Cognitive Science:

The Science of the (Nearly) Obvious

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PERC
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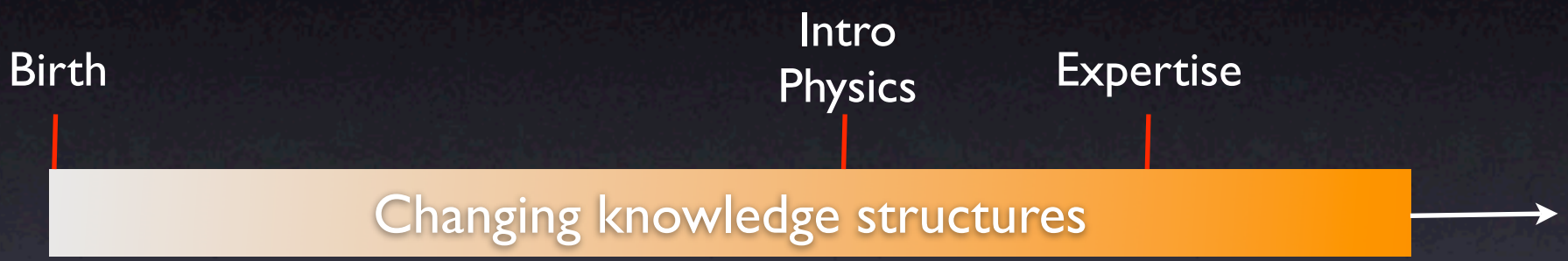
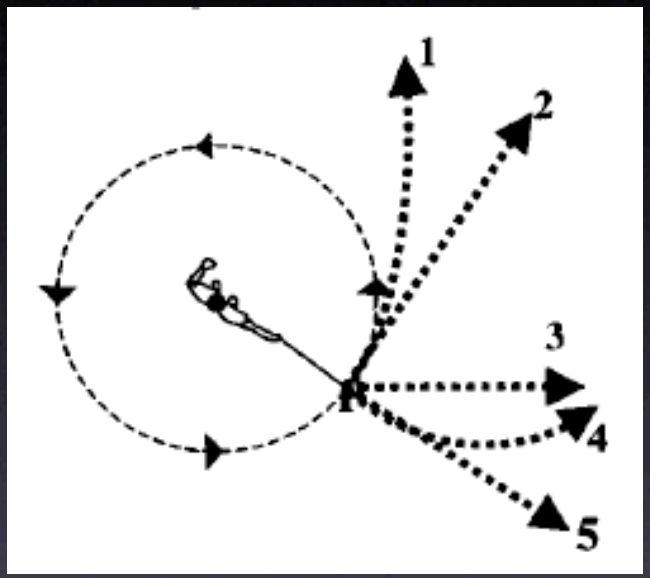
A "grand" theory of physics cognition and learning:

- The physics knowledge students possess and how that changes over time, from before instruction, all the way through expertise.



- Both the form (structure) of the knowledge, and its content.
- Description of the knowledge at an "elemental" level that is appropriately reductive.

*Which is the right "elemental" account of path **1** ?*



(A) When a ball moving in a circle at the end of a string is released, it moves in a curved path but then gradually straightens.

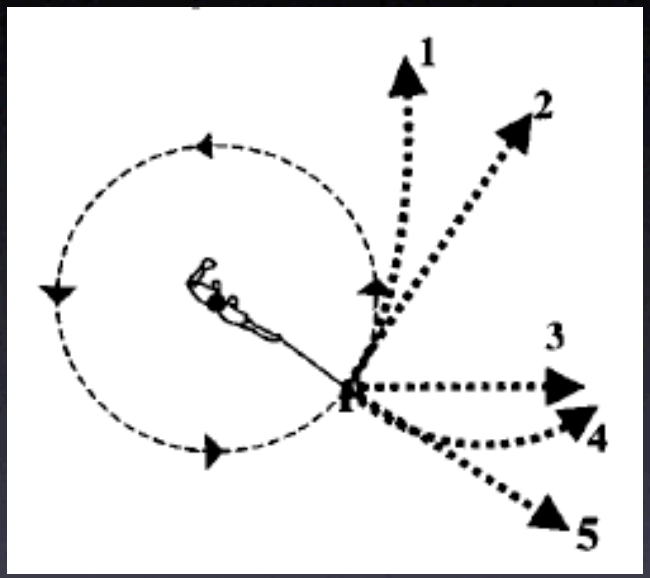
(B) Several elements of knowledge

- Straight motion is the natural state.
- An object moving in a circle will have a tendency to keep moving in a circle.
- Unnatural motions die away.

(C) Several elements of knowledge

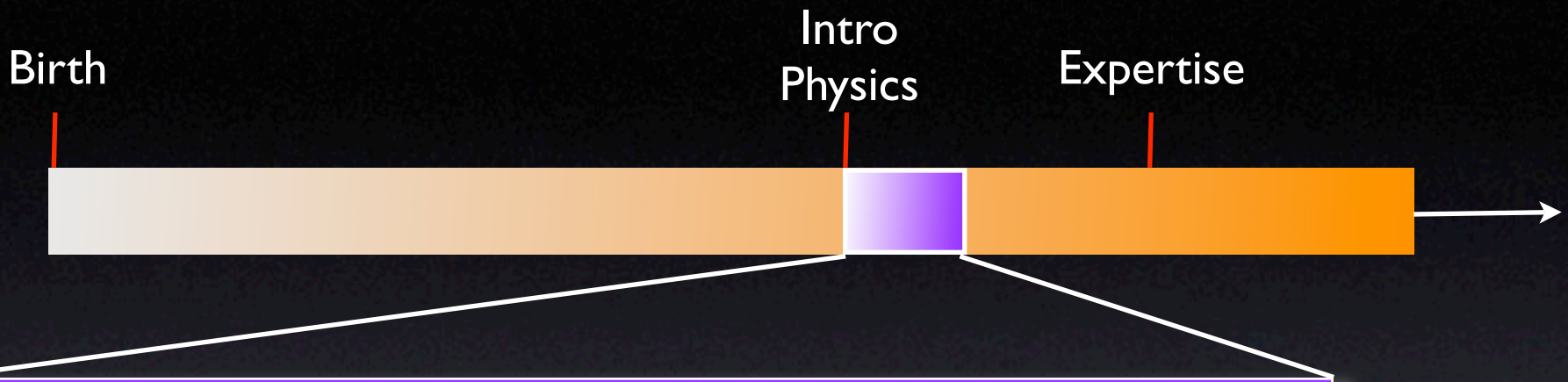
- Straight motion is the natural state.
- Things have a tendency to keep doing what they're doing.
- Unnatural motions die away.

*Which is the right "elemental" account of path **1** ?*



- What we want is the elemental account – the reduction – that explains the most of the student's reasoning across tasks and over time.
- Having the grand theory, constrains which is the best elemental account.

As a field, how close are we to the grand theory?



Student performance on short, qualitative questions

- Conceptions prior to instruction
- How these conceptions change during introductory instruction

Textbook problem solving

- Students
- Experts

Student epistemology research

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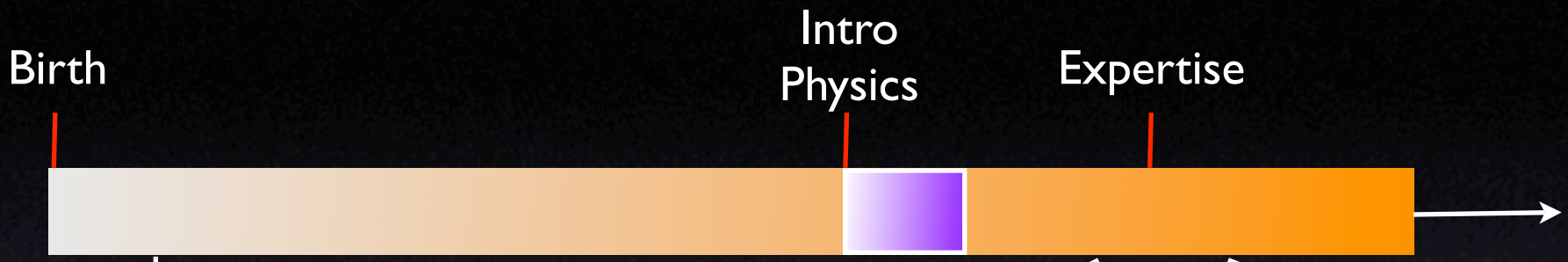


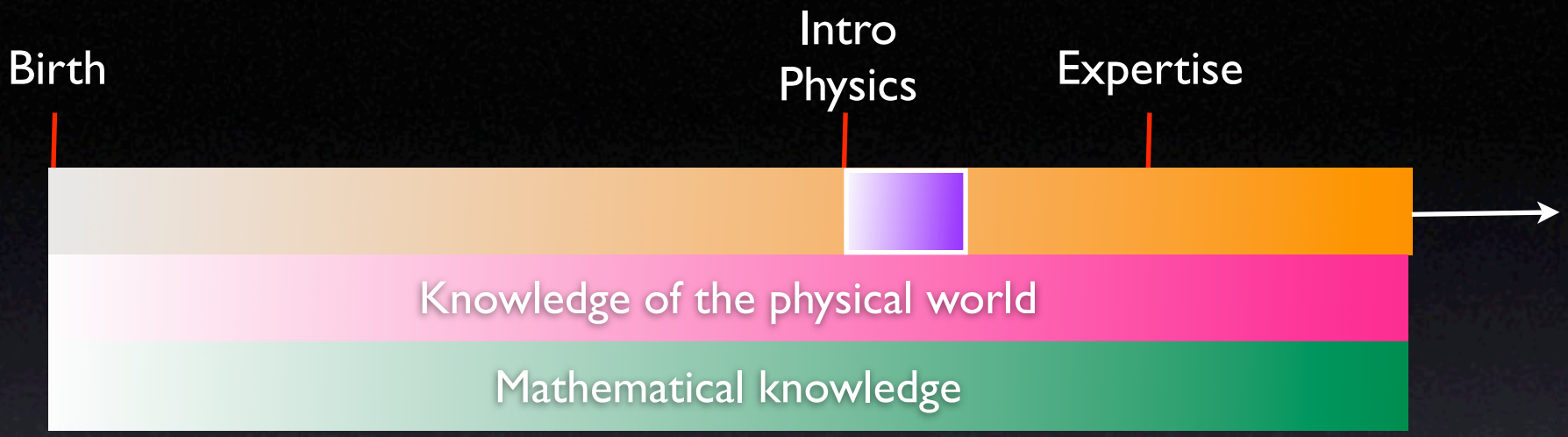
- We don't do much down here. But other fields do some.

- Experts are often studied solving problems trivial for them.
  - Of course there are notable exceptions (e.g., Clement 1994)
- We should study physics experts doing the full range of what they do as physicists.

<u>The biggest point of this talk</u>:

- Even if we only cared about intro physics learning, having in mind the grand theory would help.

Doing this right will be really, really hard



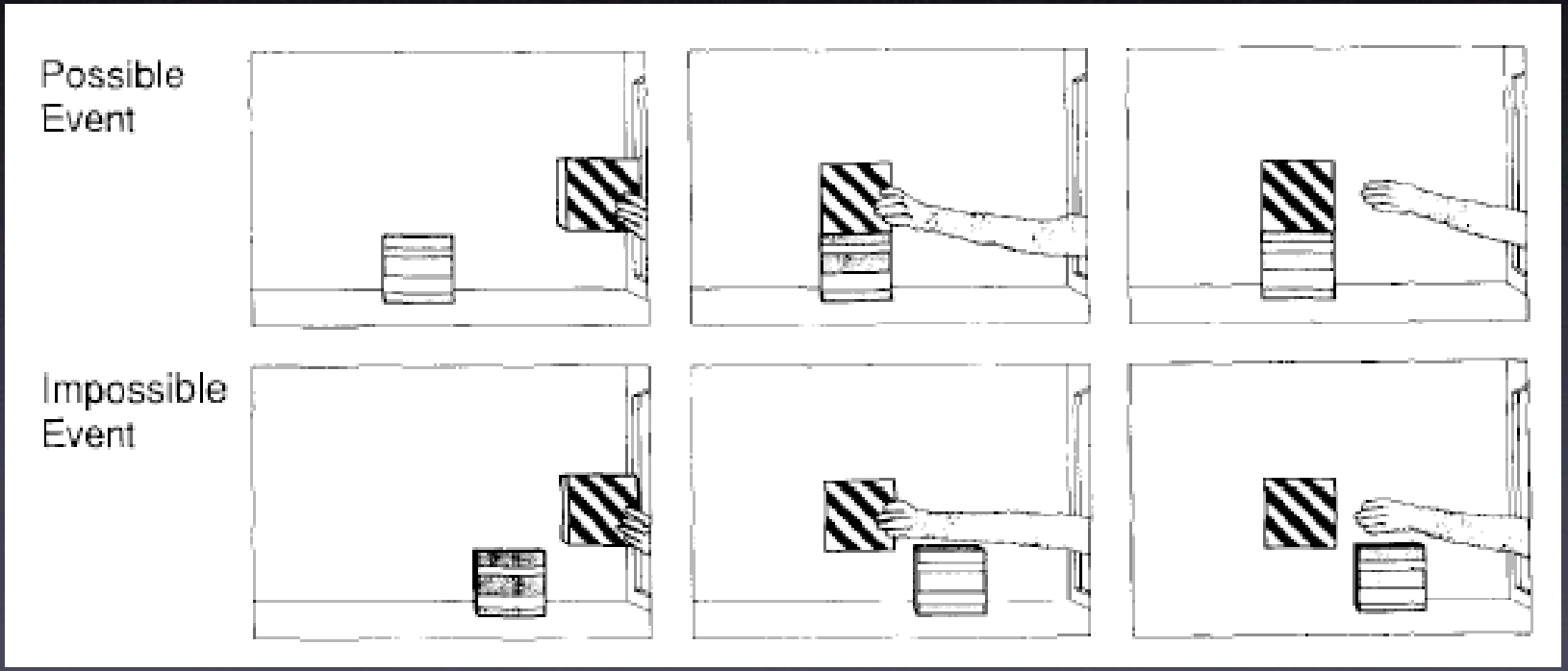
What the heck can we reasonably do?

1. Look to other fields, especially for the early life cycle
   - Psychology
   - Mathematics Education research
2. Study experts a bit more
3. Tweak our efforts within the purple region so that they fit more neatly in the grand program. Get the grain size just right.

An example from psychology

Needham & Baillargeon, 1993

- How 4.5 month old babies understand the notion of support



Tweak our efforts so that they fit more neatly into the grand program

The science of the (nearly) obvious

A change in stance: Refocus our attention on what is nearly obvious to us.

An example: The alphabet

1. What letter is the 12th letter in the alphabet?
2. What's the 10th letter after C?
3. Say the alphabet backwards starting at Q.
4. Is G before or after J?
5. Is M before or after W?

An example: The alphabet

- In retrospect, this structure is fairly obvious. People can discuss it.
- This is tacit knowledge.
  - ➡ The clumps are not usually explicitly taught, there are no names for them.
- The grain size is down a level from something that is named. (“the alphabet”)
- The knowledge retains the stamp of its origins
  - ➡ The alphabet song, perhaps

An example from physics: Symbolic forms

$$F = -kx$$

$$F = mg \qquad kx = mg$$

$$x = \frac{mg}{k}$$

$$v = v_o + at$$

$$t = \frac{v}{a}$$

$$F = ma \qquad x = x_o + v_o t + \frac{1}{2}at^2$$

$$a = \frac{F}{m}$$

$$x = \frac{1}{2}a\left(\frac{v}{a}\right)^2$$

$$x = \frac{1}{2}\frac{v^2}{a}$$

The data corpus

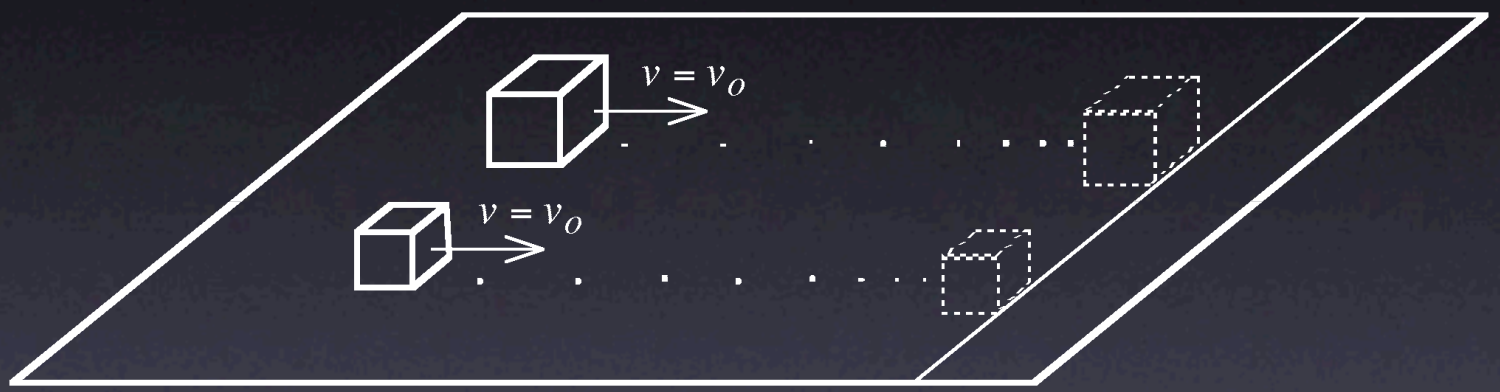
Sherin, B. (2001). How students understand physics equations. Cognition and Instruction, 19 (4), 479-541

Sherin, B. (2006). Common sense clarified: Intuitive knowledge and its role in physics expertise. *Journal of Research in Science Teaching*, 33 (6), 535-55.

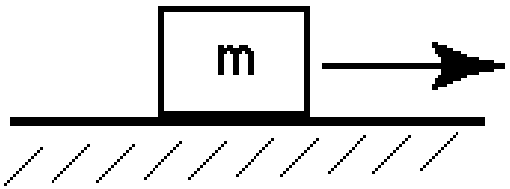
- Students in a third semester introductory physics course for engineers.
- Students worked at a whiteboard in pairs.
- A range of physics problems.
- All student work was videotaped and transcribed.
- 5 pairs of students.
- ~5, one-hour sessions for each pair

An example episode:

Mike and Karl work on the Shoved Block problem.



An example episode



μ = some function of mass

Karl	I guess what we're saying is that the larger the weight, the less the coefficient of friction would be.

Karl	Well yeah maybe you could consider the frictional force as having two components. So that one component would be dependent on the weight. And the other component would be independent of the weight.
Mike	So, do you mean the sliding friction would be dependent on the weight?
Karl	Well I'm talking about the sliding friction would have two components. One component would be fixed based on whatever it's made out of. The other component would be a function of the normal force. The larger the normal force, the smaller that component.

$$\mu = \mu_1 + C\frac{\mu_2}{m}$$

Symbolic forms

Symbolic form =

conceptual schema + symbol template

A few entities and some simple relations among those entities.	Species how to write the schema in a symbolic expression.

Stated crudely, a symbolic form is:

An "idea" plus a specification of how to express that idea in an equation.

$$\mu = \mu_1 + C\frac{\mu_2}{m}$$

parts of a whole

conceptual schema	*symbol template*
a whole is composed of two or more parts	□ + □ + □

"The coefficient of friction has two components…"

"The other component would be a function of the normal force. The larger the normal force, the smaller that component."

prop-	$\left[\frac{\ldots.}{x}\right]$

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coefficient	C □

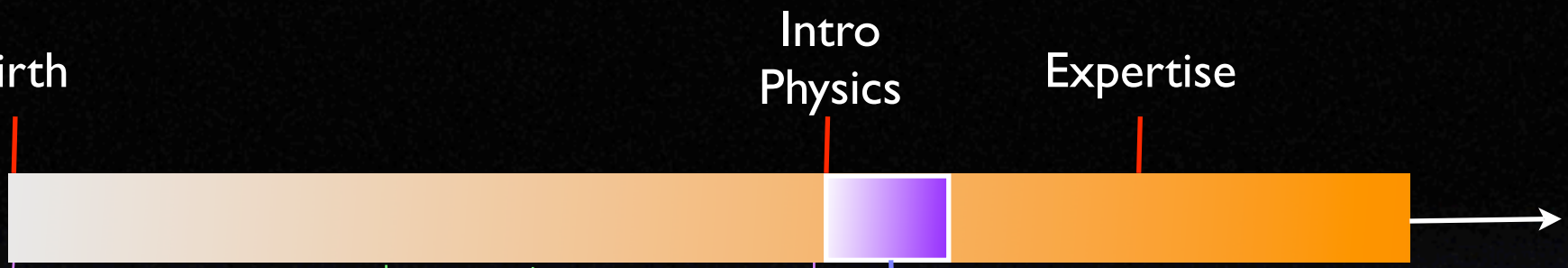
identity	$x = \ldots$

Competing Terms	Terms are Amounts
COMPETING TERMS	PARTS-OF-A-WHOLE
OPPOSITION	BASE ± CHANGE
BALANCING	WHOLE - PART
CANCELING	SAME AMOUNT
Dependence Cluster	**Coefficient Cluster**
DEPENDENCE	COEFFICIENT
NO DEPENDENCE	SCALING
SOLE DEPENDENCE	**Proportionality Cluster**
Multiplication Cluster	PROP+
INTENSIVE•EXTENSIVE	PROP-
EXTENSIVE•EXTENSIVE	RATIO
Other	CANCELING(B)
IDENTITY	
DYING AWAY	

21 forms in 6 clusters

competing terms	*balancing*	$a = b$
	competition	$a \pm b \pm c$

terms are amounts	*parts-of-a-whole*	$\square + \square + \square$
	base±change	$\square \pm \Delta$



sense-of-mechanism (diSessa, 1993)

"patterns in arithmetic word problems" (Greeno, 1987)

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A part of commonsense physics knowledge

diSessa, Andrea (1993). Toward an epistemology of physics. Cognition and Instruction, 10(2 & 3), 165-255.

The *sense-of-mechanism:*

- A sub-system of commonsense physics knowledge
- Consists of elements called "phenomenological primitives" or "p-prims."

An Example: Why does the vacuum cleaner's pitch increase?

A primitive notion:

Things have to work harder in the presence of increased resistance if they want to produce the same result.

<u>Ohm's p-prim:</u>

AGENT

works against RESISTANCE

to produce RESULT

The variety of p-prims

Force and Agency	**Constraint Phenomena**
OHM'S P-PRIM *SPONTANEOUS RESISTANCE* *FORCE AS MOVER* *DYING AWAY*	*BLOCKING* *SUPPORTING* *GUIDING*
Balance and Equilibrium	
DYNAMIC BALANCE *ABSTRACT BALANCE*	

Patterns in arithmetic word problems

John has five apples and Mary gives him three more, how many does he have?

Carpenter & Moser, 1983; Riley, Greeno, & Heller, 1983; Vergnaud, 1982

Change	$A + \Delta \rightarrow A'$
Combine	$A + B \rightarrow C$
Equalization	$A + ? \rightarrow B$
Compare	$A - B \rightarrow C$

support

sense-of-mechanism

balancing, dying away

"patterns in arithmetic word problems"

parts-of-a whole, base±change

Competing Terms	Terms are Amounts
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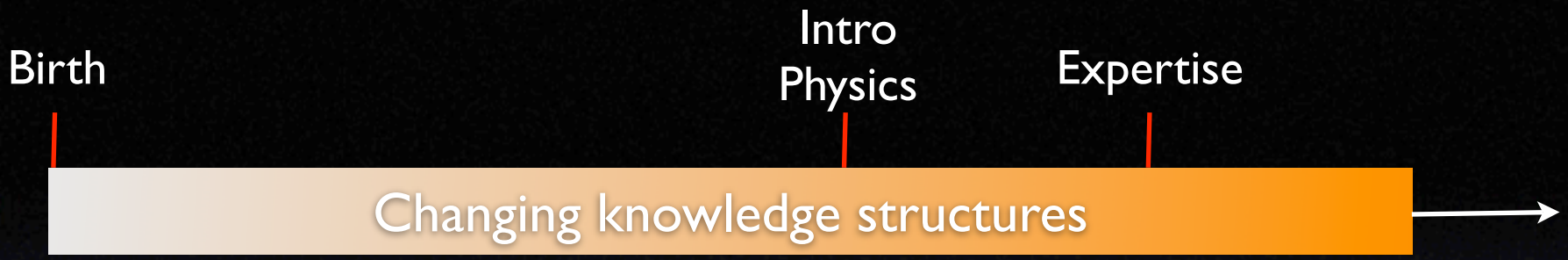
Conclusion



- Toward the grand theory
  - Knowledge structures throughout the life cycle
  - Form and content, at the "elemental" level.
- We should look more broadly
  - Over more of the lifespan
  - Across a broader range of tasks
- Having the grand theory in mind will help even in our analysis of what happens just in intro physics
- Look to other fields, especially for early story
- A change in stance: A focus on the (nearly) obvious