Naive Physics/Savvy Science

Causal learning in very young children ... and the rest of us

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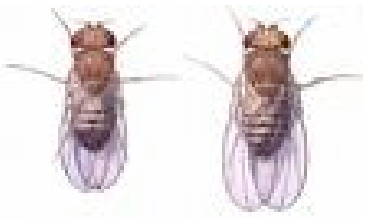
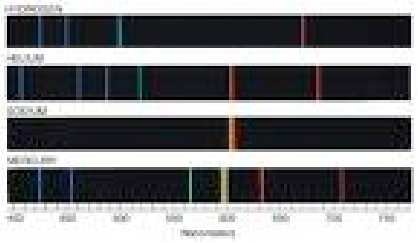
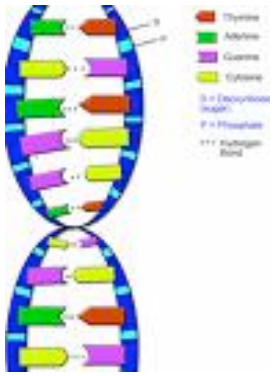
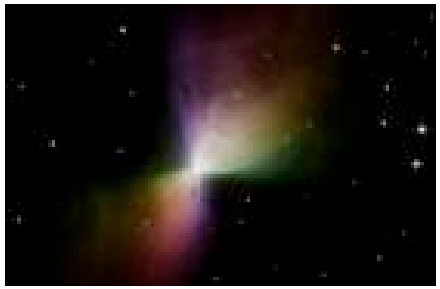
“There’s something fascinating about science -- one gets such wholesale returns of conjecture out of such a trifling investment in fact” -- Mark Twain









The quandary

- If children are so good at learning, why are they so hard to teach?

What can developmental cognitive science tell us about science learning?

- We can understand causal relationships without understanding mechanical relationships.
- We can make good inferences about statistical evidence without treating identical evidence identically.
- We can be good at causal discovery without being good at designing controlled experiments.
- The processes that make us good at learning are the same processes that make belief revision hard.

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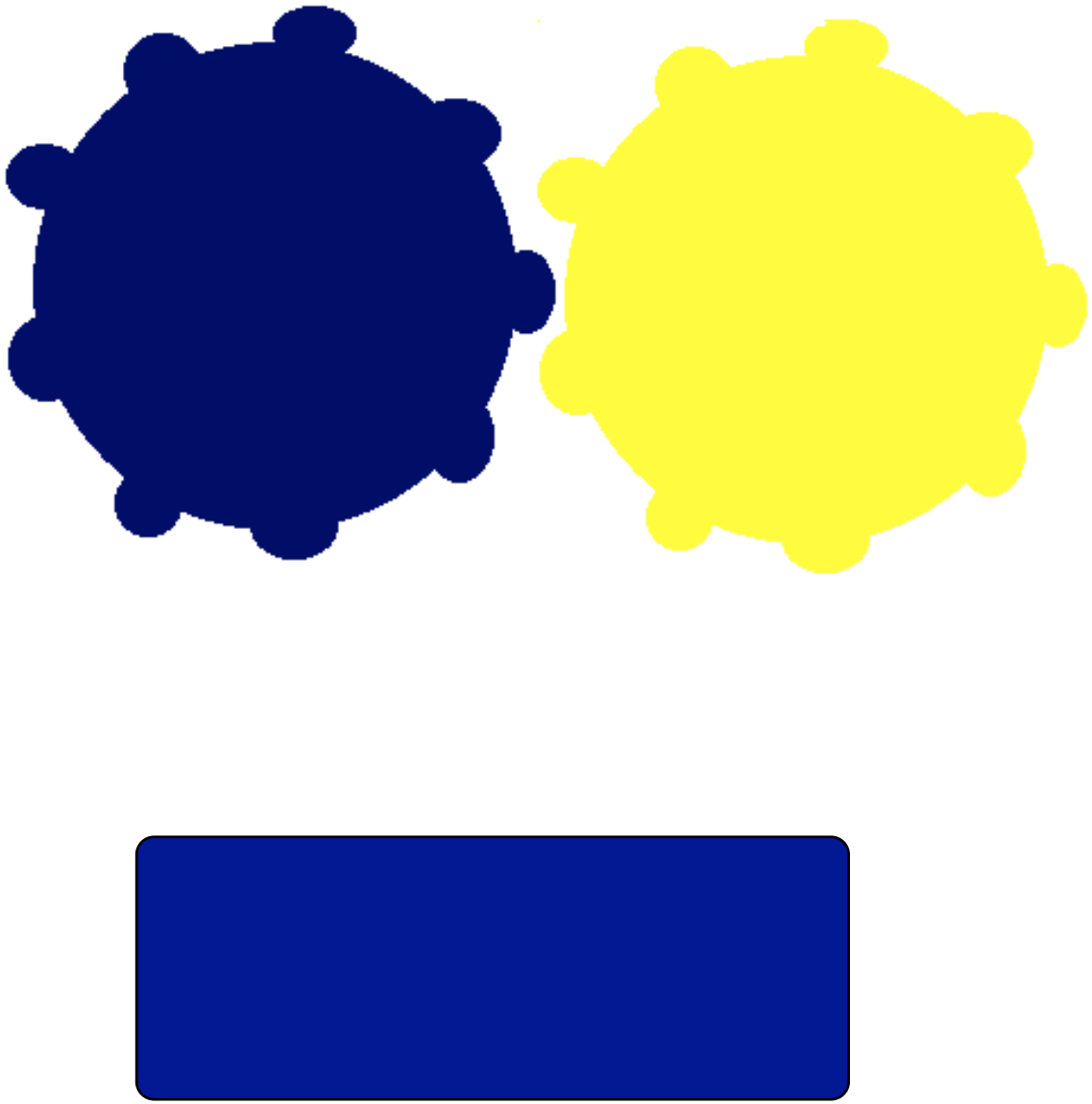
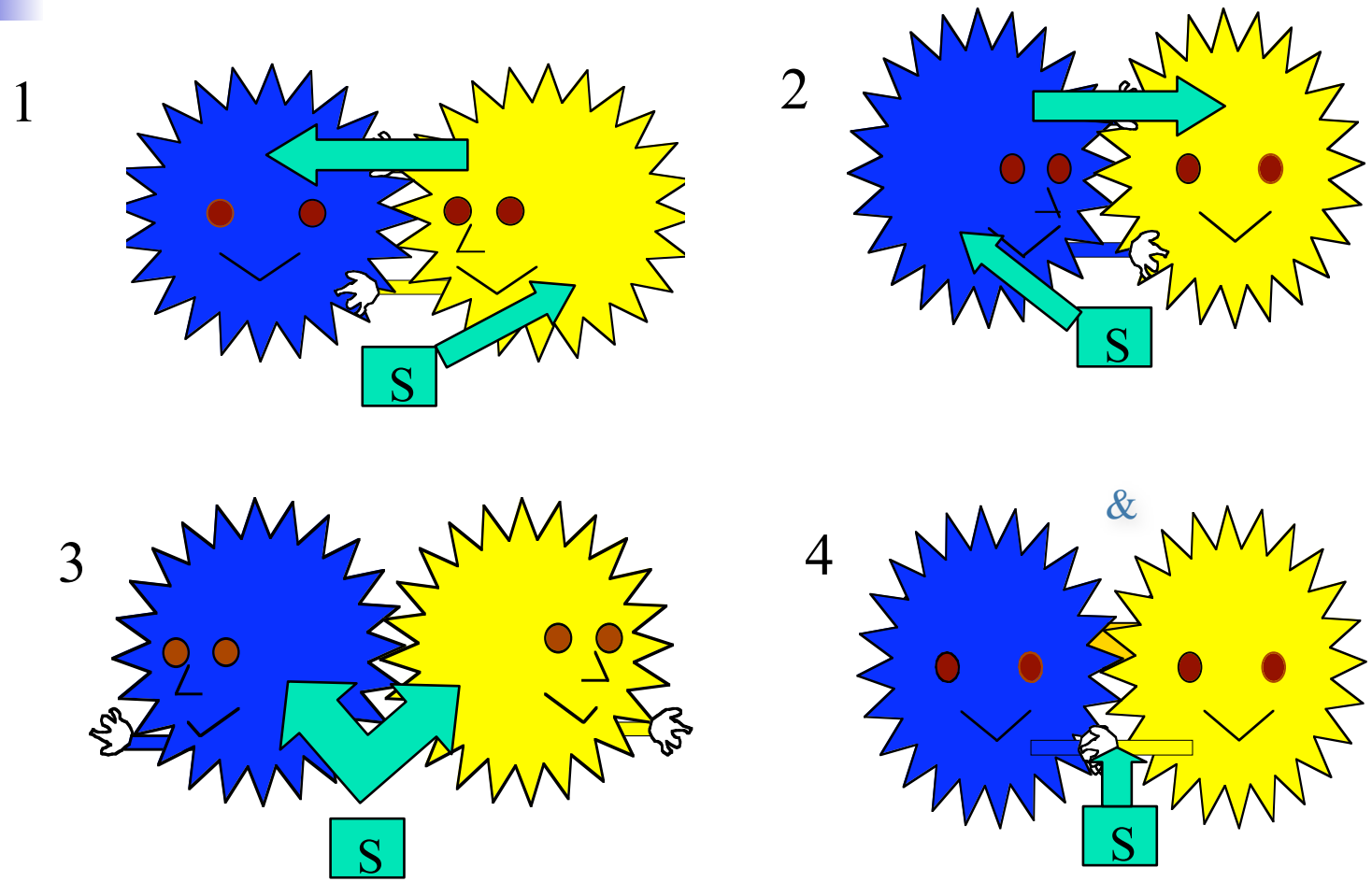


Schulz, Gopnik, and Glymour, 2007, Developmental Science

The Causal Possibilities



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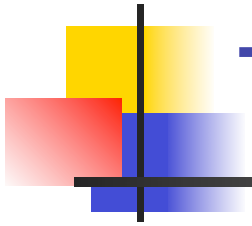
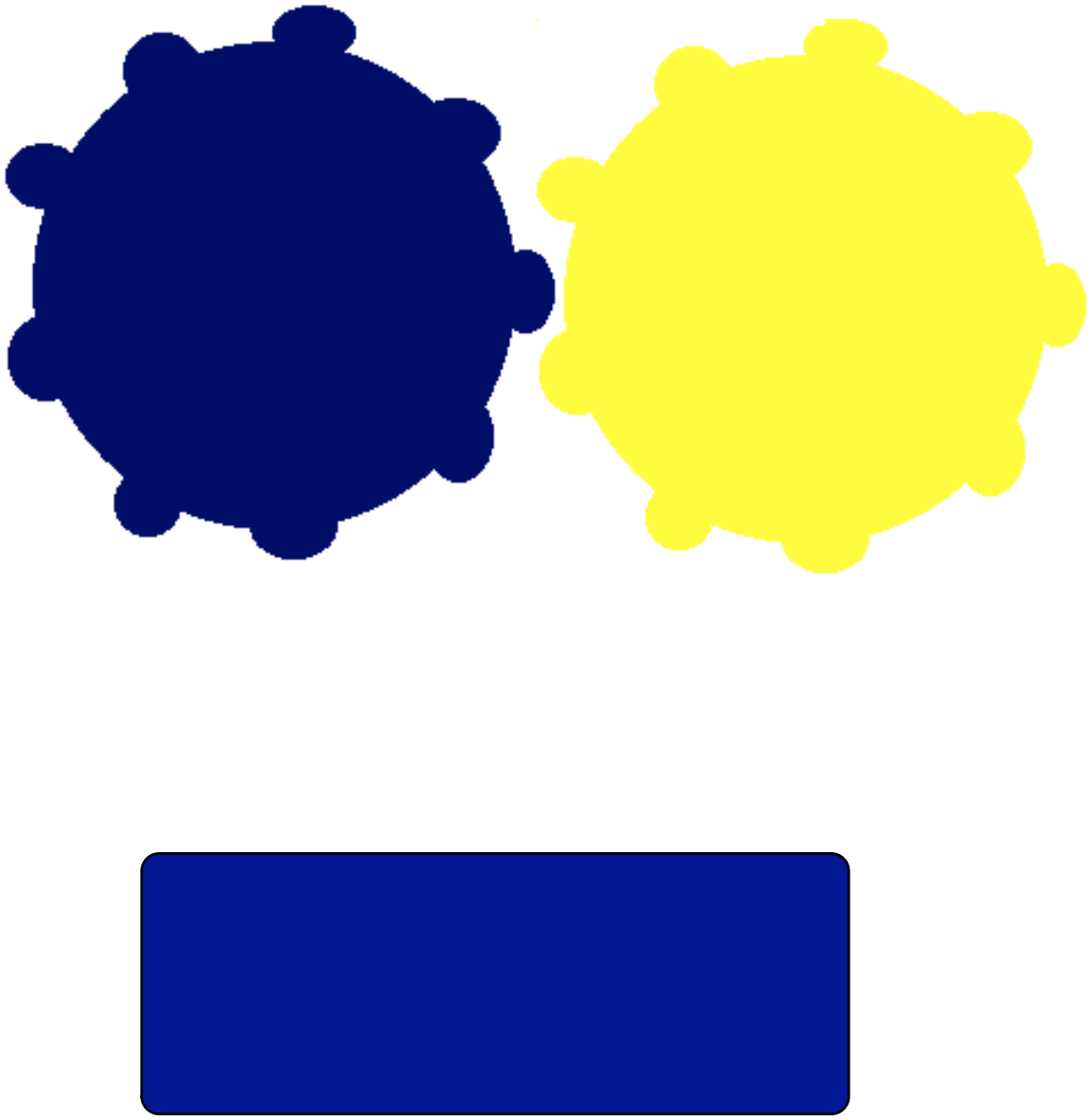


The usual suspects

- Mechanism knowledge
- Direct interventions
- Spatiotemporal information
- Covariation information

Schulz, Gopnik, and Glymour, 2007, Developmental Science



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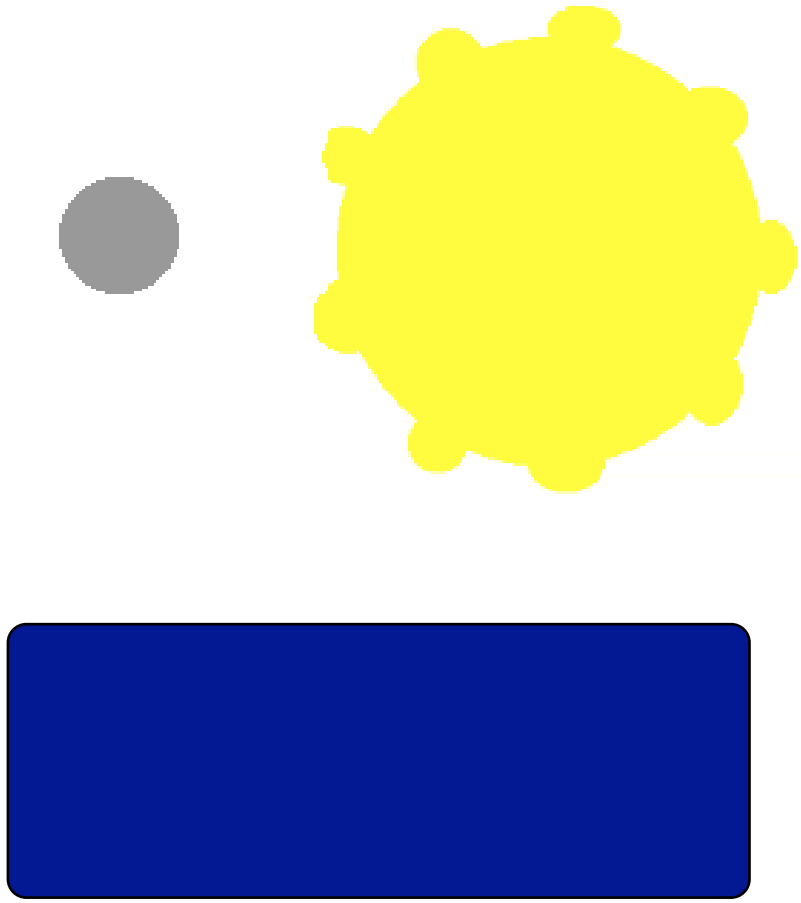

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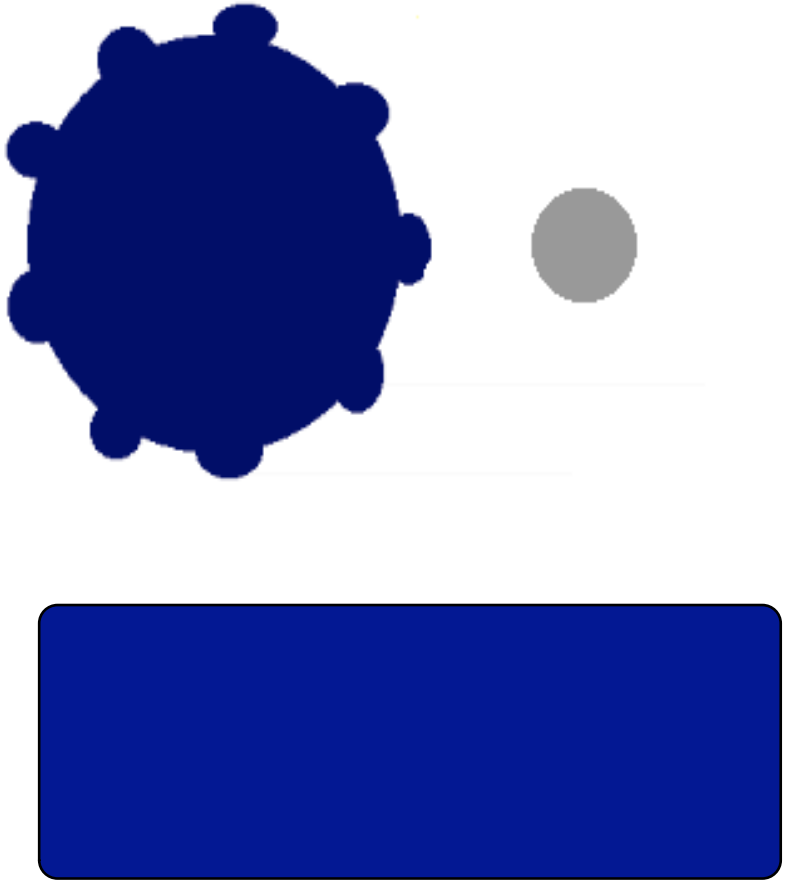

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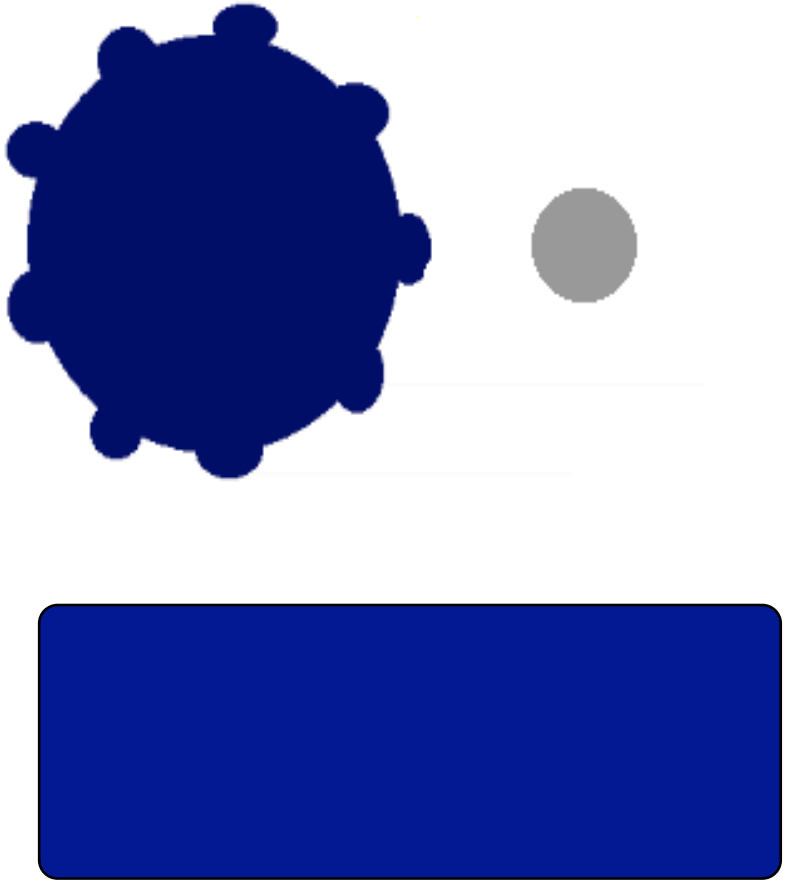

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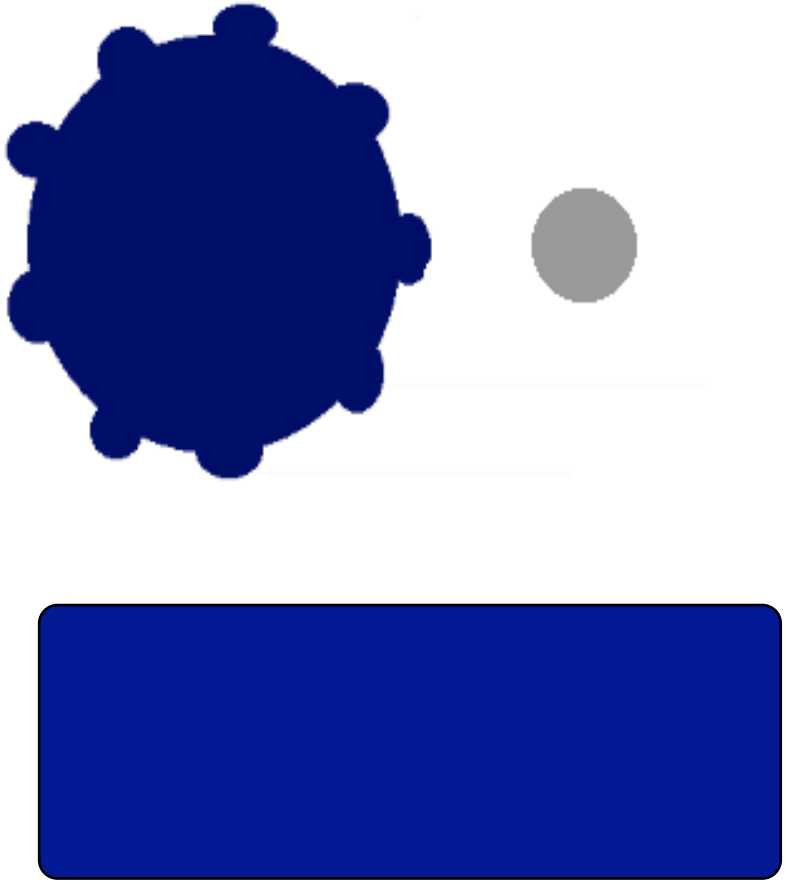

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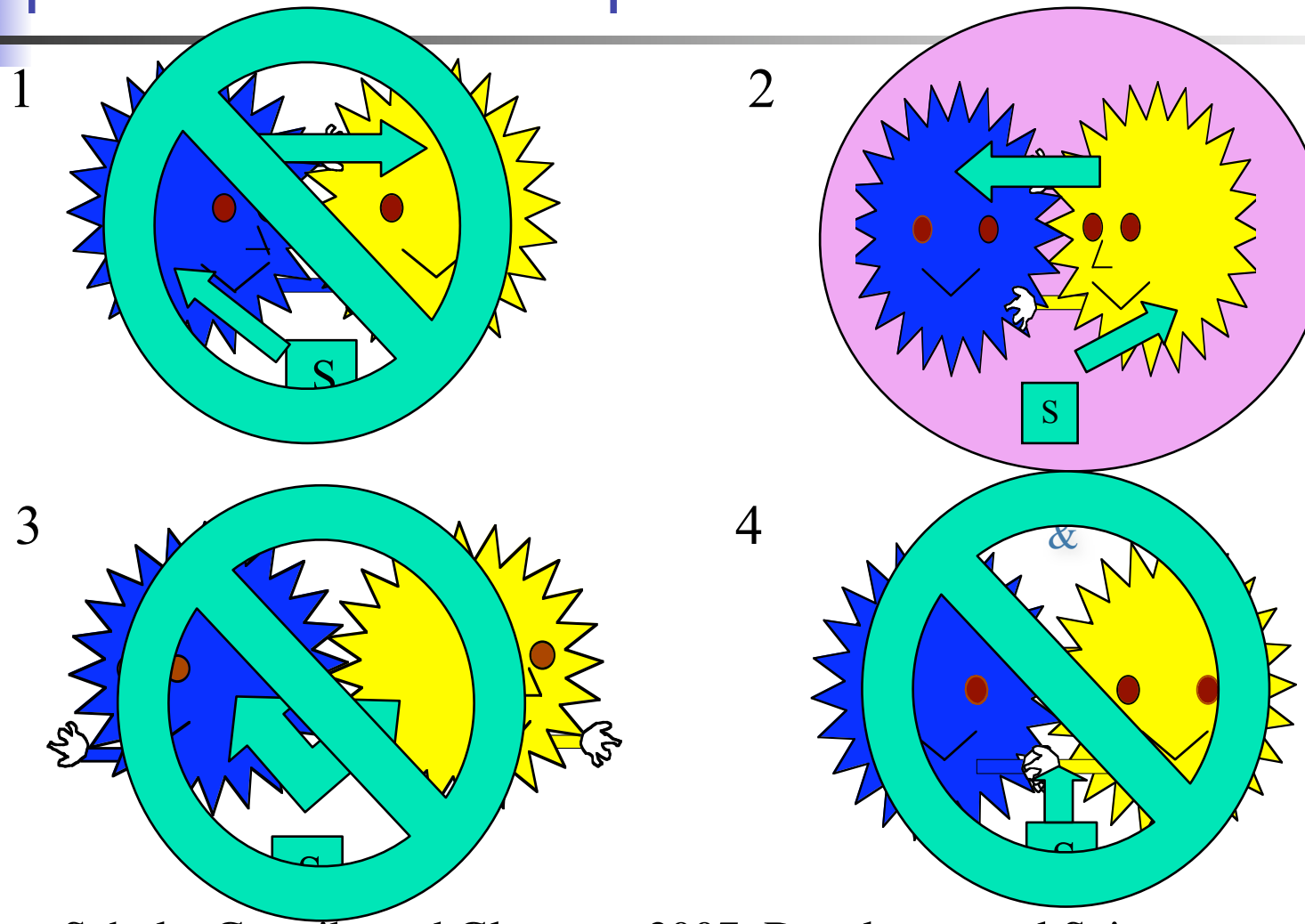
Interventions on each causal structure will produce different patterns of evidence.



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Conditional intervention principle

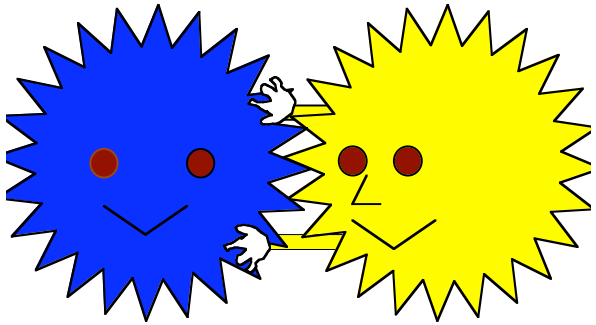
- X is a cause of Y iff:
- holding other causes of Y constant, an intervention to change the value or probability distribution of X changes the value or probability distribution of Y.

- "Interventionist" account of causation (Pearl, 2000; Woodward, 2003)

Schulz, Gopnik, and Glymour, 2007, Developmental Science

The principle in practice . . .

	Interventions		Outcome
1	S Off	Y on	B still
2	S Off	Y off	B still
3	*S Off*	*B on*	*Y still*
4	*S Off*	*B off*	*Y still*
5	**S On**	**Y on**	**B spins**
6	**S On**	**Y off**	**B still**
7	*S On*	*B on*	*Y spins*
8	*S On*	*B off*	*Y spins*



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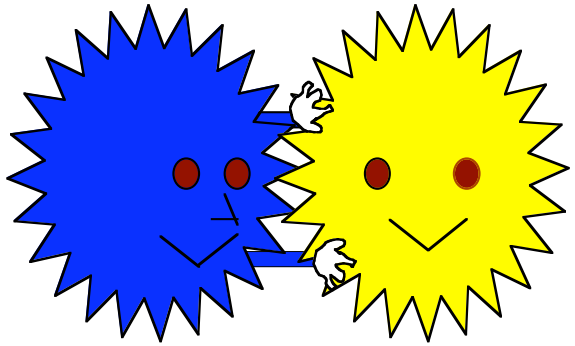
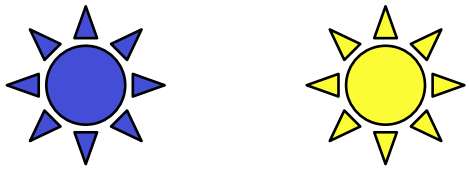
Predicting evidence from structure





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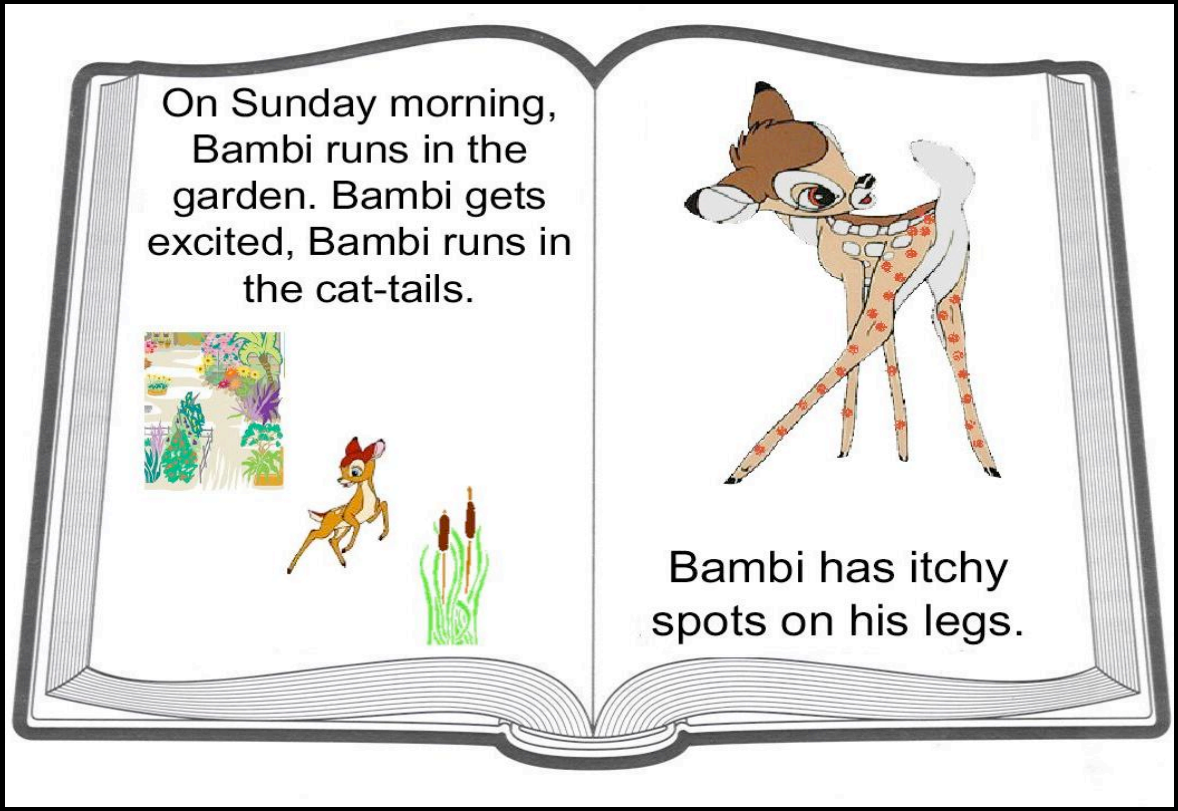
Conclusions Part 1

- Preschoolers may not understand much about physical mechanisms ...
- but they do understand the relationship between interventions and outcomes
- and can use information about the conditional probability of interventions and outcomes to disambiguate causal structures.

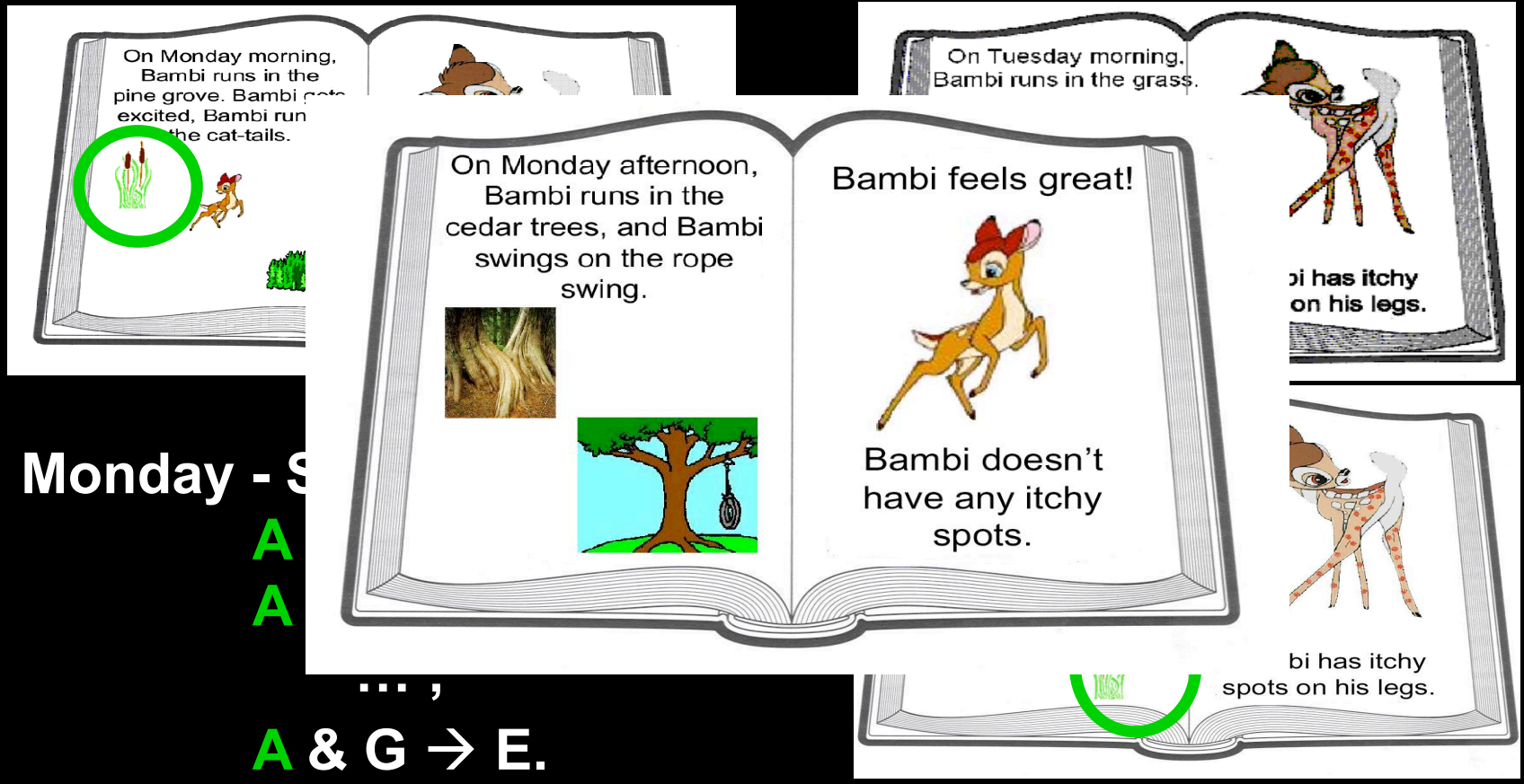
What can developmental cognitive science tell us?

- We can understand causal relationships without understanding mechanical relationships.
- We can make good inferences about statistical evidence without treating identical evidence identically.
- We can be good at causal discovery without being good at designing controlled experiments.
- The processes that make us good at learning are the same processes that make belief revision hard.

How do evidence and prior knowledge interact to affect children's causal judgments?



Within-domain (theory-neutral) evidence



Monday - S

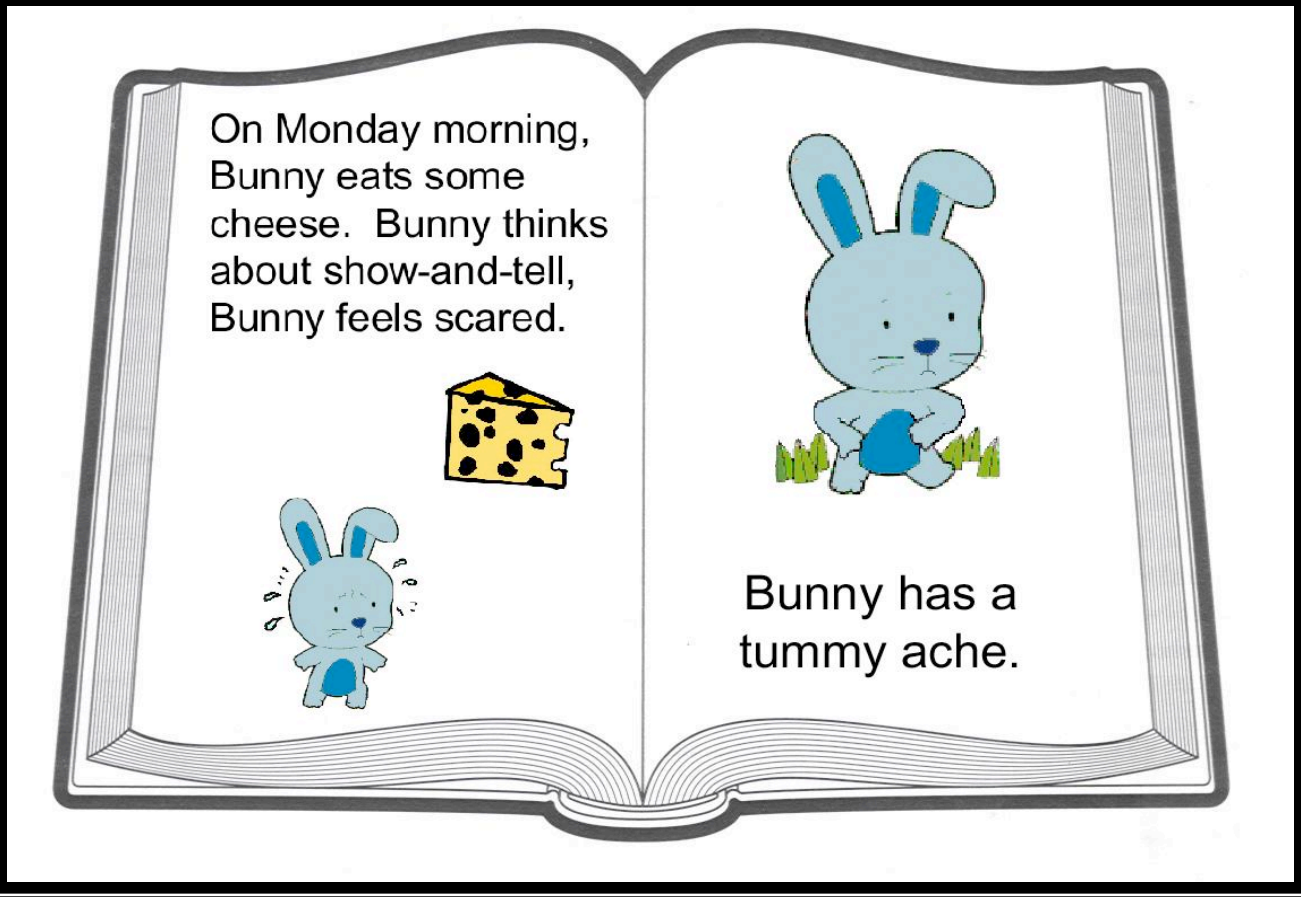
A

A

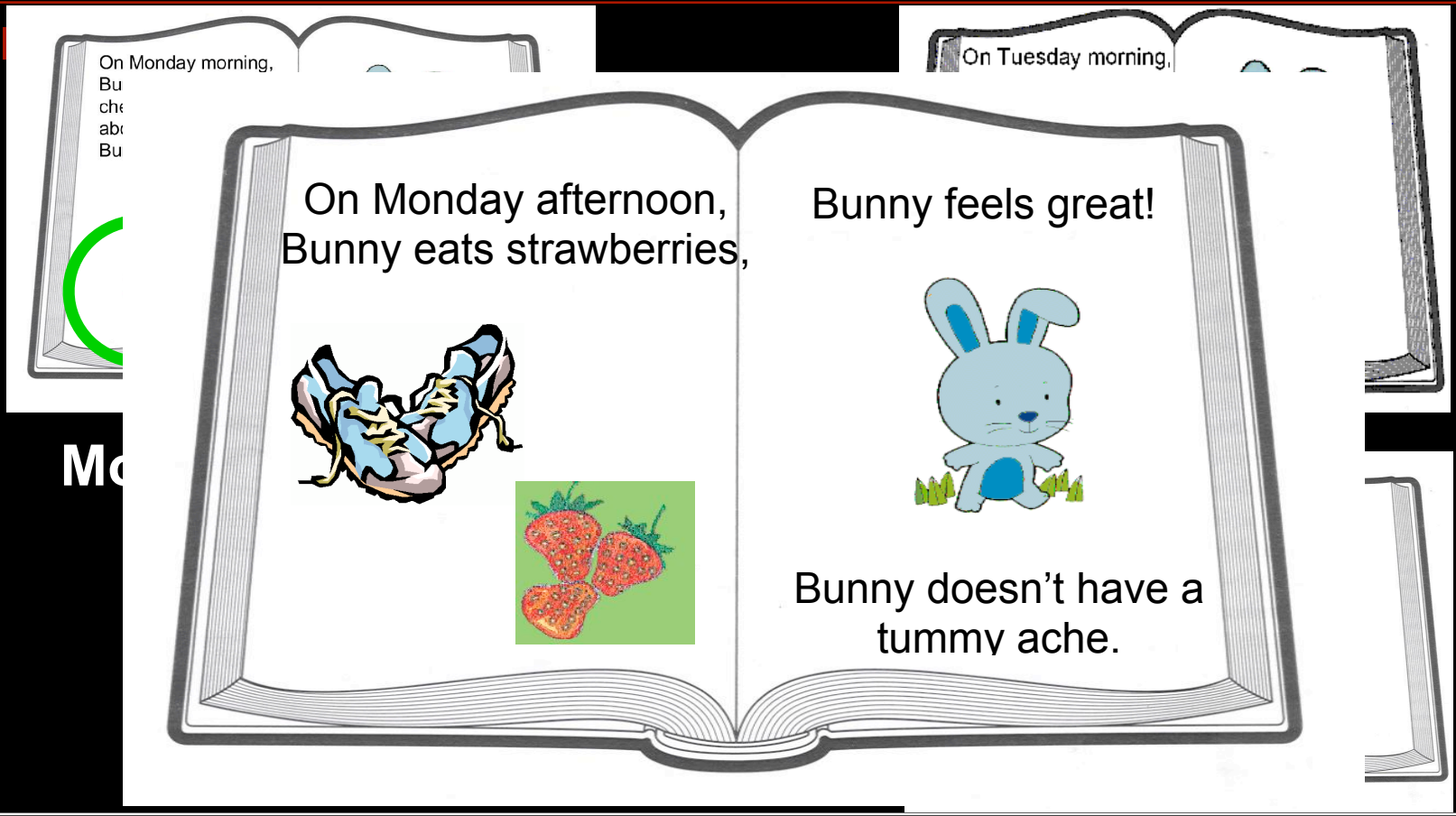
… ,

A & G → E.

How do evidence and prior knowledge interact to affect children's causal judgments?



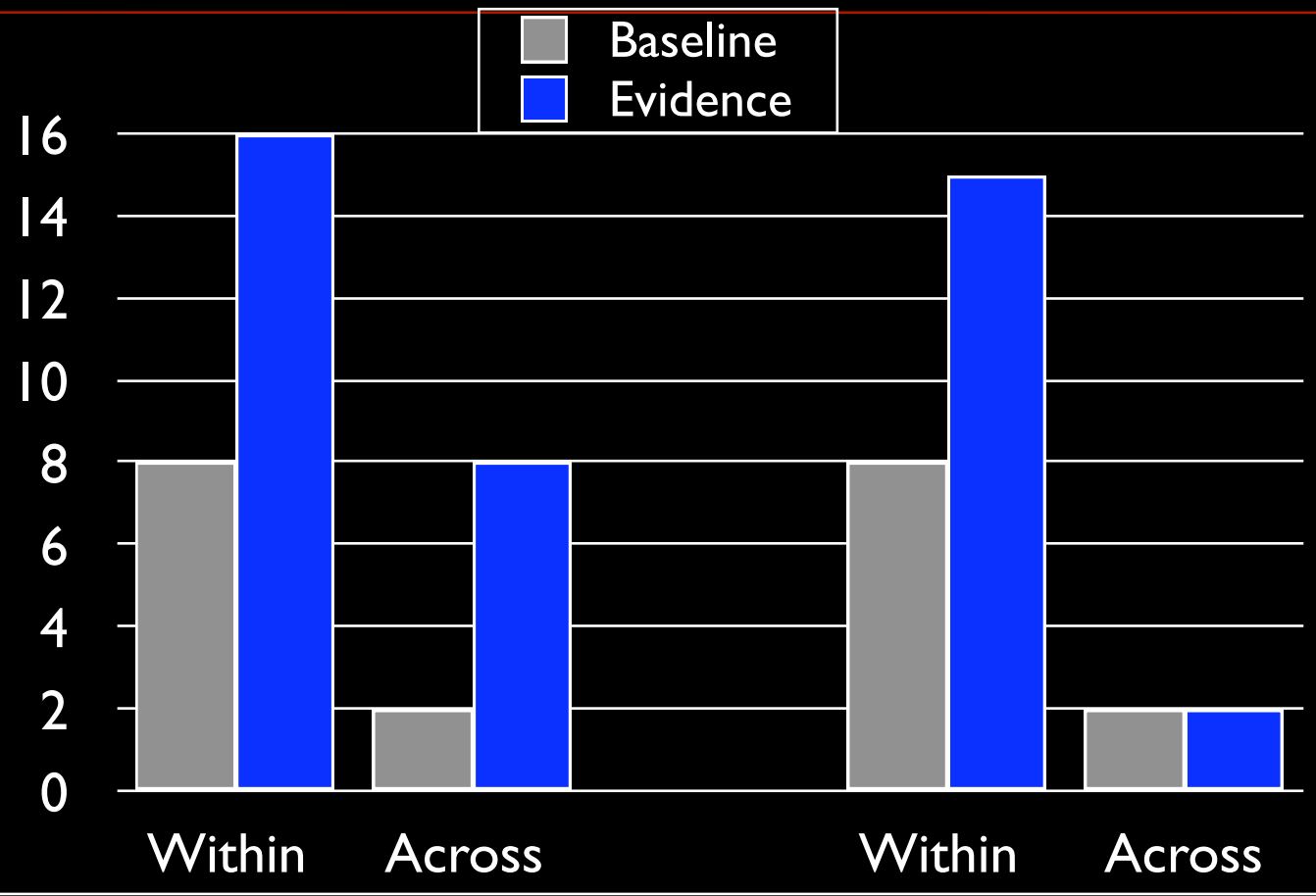
Cross-domain (theory-violating) evidence



Identical evidence; different theories

Schulz, Baraff Bonawitz, & Griffiths, 2007, Developmental Psychology

Results: 4 1/2 y-olds | 3 1/2 y-olds



Identical evidence; different theories

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Conclusions Part 2

- By the age of four, children can make inferences from ambiguous statistical data ...
- ... and integrate this evidence with their prior knowledge.

What can developmental cognitive science tell us about science learning?

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- We can make good inferences about statistical evidence without treating identical evidence identically.
- We can be good at causal discovery without being good at designing controlled experiments.
- The processes that make us good at learning are the same processes that make belief revision hard.

Learning by doing?

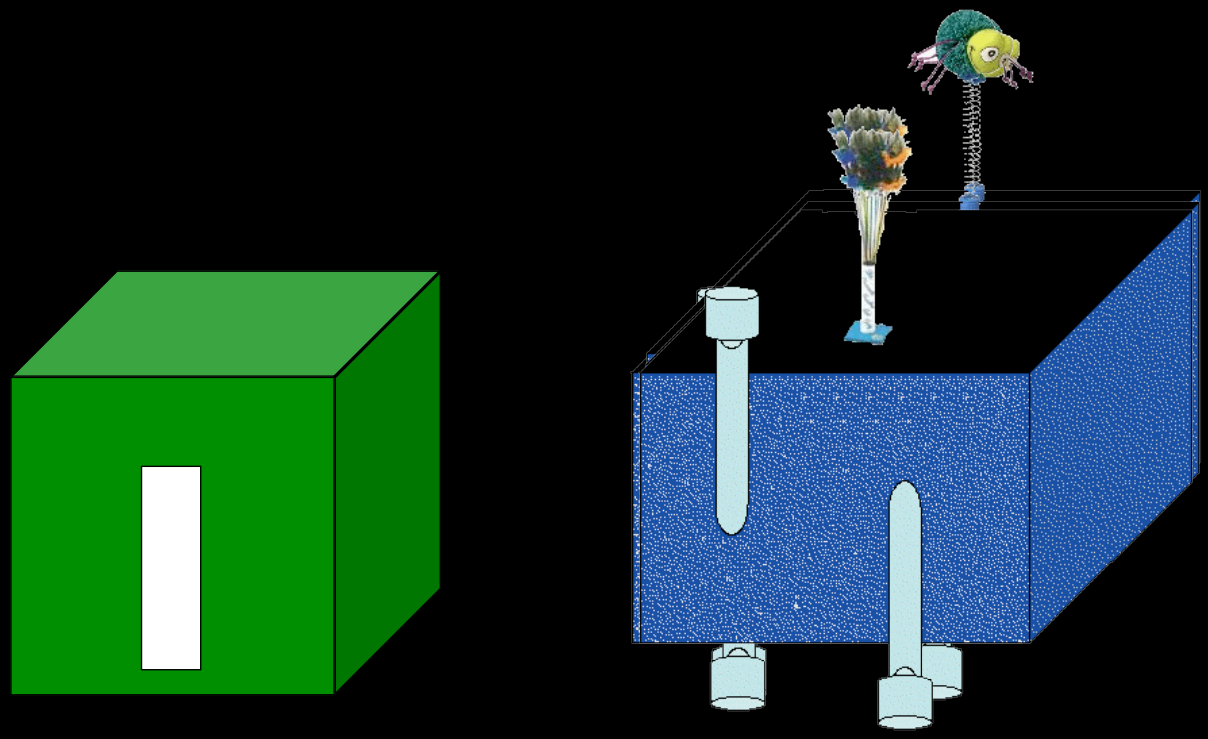
- We all believe children learn by play and active exploration …
- … but children are bad at designing informative experiments …
- … and there is little evidence for any systematic patterns in children's exploratory play.

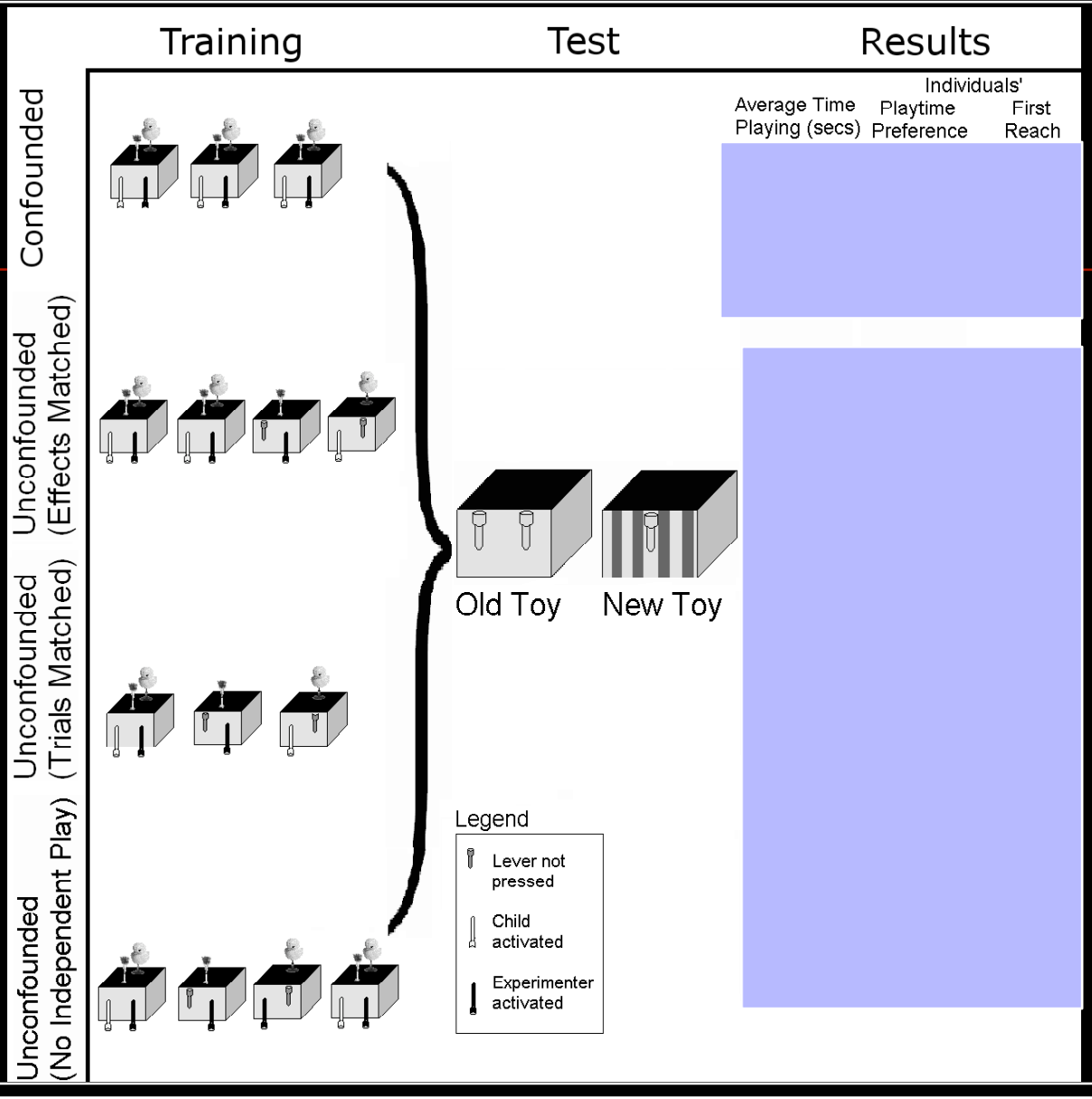
Learning by doing?

"No behavioral concept has proved more ill-defined, elusive, controversial, and even unfashionable than play" (E. O. Wilson, 1975)

Learning by doing?

- Even though children's particular actions are unsystematic
- children might selectively engage in exploratory play when evidence is ambiguous.




Training
Test
Results
Confounded
Unconfounded (Effects Matched)
Unconfounded (Trials Matched)
Unconfounded (No Independent Play)
Average Time Playing (secs)
Individuals' Playtime Preference
First Reach
Old Toy
New Toy
Legend
Lever not pressed
Child activated
Experimenter activated

Conclusions Part 3

- Although young children do not design controlled experiments ...
- they are sensitive to formal properties of evidence like confounding.
- Children's tendency to selectively explore confounded evidence ...
- can disambiguating evidence that could support causal learning.

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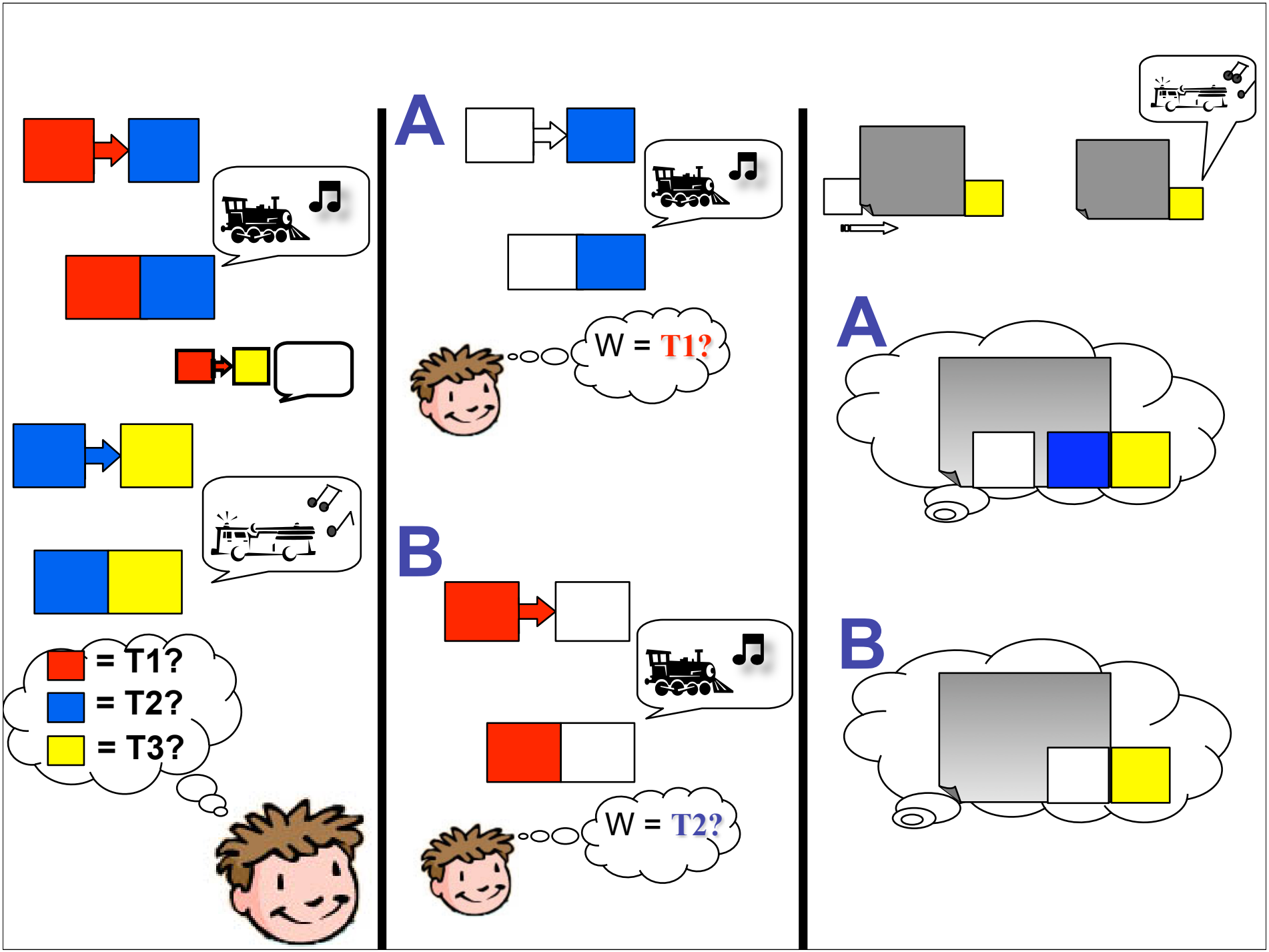
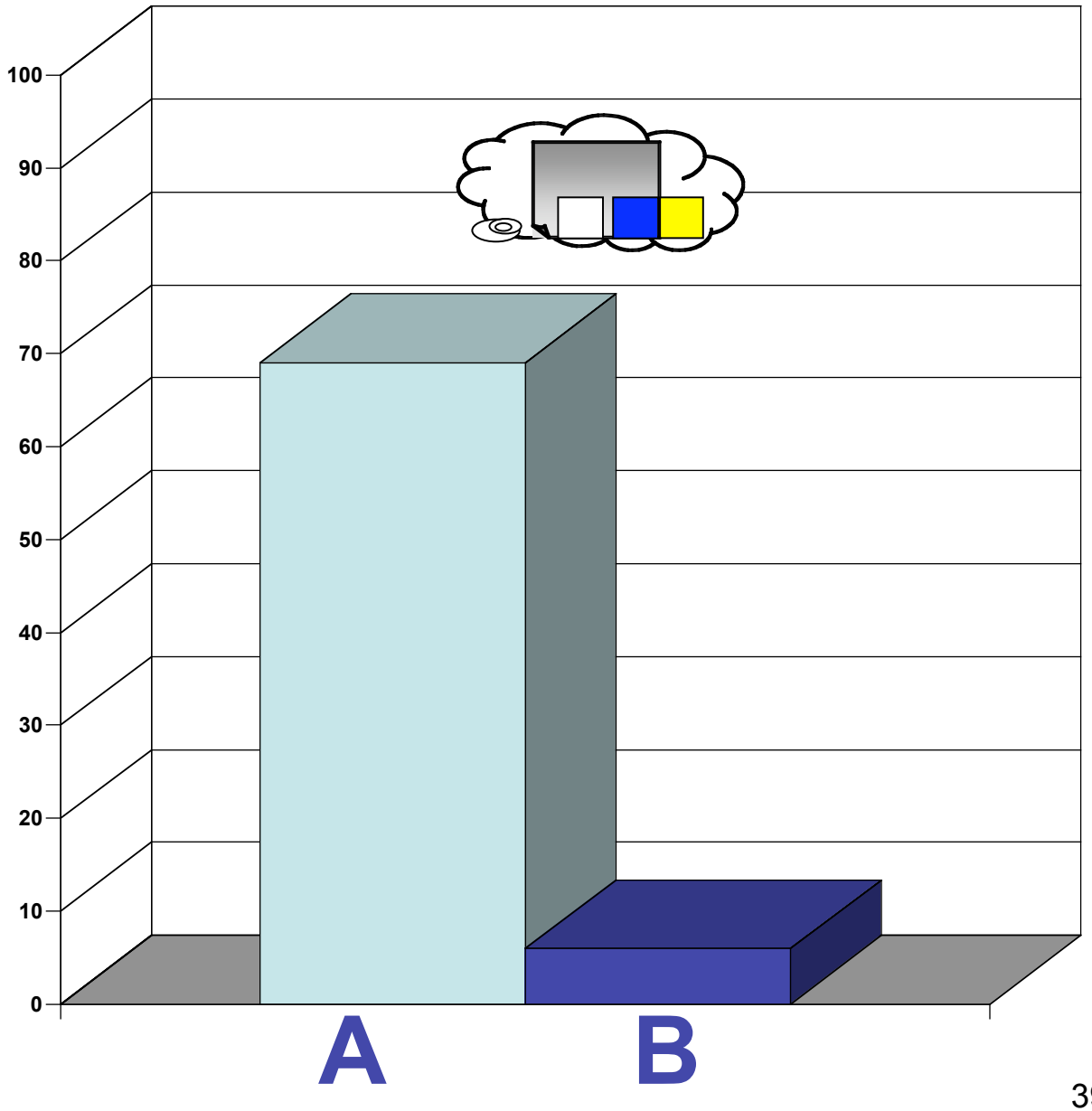

= T1?
= T2?
= T3?
A
W = T1?
B
W = T2?
A
B


100
90
80
70
60
50
40
30
20
10
0
A
B

Conclusions Part 4

- We make abstract inferences very quickly
- These abstract inferences constrain our hypotheses -- for better and for worse --

What can developmental cognitive science tell us about science learning?

- We can be good at causal discovery without being good at designing controlled experiments.
  - Mere ignorance is not sufficient to motivate curiosity. Students have to know enough to know when there are competing plausible causes. Curiosity requires expertise.
  - Children do learn by doing and are sensitive to formal principles of experimental design. But this does not mean, absent explicit instruction, students can design informative experiments. Left to their own devices, students are as likely to generate uninformative interventions as informative ones.

Conclusions Part 4

- Inductive biases account both for the rapid, accurate learning from minimal data ...
- And the relative intransigence to counter-evidence ...
- That characterizes causal learning.

What can developmental cognitive science tell us about science learning?

- We can understand causal relationships without understanding mechanical relationships.
  - Students may believe they understand physical mechanisms much better than they actually do.
- We can make good inferences about statistical evidence without treating identical evidence identically.
  - Student's prior knowledge will have a dramatic effect on how they interpret evidence. Students with different prior beliefs will construe identical differently.

What can developmental cognitive science tell us about science learning?

- The processes that make us good at learning are the same processes that make belief revision hard.
  - Students' causal learning has to balance a need for flexibility (rapid learning from new data) and conservatism (because evidence is sometimes misleading, and sometimes fails to be representative).
  - When students' initial inferences are accurate, they make remarkable insights from small amounts of evidence -- but when they are wrong, students might have a hard time overcoming them.

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