Does PER Need Theory? If so, what kind?

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Outline

- Where are we now?
- What do I mean by “theory”?
- What theories might be ready for development now?
- An outline of a theoretical frame
- Examples of what theory might buy us in instruction
- The implications for research in PER

What are we trying to do?

- Transform good teaching from an art (that only a few natural experts can do) to a science (that can be taught)
  - Understand what good teaching is in order to be able to teach people to do it.
  - Understand what learning physics means in order to be able to teach it more effectively (and efficiently).
  - Understand how to create environments and curricular materials that will help good teaching flourish.

Where are we?

- We have begun to reach a consensus on:
  - A fundamental philosophy of learning: “Constructivism”
    - Students bring in knowledge
    - Students interpret new knowledge in terms of their existing knowledge
  - A fundamental approach to instruction: “Active learning”
    - What matters is what students do, not what is given to them
    - Focus on creating appropriate environments in which they will do what they need to.
  - A broader approach to assessment and evaluation
    - “Explain your reasoning”
    - Conceptual surveys
    - Wider variety of tasks: Rep. Trans. problems, essays, etc.

Implications?

- What knowledge do they bring in?
  - We've made lots of observations and have identified many "student difficulties" in topics ranging from instantaneous velocity to quantum wavefunctions.
- How do we create effective active learning environments?
  - We've created a wide variety of research-based instructional environments: PbI, Tutorials, WP, JiTT, TST, ILDs, PI, …
- How do we share evaluation and assessment?
  - We've begun to create problem collections and carefully validated surveys and these problems have begun to work their way into textbooks.

Do we need a theory now?
Do we have one?

- "Science" is not a collection of results; it is the development of a coherent system of understanding of a phenomenon.
- That system is informed by observation and guides it.
- Do we have one? Is "constructivism" a theory? What about other "theories of education"?

There are lots of "theories"

- Greg Kearsley, has created a webpage with more than 50 "theories for education" (http://tip.psychology.org/).
- A bewildering array.
- Don't look like theory to a physicist
  - Either are guidelines
  - Or seem useless.

- Conditions of Learning (R. Gagne)
- Connectionism (E. Thorndike)
- Constructivist Theory (J. Bruner)
- Contiguity Theory (E. Guthrie)
- Conversation Theory (G. Pask)
- Criterion Referenced Instruction (R. Mager)
- Double Loop Learning (C. Argyris)
- Drive Reduction Theory (C. Hull)
- Dual Coding Theory (A. Paivio)
- Elaboration Theory (C. Reigeluth)
- Experiential Learning (C. Rogers)
- Functional Context Theory (T. Sticht)
- Genetic Epistemology (J. Piaget)
- Gestalt Theory (M. Wertheimer)
- GOMS (Card, Moran & Newell)
- GPS (A. Newell & H. Simon)
- Information Pickup Theory (J.J. Gibson)
- Information Processing Theory (G.A. Miller)
- Lateral Thinking (E. DeBono)

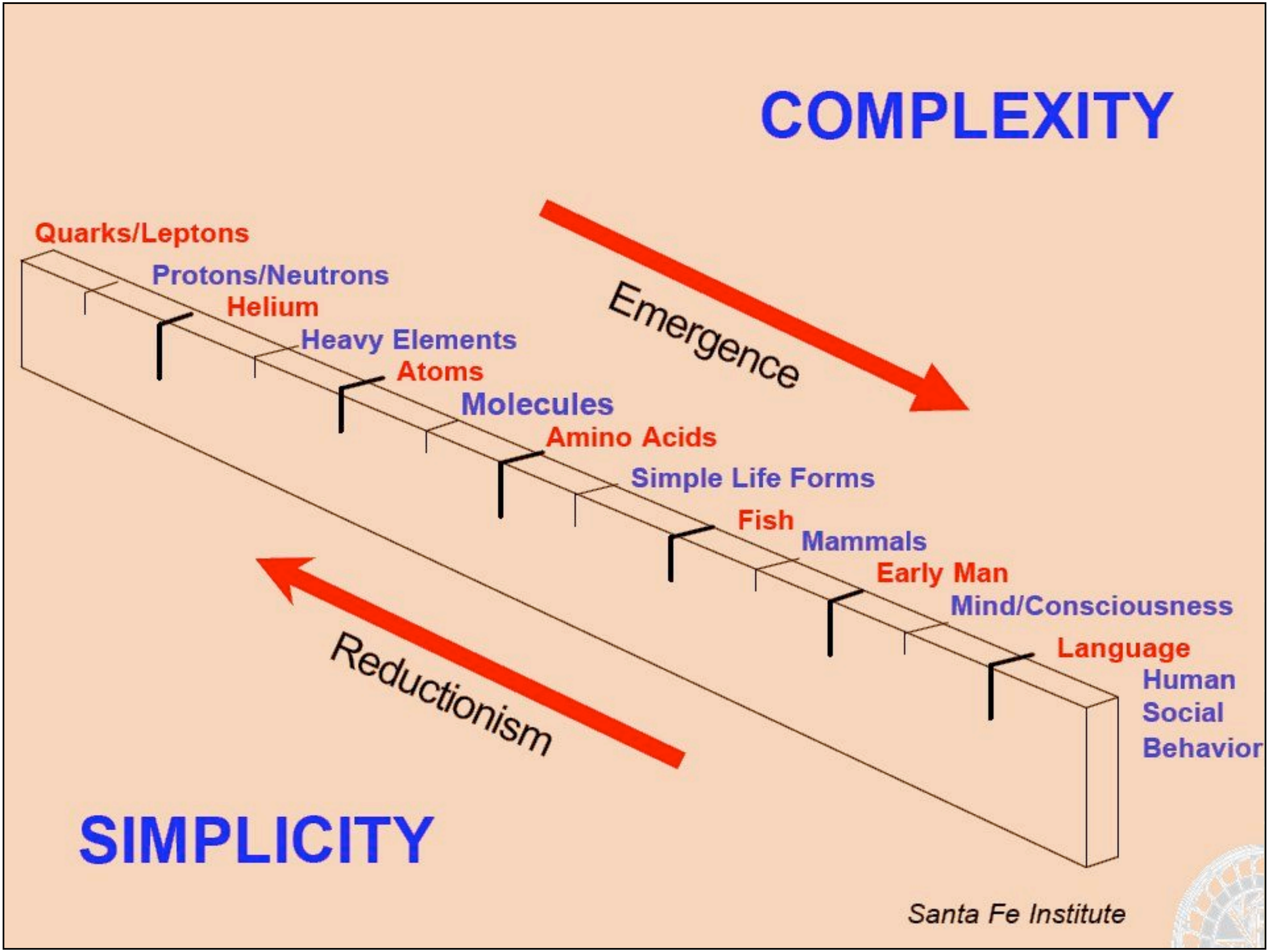
What should a theory provide us?

- Explanatory power
  - We often see students saying things or behaving in ways that seem strange to us. A good theory should help us understand why they do this.
- Productive modeling
  - A theory should give us a way of modeling classes of phenomena — not necessarily everything at once. (Think about the SE for atoms and molecules, e.g.)
- Guidance for instructional design
  - Though the theory may not be predictive, it should be schematically so — suggesting options for instruction and things we might want to look at to test.
- Cumulability
  - We ought to be able to add to the structure incrementally — learning new things that are consistent and make the entire structure stronger and more powerful.

What do we need a theory of?

- There are a hierarchy of relevant structures
- Each has its own set of interacting units.
- Each has its own scales of time and space.
- Different levels interact.

- World cultural system
- National system
- School / University system
- Departmental culture
- Classroom culture
- Small-group interaction
- Individual cognition
- Brain modules
- …???…
- Neural nets
- Neurons



COMPLEXITY
Quarks/Leptons
Protons/Neutrons
Helium
Heavy Elements
Atoms
Molecules
Amino Acids
Simple Life Forms
Fish
Mammals
Early Man
Mind/Consciousness
Language
Human
Social
Behavior
Emergence
Reductionism
SIMPLICITY
Santa Fe Institute

We need to work at many levels

- How constructivism works
  - How do individuals build new knowledge from what they know?
- How the classroom works
  - How does the interaction with peers and instructors affect learning?
- How the system works
  - How do broad cultural and systemic pressures affect how students and teachers behave?

The Cognitive Level: A good place to start (for some of us)

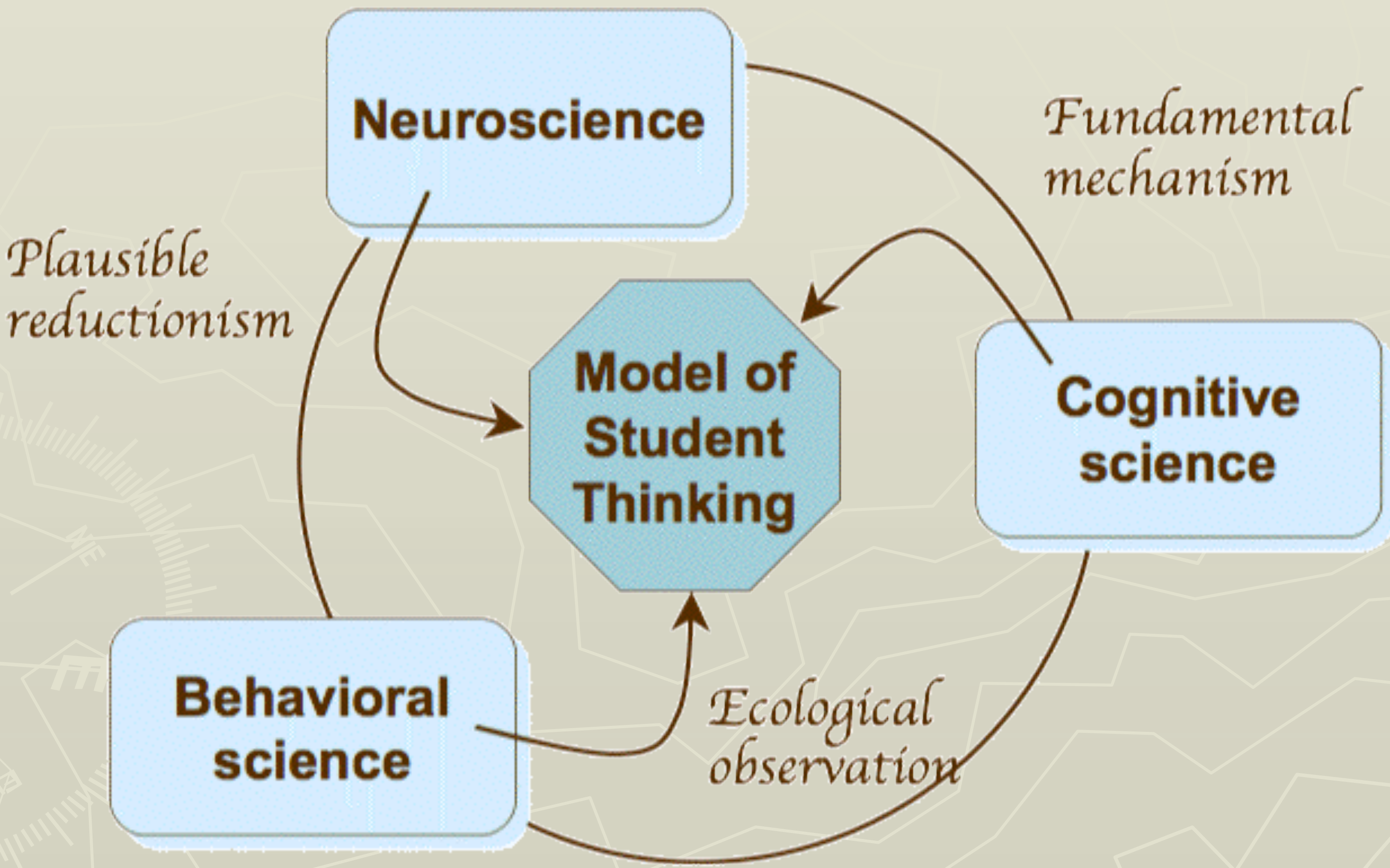
- As teachers, our goal is to improve the knowledge and skills of individuals.
- Socio-cultural effects act through impact on individuals.
- Psychology (with input from neuroscience) has made great strides in the past 30 years.
- Physicists need a sense of mechanism for something to look like a science. It returns PER to our roots.

Trowbridge & McDermott, AJP 1980

We began our investigation by replicating and extending some of the Piagetian tasks on motion. We then developed new tasks that we administered during individual demonstration interviews. Knowledge gained in this way was supplemented by information obtained from written examination questions.

We refer to our primary data source as the "individual demonstration interview." It resembles the "clinical interview" pioneered by Jean Piaget, the Swiss psychologist. In the individual demonstration interview the student is confronted with a simple physical situation and asked to respond to a specified sequence of questions.

Triangulation



Foothold ideas: Neuroscience

- Neurons connect to each other.
- Neurons send information to each other via pulse trains when they are activated.
- Neurons may be in various stages of activation.
- Neural connections can enhance or inhibit other neural connections.
- Learning appears to be associated with the growth of connections (synapses) between neurons.

Foothold ideas: Cognitive science

- Memory has two functionally distinct components:
  - *working memory*
  - *long-term memory*.
- Working memory
  - can only handle a small number of data blocks.
  - labile, often lasting only a few seconds without specific activities to prolong it.
- Long-term memory
  - contains a vast quantity of facts, data, and rules for how to use and process them (declarative and procedural memory).
  - highly stable and can store data for decades.
- Working → long-term memory requires repetition.
- Long-term → to working memory may take time.

Elements of a Theoretical Framework

1. Knowledge elements
   - Activation
   - Compilation
2. Patterns of Association
   - Linking
3. Control
   - Selective attention
   - E-games

What does a theory do for you?

- Explore the implications
  of seeing our instruction and research
  through the lens of a theoretical frame.
- First, see what it means in our own heads
- Next, see an example of how it affects
  how we think about
  - what our students are doing
  - what are our goals in our classes

Find the change!

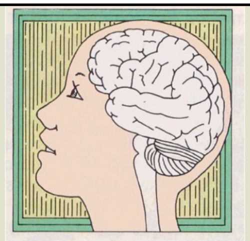
1. Knowledge Elements Activation / Compilation

- We know lots of things
  - Facts
  - Procedures
  - Ways to use these
- A lot of knowledge is built by combining different elements into a "thing."
- Once we "see" something,
  it's hard to remember
  what it was like not to see it.

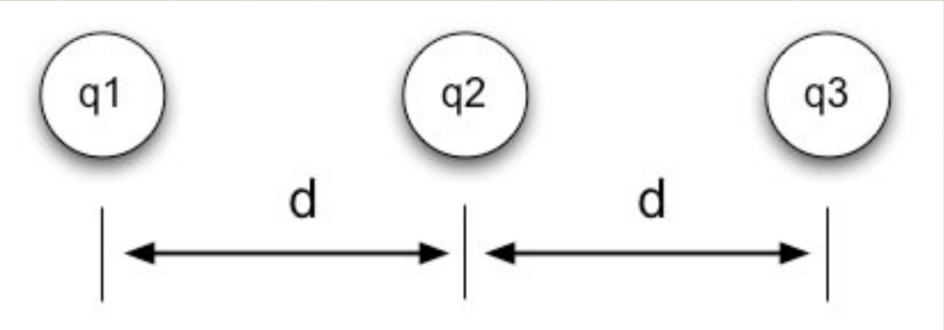
Binding / Compilation and the expert-novice gap

- As we learn, we bring together many different pieces of knowledge, binding them into a single coherent unit.
- Sometimes this process is very fast, sometimes it takes seconds, sometimes it takes years.

How much time should students spend on an “easy” problem?

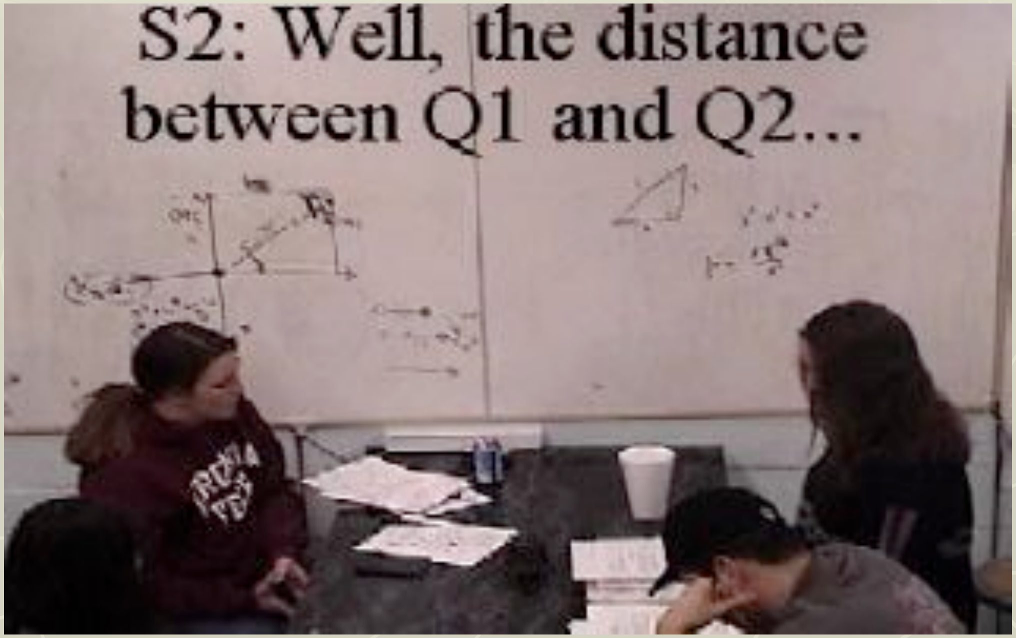


- Problem:
  - Three charged particles lie on a straight line and are separated by distances *d*. q_1 and q_2 are held fixed. q_3 is free to move but is in equilibrium (no net electrostatic force acts on it). If q_2 = Q, what is q_1?



Working on a solution

- A group of four students spends nearly an hour working on this problem in the Course Center.
- All had taken the first semester in our meta-learning class.



An hour?

- When we first viewed the video we were concerned that they took so long to solve what (on the surface) appeared to be a relatively trivial problem.
- After a careful analysis, we became convinced that the work they did was worthwhile and a valuable part of their learning experience.

How they get there

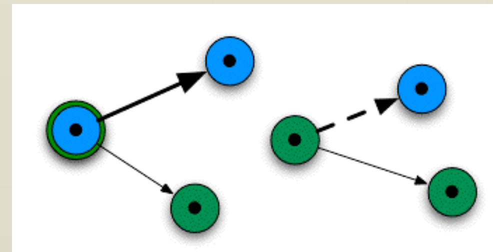
Description of events
They make some progress thinking qualitatively, but are at first unsure about forces, directions, and fields.
The Teaching Assistant suggests they draw a diagram so they can agree on what is happening.
They now agree on which charges are exerting which forces in which directions and settle on a factor of 2.
One student, recalling a result of the non-linearity in a previous problem tries to get them to think using the equation (Coulomb's law).
Eventually, she manages to turn their attention to using the equation and she works out the correct solution to the problem using algebra — constructing a clean proof. The group is convinced.

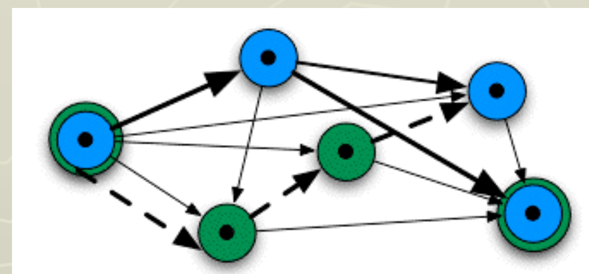
Why so long?

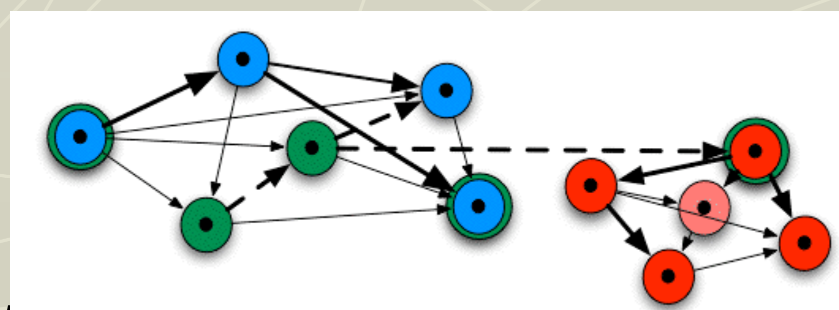
- The instructor's "simple" solution involves lots of hidden binding.
  - Forces as interactions
  - Newton's zero-th law (isolation of objects)
  - Superposition of field forces
  - Working with abstract symbols rather than numbers (you don't even know the signs of any of the charges)

2. Association / Links

- Activation of a bit of knowledge in long-term memory may lead to activations of additional knowledge.
- What matters for building a knowledge base that activates knowledge in appropriate situations are the links.







If the links are what matters, what should they link to?

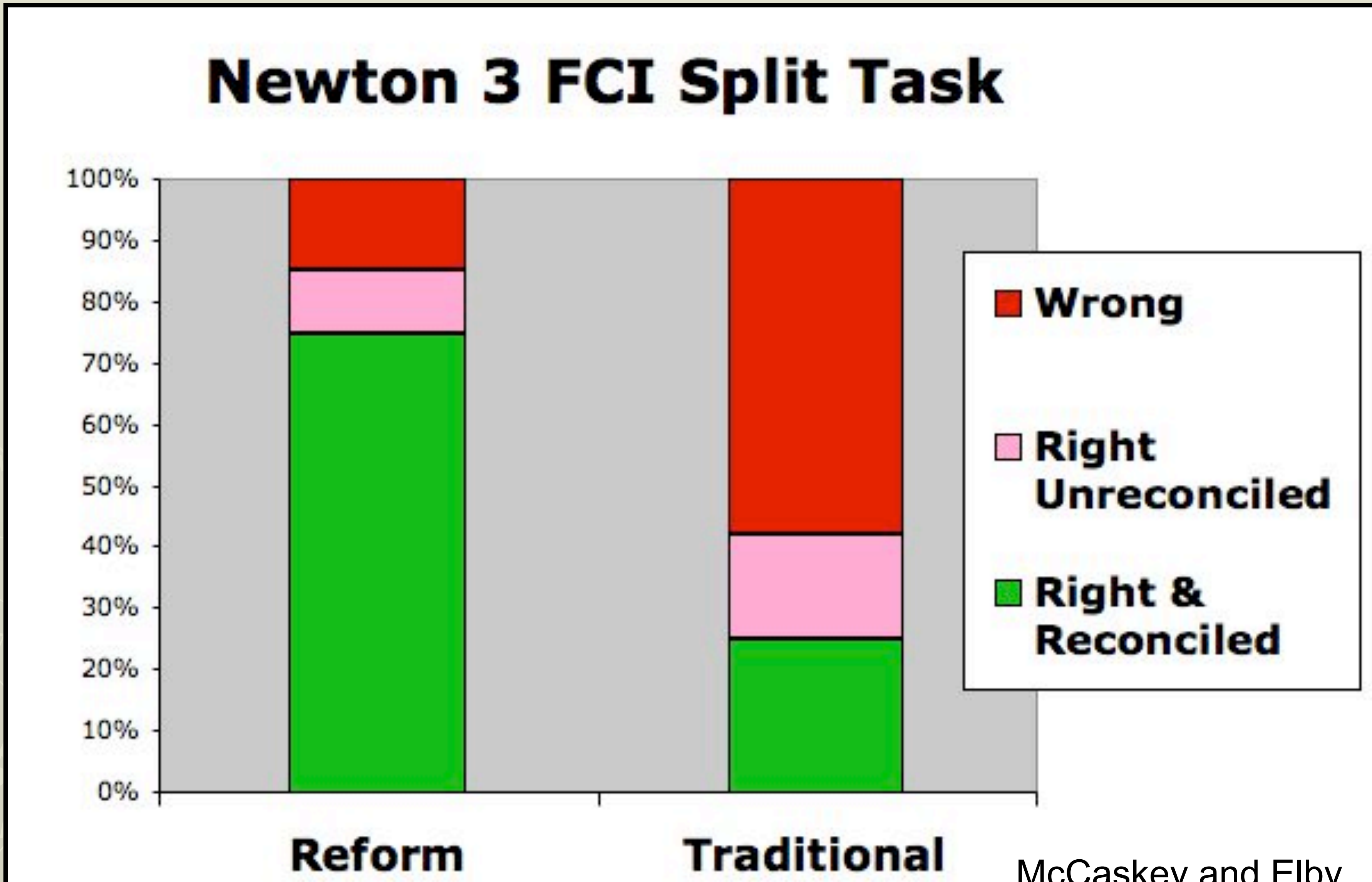
- Build intuition by tying physics knowledge to personal experience
- We create paired questions ("Elby pairs"),
  - one which most students are likely to answer correctly using their everyday intuition,
  - one in which their everyday intuition is likely to lead them astray.
- We then help them to see there is a contradiction in their thinking and help them resolve it.

Does it work? “Splitting”

- FCI given to my algebra-based Physics II class at start of second semester.
- Students (N~160) included 1/3 from traditional instruction, 2/3 from our reformed instruction with Elby pairs.
- Instructions:

> “Please **circle** the answer
> **that makes the most intuitive sense to you.**
>
> Please draw a **square** around the answer
> **you think physicists would give.**”

Results

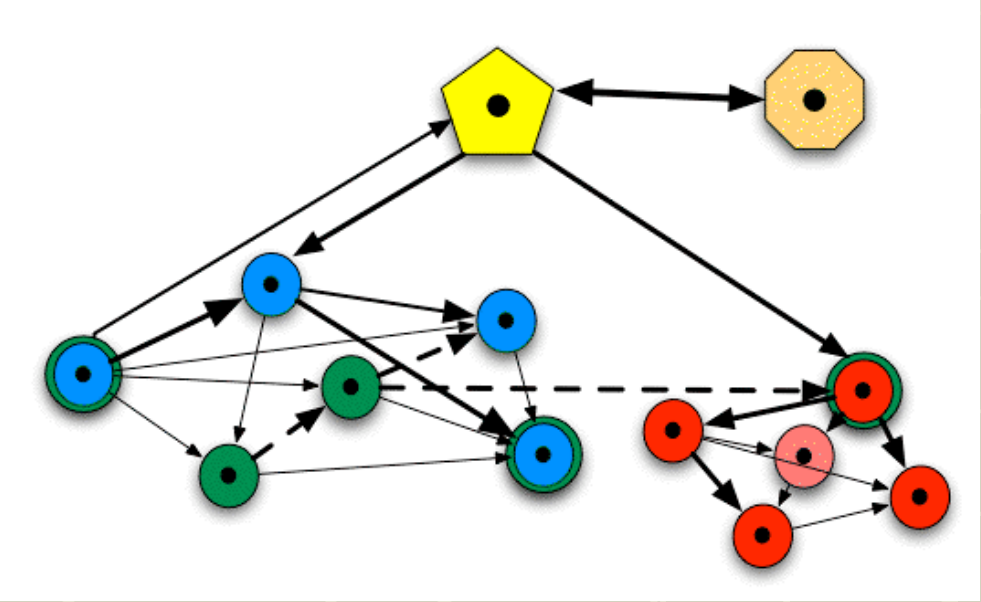


McCaskey and Elby

Count the passes!

3. Control / Selective Attention

- Synapses can be excitatory or inhibitory.
- The brain is filled with both feedforward links (for association and activation) and feedback links (for control).



Selective Attention

- One way control plays out is through selective attention.
- There is too much in the world for our brains to process at once.
- We learn to select and ignore, *framing* our situation — deciding what matters and what doesn't — quickly and (often) unconsciously.

Control: E-games and E-frames

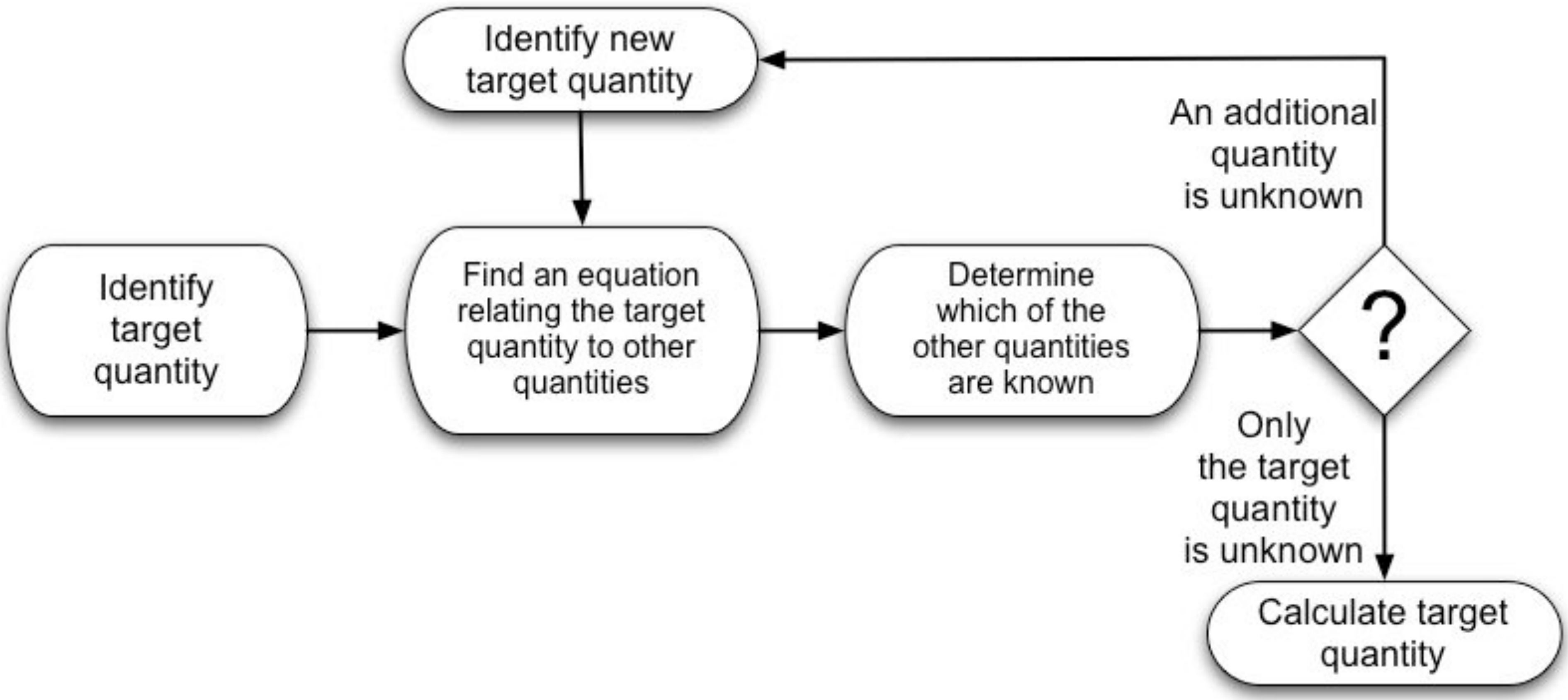
- Epistemic games — a coherent local (in time) pattern of association for building knowledge or solving a problem.
- Epistemological frame — a selective attention decision (often tacit) as to what are the appropriate e-games to play in a given situation.

Students sometimes play the wrong game.

- Problem:
  - *Estimate the difference in pressure between the floor and the ceiling in your dorm room.*
  - (Note: the density of air is ~ 1 kg/m^3.)
- Circumstance
  - Three students working on this problem in the course center.

An E-game

- Recursive plug-and-chug



Framing the activity incorrectly

- In choosing which game to play what matter is not just which moves are allowed but which are forbidden.
- It's not that she can't estimate how big her dorm room is.
  - She has decided that doing that is not the way to solve the problem.
  - She expects to solve the problem by relying on information found from some authority

Implications for research

- Having a theoretical frame
  1. helps us make explicit our previously hidden assumptions in research.
  2. helps us learn to look for “side effects” of otherwise effective instruction.
  3. can help us find new, potentially more effective, instructional methods.
  4. assigns experimental researchers a new task: testing theories.

1. Hidden assumptions: fragmentation vs. misconceptions

- There are different models of student knowledge.
  - Some researchers (McCloskey, Vosniadou) see “student alternative theories.”
  - Some researchers (diSessa, McDermott) see student thinking as fragmented.
- These are not orthogonal: In our theoretical frame, a “misconception” (robustly activated incorrect element) can be a fragment (p-prim).
- If you don’t think about it you may be surprised at what you are assuming.
- If novices are (mostly) fragmented, and experts have (coherent) theories, how does the former turn into the latter?

Physics instructors generally share a common interpretation of the kinematical concepts based on operational definitions and precise verbal and mathematical articulation. On the other hand, students in an introductory physics course are likely to have a wide variety of somewhat vague and undifferentiated ideas about motion based on intuition, experience, and their perception of previous instruction.

Trowbridge & McDermott, AJP, 1980

2. Side effects: Does cognitive conflict hurt epistemology?

- Cognitive conflict has proven effective in improving student responses to conceptual questions.
- Does cognitive conflict undermine students faith in their intuition and weaken the linking of school knowledge to everyday knowledge?
- Our videotapes of students in tutorials suggests that many are convinced that their physics intuition is useless and counterproductive.

3. New instructional methods?

- Elby pairs arise out of a knowledge that students in intro physics tend to respond to qualitative questions with p-prims.
  - Allows construction of questions students are likely to answer correctly.
- Many “misconceptions” seem to be mis-mappings of general principles into robust facets. (“More force → More velocity”)
  - Is it more effective to help students “remap” (“More force → More acceleration”) than to use cognitive conflict?

4. Testing Theories

- In experimental physics, a major task is challenging, testing, and comparing theories.
- PER will never be recognized as engaged in scientific exploration until we can be seen as
  - developing theories to explain our observations
  - doing experiments that test our theories
  - creating coherent and consistent explanations of why we choose the instructional methods we do and why they work.