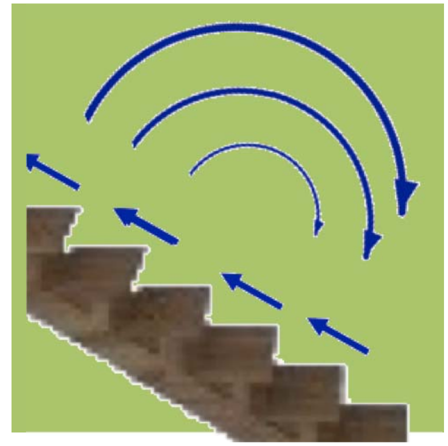
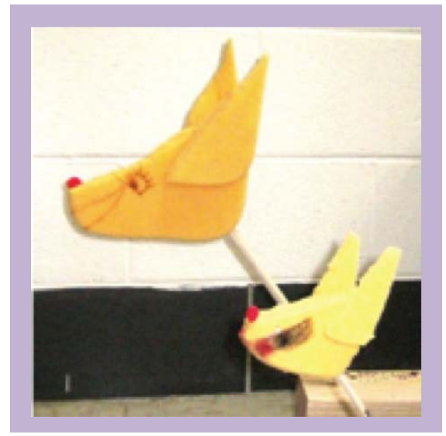
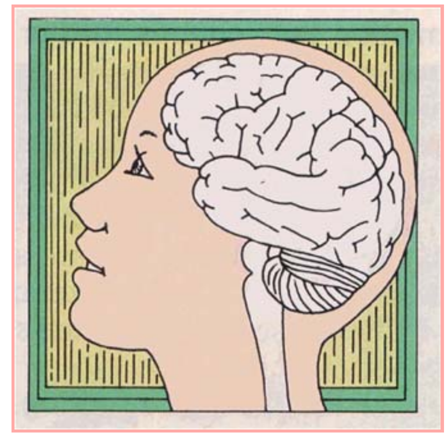








How should we think about how our students think?

Edward F. Redish

November 18, 2013

Yale STEM Ed seminar

Outline

- What's "a theoretical framework"?
- What do we need for science education?
- The resources framework
  - Cognitive basics
  - Socio-cultural basics
  - Expectations
- How expectations play out: Context and framing
- Lessons for Researchers and Teachers

“The most important leg of a three-legged stool is the one that’s missing.”

Remember

- *"It is also a good rule not to put overmuch confidence in the observational results that are put forward until they are confirmed by theory."*

Arthur Eddington

A. D. Wilson & S. Galonka
http://psychsciencenotes.blogspot.com/2013/11/replication-will-not-save-psychology.html

What's a theoretical framework?

Theoretical frameworks

- When we teach physics, we focus on well-developed theories. These come with well-established models that are viewed as integral parts of the theory.
- At a level where we are trying to establish a new framework, it is useful to separate the “bones of the framework” (the basic ontological assumptions) from the “fleshing out of the framework” (models and examples)

Redish, Varenna Lectures, arXiv preprint physics/0411149

Redish & Smith, J. of Eng. Educ. 97, 295-307 (July 2008)

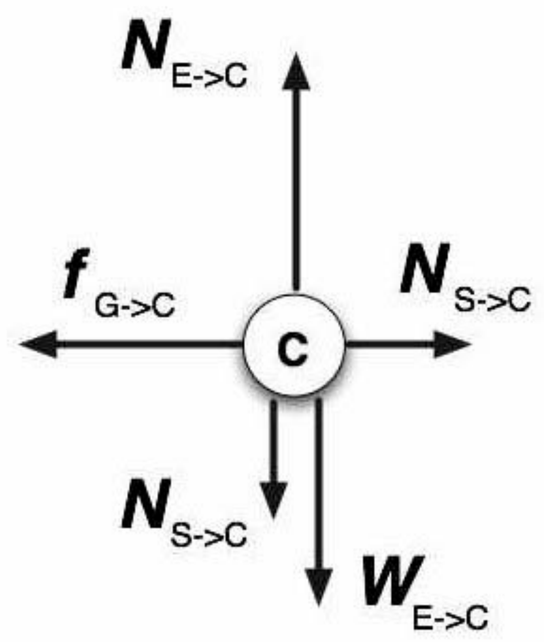
Examples of theoretical frameworks

- Math
  - Euclidean (plane) geometry
  - Cartesian (algebraic) geometry
- Physics
  - Newtonian physics
  - Quantum field theory
- Biology
  - Evolution

The Newtonian Framework

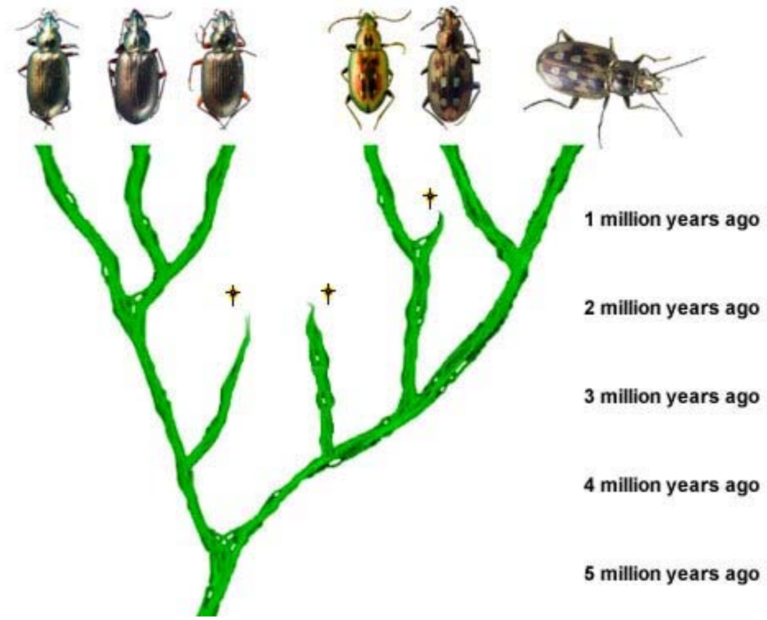
- Identify Objects
- Objects have: mass,
position (vector from an origin),
and velocity (vector)
- Interactions between objects
(force vectors)
  - Satisfy N3
- Objects respond to the vector sum of forces acting on them at the instant they feel them by changing velocity according to

$$\vec{a}_A = \frac{\vec{F}_A^{net}}{m_A}$$



The Evolutionary Framework

- Heredity (genotype)
- Variation
- Phenotype
- Interaction with other organisms
  - Prey
  - Predators
  - Parasites
  - Symbiotes



- Interaction with environment
- Natural Selection + random historical input (at all levels from molecules to asteroids!)

What good would it do us in DBER if we had a theoretical framework?

- We tend to build our interpretation of student behaviors on "natural" or "folk models" learned from childhood.
  - This is similar to the "folk models" of how the physical world works that our students bring to our classes.

- A theoretical frame can warn us when our generalizations of those models lead us astray. Folk models of teaching often miss:
  - Dynamic variability and incoherence
  - Importance of expectations

The Resources Framework: The basics

+ What should it look like?

- We don't want a micro → macro fundamental theory (from neurons).
- We want a macro-level system to guide phenomenological modeling. Something like
  - Newton with rigid bodies
  - Kirchhoff level theory of electric currents
  - Biological models of process without micro mechanism
- Draw on
  - Psychology / Neuroscience
  - Sociology / Anthropology
  - Linguistics / Semantics
  - Ethology / ...
- Establish foothold principles.

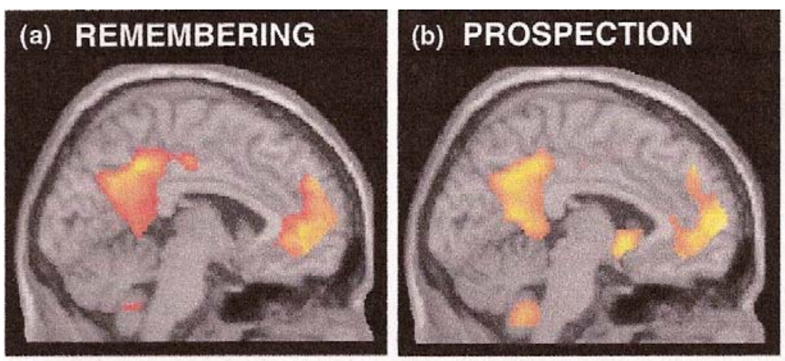
+ Memory is not veridical – A model of memory: Predicting the past

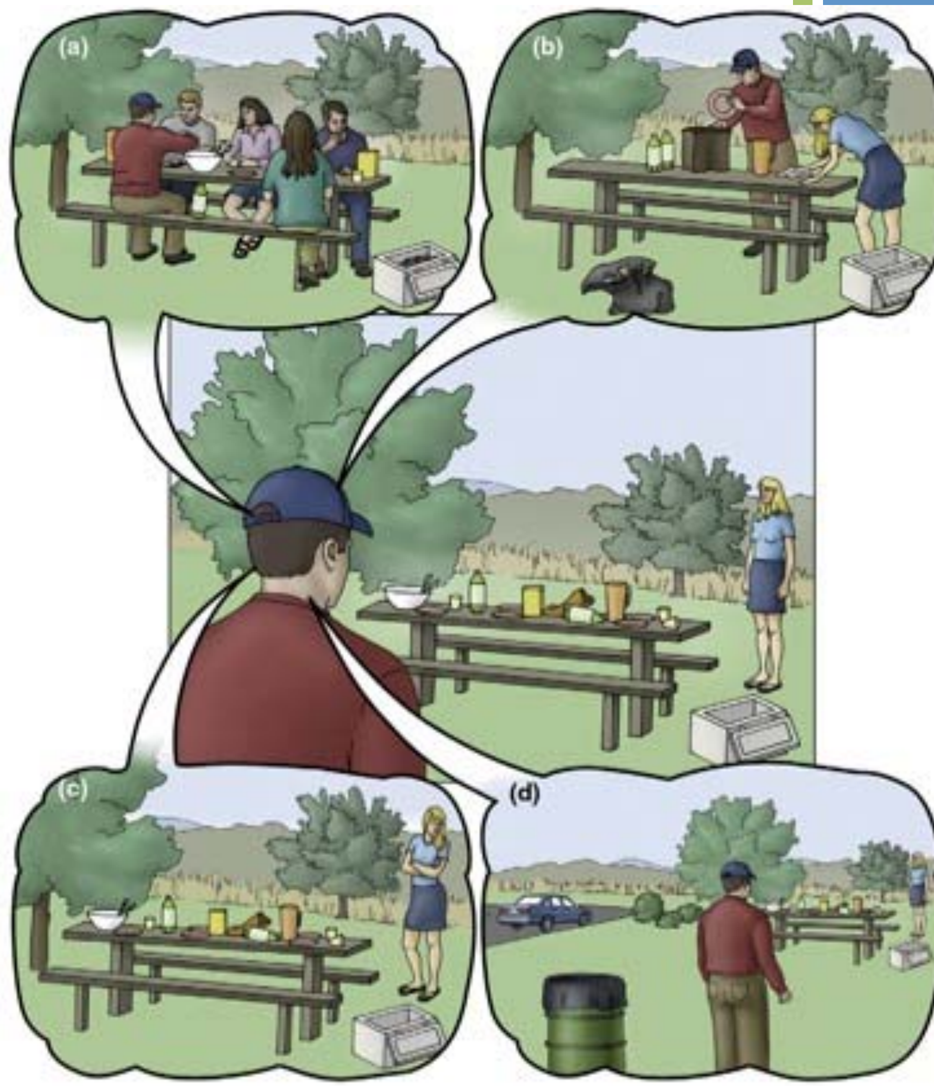
(a) Recalling past events

(b) Imagining future events

(c) Seeing things from someone else's perspective

(d) Navigation





From Buckner & Carroll Trends in Cog. Sci. 11:2 (2006)

+ Key cognitive principles

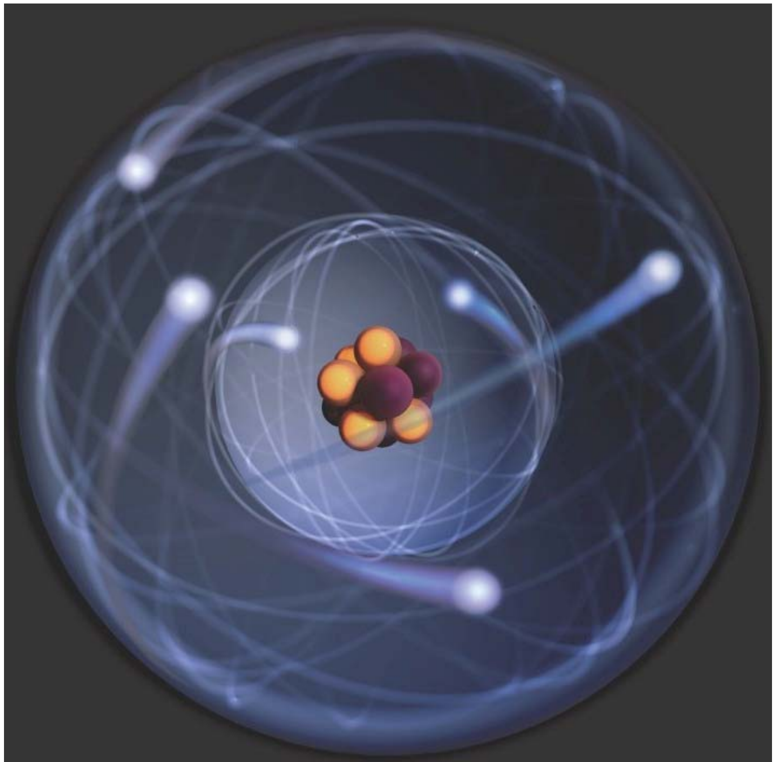
1. Memory is ***reconstructive*** and ***dynamic***.
   - People can bring up different interpretations of what they are seeing and doing quickly.
2. Working memory is ***limited***.
   - At one time you can hold in your mind and manipulate a small number of items (4-10).
3. Strong associations build ***chunks*** that can be manipulated as single units.
   - Clusters of elements can be compiled – to appear to the user as a single unit – then unpacked.
4. Access to long-term memory is controlled by ***executive function***.
   - The structure of how knowledge is organized and accessed is critical.

Gak! Can we do all this?

- There are a huge number of factors affecting each individual's behavior at each instant.
- The brain is highly dynamic, continually re-evaluating what knowledge it needs to bring to bear.
- Is it crazy to think that we can describe cognitive and cultural effects on the behavior of an individual student?

Mean fields

- The behavior
  of an individual electron
  in a complex atom
  fluctuates wildly.
- There are <u>huge</u>
  electron-electron
  correlations.
- Yet a mean field
  approximation – averaging
  over pair correlations –
  enables us to do
  all of chemistry.



The nucleus has been magnified
by a factor of ~1000 so it can be seen

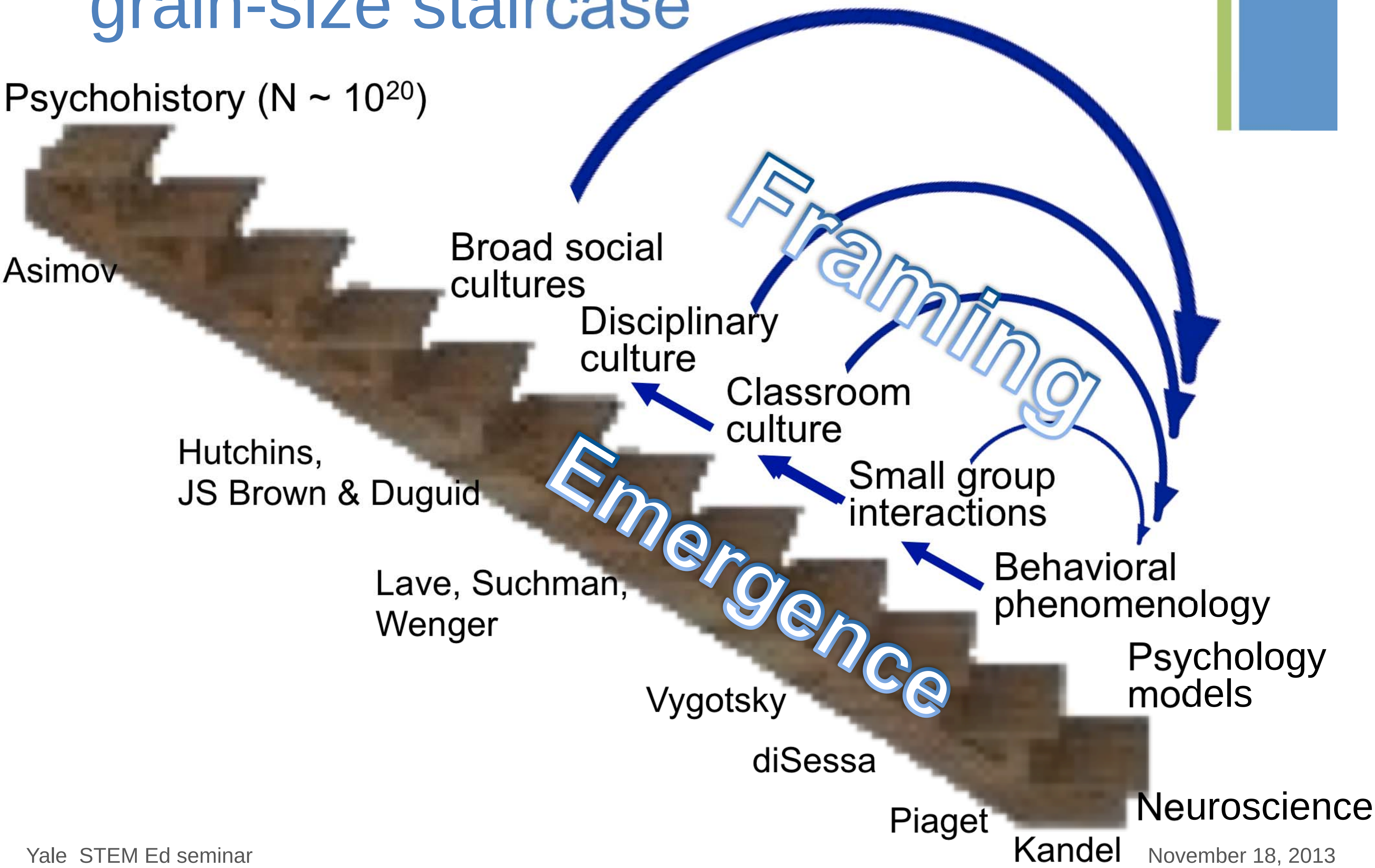
The Resources Framework

- A two-level structure
  - Concept knowledge (***basic knowledge***)
    - Compilation and chunking
    - Knowledge organization (associations)
  - Knowledge about when to use knowledge (***switching mechanisms*** or ***control structures***)
    - Cultural knowledge
    - Framing
    - Epistemology

+ Key concepts for discussing control

- Cultural knowledge
  - Knowledge about what behavior is expected comes from a wide variety of sources.
- Framing
  - The process of “choosing” a set of data in your environment to selectively pay attention to – equivalent to deciding what you expect to be important and that everything else can be safely ignored. (NOT conscious – mostly “under the hood”.)
- Epistemology: Knowledge about knowledge
  - What is the nature of the knowledge I am going to learn in this class and what is it that I need to do to learn it?
  - What of the knowledge that I have is appropriate to use in a particular problem or situation?

+ The cognitive/socio-cultural grain-size staircase



+ Key socio-cultural principles

1. Executive function controls what elements of the huge long-term memory store are activated in a particular situation.

2. Long-term memory contains not only concepts but social knowledge at multiple grain-sizes – ***expectations and interpretations of context***.

3. The process of taking partial data, activating social knowledge, and controlling access to the long-term store is ***framing.***

4. Framing is ***reconstructive and dynamic*** and can be labile or stable.

Framing

- The behavior of individuals in a context is affected by their *perception* and *interpretation* of the social context in which they find themselves.
- That perception and interpretation acts as a control structure that governs which of their wide range of behavioral responses they will activate / use in a given situation.
- Framing is the *interface* within the individual between the cognitive and the socio-cultural.

+ Building the Components of the Resource Framework

- Conceptual knowledge
  - Phenomenological primitives (p-prims)
  - Reasoning primitives
  - Symbolic forms
  - Associational structures
    - Mental models / schemata
    - Coordination classes
- Control / Framing / Socio-Cultural
  - Epistemological
  - Social (one-on-one and small group)
  - Cultural scripts
  - Disciplinary expectations
  - Affective responses

http://www.physics.umd.edu/perg/tools/resourcesreferences.pdf

Context and Framing

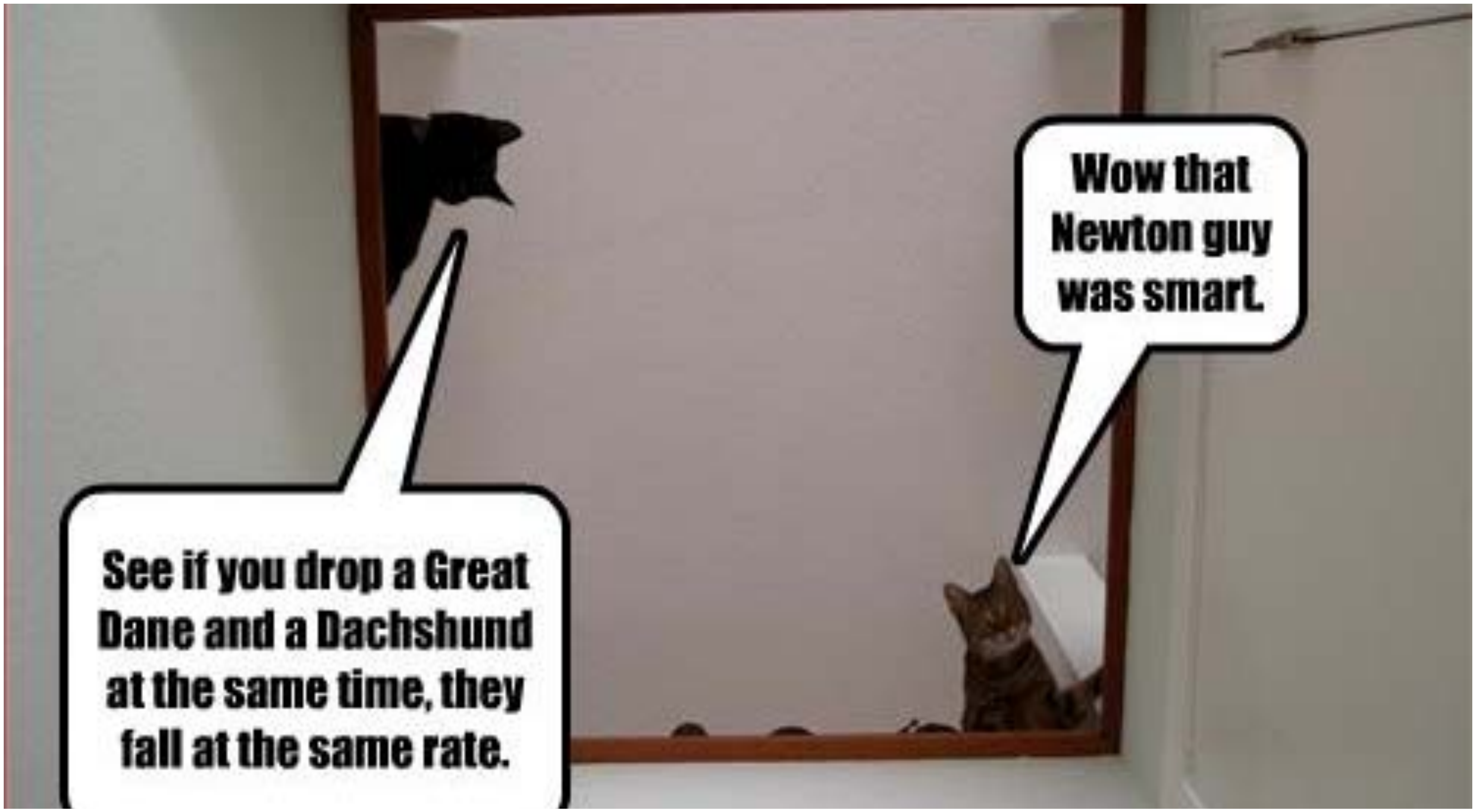
Examples of framings

1. ***One-step thinking:***
   "The answer is obvious.
   I don't have to worry about coherence."

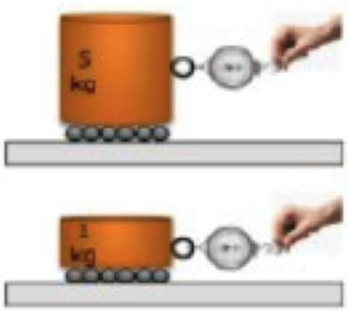
2. ***P-priming:***
   "The answer is obvious.
   I don't have to worry about mechanism."

3. ***Disciplinary siloing:***
   "This is biology.
   I shouldn't have to do math."

Framing example 1: Coherence

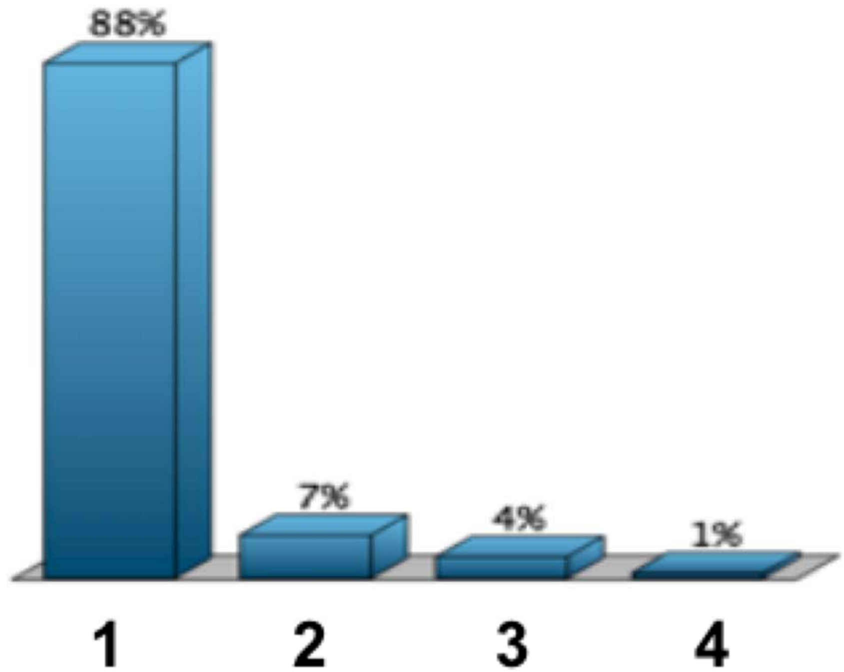


Data: Beginning of 1st term of intro physics (F13)



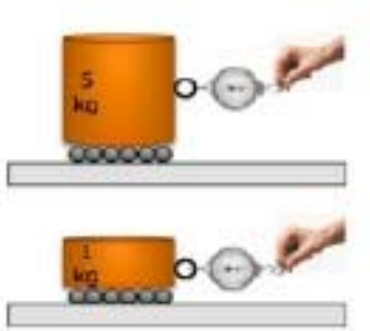
You are pulling two weights along a table with equal force. Which one would speed up faster?

1. The 1 kg weight
2. The 5 kg weight
3. The would speed up the same way.
4. There is not enough information to tell.



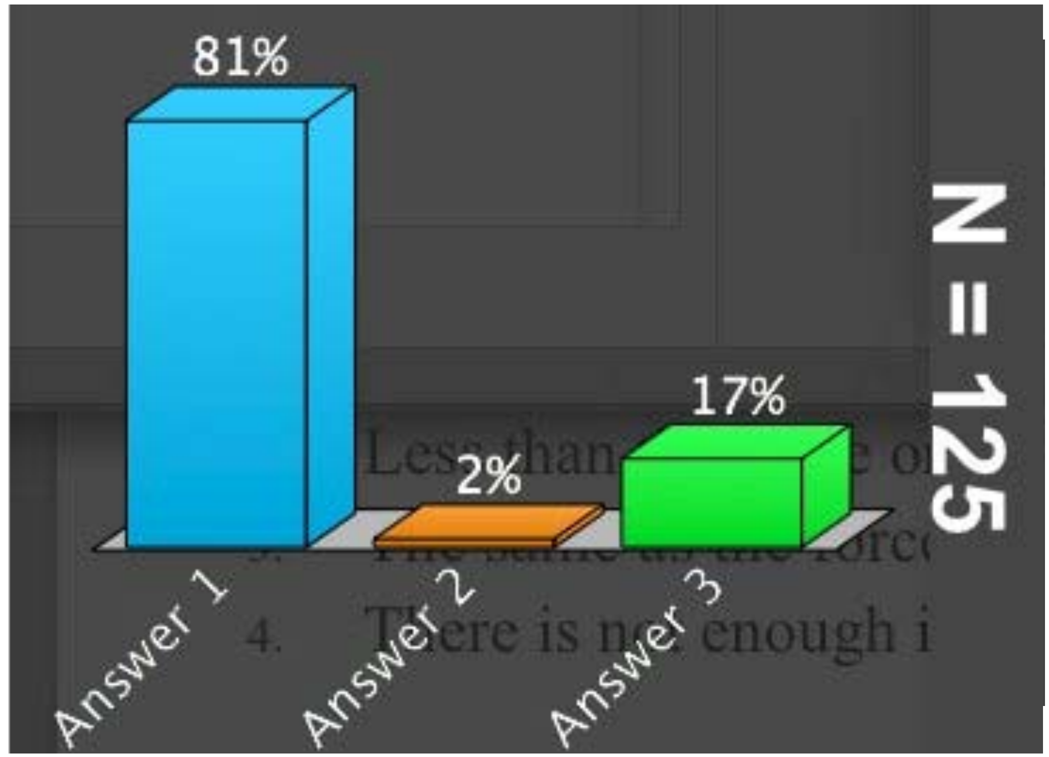
N = 111

Data: Beginning of 2nd term of algebra-based physics (S11)



You are pulling two weights along a table with equal force. Which one would speed up faster?

1. The 1 kg weight
2. The 5 kg weight
3. The would speed up the same way.
4. There is not enough information to tell.



Implication:

- Many students often exhibit ***one-step thinking*** and fail to call on knowledge that they know perfectly well even when that knowledge would be highly appropriate.
- This is likely associated with a “mean field” brought from school testing experience: *Each question is independent and should be approached anew*.
- Getting them to change their approach may not be easy. (***epistemological misconception***)

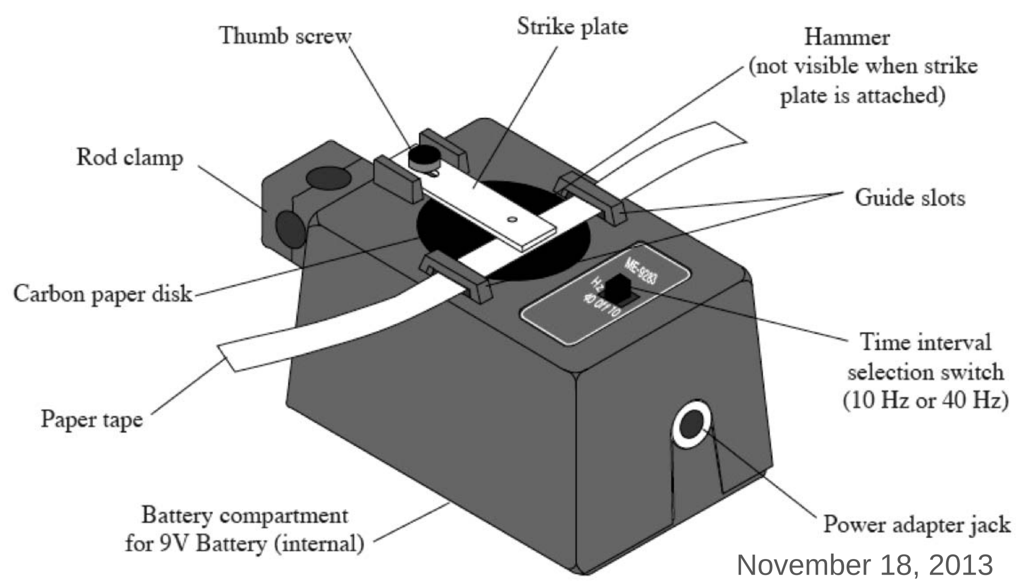
Framing example 2: Tutorials

- Tutorials are **research-based** worksheets done in small groups.
- Students are guided through expressing **their own ideas**, comparing them with observations and reasoning qualitatively.
- The critical component of the environment is **independent small group discussion**, *lightly* facilitated by an instructor.

L. C. McDermott, et al., *Tutorials In Introductory Physics* (Prentice Hall, 1998)
M. Wittmann, R. Steinberg, E. Redish, *Activity-Based Tutorials* (Wiley, 2003)
A. Elby et al., *Open Source Tutorials* (UMd, 2008).

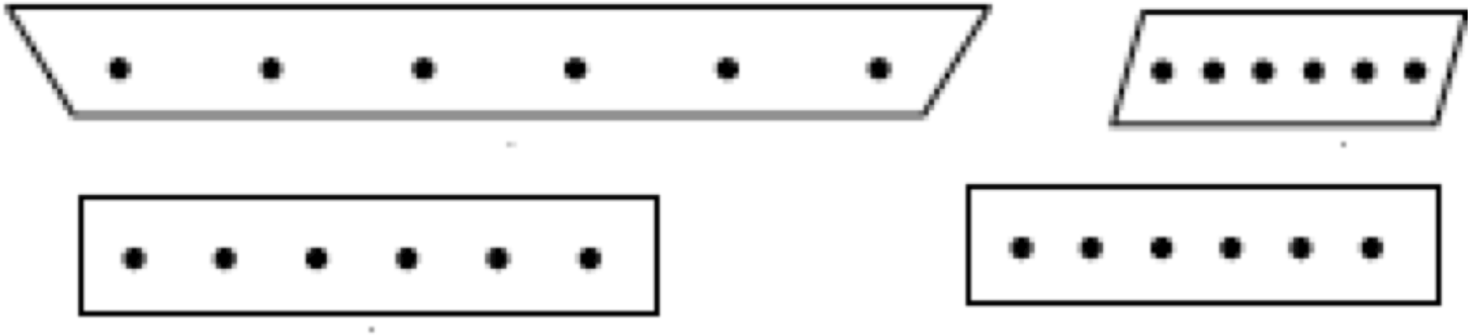
Mechanism

- In our first tutorial of the year, students are asked to analyze speed.
- Paper tapes are made beforehand by a machine tapping at regular intervals (6 times/sec). A cart attached to the tape slowly accelerates down a long ramp.



The task

- Each group of students is given 4 tapes containing 6 dots and asked “Which tape took the longest time to make?”



The result

B. Frank, PhD Dissertation, U. of Maryland, 2010

+ A few minutes later

Implication

- In their first look, the students activated a common reasoning primitive – “more is more”. They framed the task as ***answer-making***: that the result could be found directly and did not require considering the mechanism of the process .
- A few minutes later, in a new context, they quickly and easily reframed the task as ***sense-making***; one that required thinking carefully about the mechanism.
- Many students brought a “mean field” expectation that if a question at the beginning of a lesson sounded easy, it probably was, and therefore did not require careful thought.
- Appropriate cuing was, however, able to shift many students quickly and easily into a “consider the mechanism” frame – one that they had in their toolkit and were competent to use.

Framing example 3: Disciplinary siloing

- Often, physics students learn to manipulate mathematics effectively, but fail to blend their math with a physical interpretation of what's happening.
- Effective cognitive integration of physical intuition with mathematical tools is a key developmental skill for advanced physics students.
- In our advanced classes, we often fail to stress these skills or give students support in developing them.

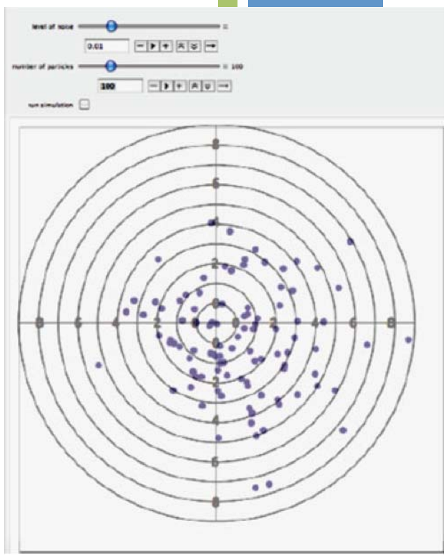
+ The Context: OrgBio

- At UMd, all bio majors take a sequence of 3 required bio courses:
  - cellular/molecular,
  - ecology/evolution, and
  - organismal/diversity (OrgBio)
- Instead of the traditional “forced march through the phyla”, OrgBio attempts to base itself in broad general principles including
  - Biology is based on and constrain by the principles of physics and chemistry
  - Some mathematical modeling

Redish & Cooke, *CBE-LSE* 12, 175-186 (2013).

+ Not all students like this

- *Ashlyn*: I don't like to think of biology in terms of numbers and variables. I feel like that's what physics and calculus is for. So, I mean, come time for the exam, obviously I'm gonna look at those equations and figure them out and memorize them, but I just really don't like them...I think that biology is just—it's supposed to be tangible, perceivable, and to put that in terms of letters and variables is just very unappealing to me, because like I said, I think of it as it would happen in real life, like if you had a thick membrane and you try to put something through it, the thicker it is, obviously the slower it's gonna go through. But if you want me to think of it as this is x and that's D and then this is t, I can't do it.



$$\langle x^2 \rangle = 2Dt$$

Watkins & Elby, *CBE-LSE* 12, 274-286 (2013).

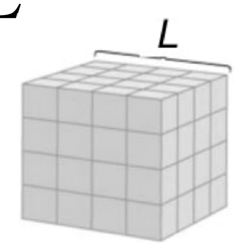
Unless it does work for them

Ashlyn: The little one and the big one, I never actually fully understood why that was. I mean, I remember watching a Bill Nye episode about that, like they built a big model of an ant and it couldn't even stand. But, I mean, visually I knew that it doesn't work when you make little things big, but I never had anyone explain to me that there's a mathematical relationship between that, and that was really helpful to just my general understanding of the world. It was, like, mind-boggling.

$$Perim = 12L$$

$$Area = 6L^2$$

$$Volume = L^3$$



+ Implication

- When Ashlyn framed the math as just making abstract what she felt should be "tangible and perceivable", she found the math "very unappealing."
- When the math helped her make sense of something she knew but didn't understand, she found it "helpful" and "mind-boggling".
- These comments occurred in the same interview a few minutes apart. This indicates that – especially for students crossing disciplinary boundaries – framing the task as *authentic* to the student's perception of the discipline (and her position in it) can be critical.

Watkins, Coffey, Redish, & Cooke, *Phys Rev STPER* 8, 010112 (2012).

+ Implication: There are multiple interacting dynamic levels of control.

You can get epistemological switching based on affect.

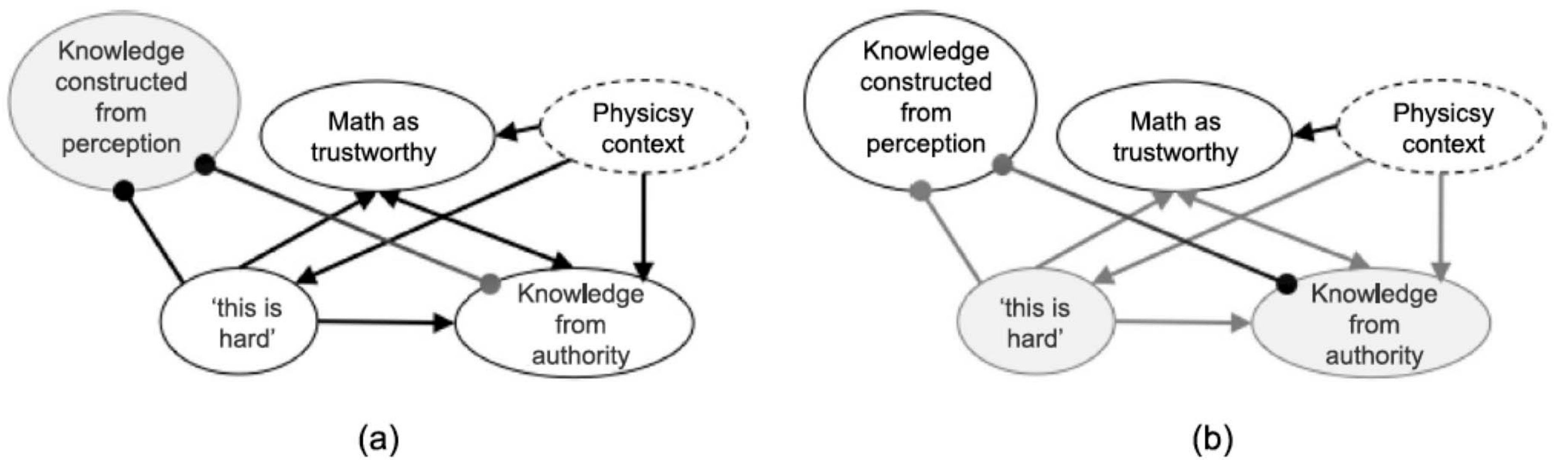


Figure 1. Modeling Jim's behavior in terms of patterns of activated cognitive elements: (a) when he is 'stuck,' and (b) after the mistake is resolved

Gupta & Elby *IJSE*. 33:18 (2011)

The take-away message

- Understanding student errors is necessary but not sufficient: Context is critical
  - Student responses don't simply represent activations of their stored knowledge. They are dynamically created in response to their perception of the task and what's appropriate.
  - The (often unconscious) choices they make may be determined by social and cultural experience (expectations and framing).
- Despite the fact that each student responds complexly and independently, common patterns of expectations can found. These can be used to create lessons that cue appropriate framings.

+

Implications for teachers and DBER researchers

Keywords!

- Constructivism!
  - Knowledge the students bring into the class matters!
- Dynamic!
  - Students are continually evaluating what knowledge they should be using!
- Framing!
  - Expectations matter a lot!

Implications for researchers and teachers

- Keep in mind that there can be many different reasons why a student gives a particular answer to a test / interview question.
  - Conceptual error in a mental model
  - Error in framing – not calling on a coherent schema
- We need to get feedback from students
  - But they may not be aware of their thinking processes.
  - Look for feedback beyond “explain your reasoning” (which might be an ex-post facto construct).
    - Language choice
    - Gestures

Advice for instructors

- Our goal should go beyond getting students able to generate correct answers to narrow (and often highly cued) answers.
  - This is <u>not</u> a good proxy for deep learning.
- We need to look for building coherent thinking and learning, not just the knowledge of physics but how and when to access and use it.
- This advice has implications across the curriculum.

Redish & Hammer, Am. J. Phys.,77 (2009) 629-642.

For more information

- On our research group (UMd PERG)
  - http://www.physics.umd.edu/perg/
- On the Resources Framework
  - http://www.physics.umd.edu/perg/tools/ResourcesReferences.pdf
- On our new *Physics for Biologists*
  - http://nexusphysics.umd.edu/