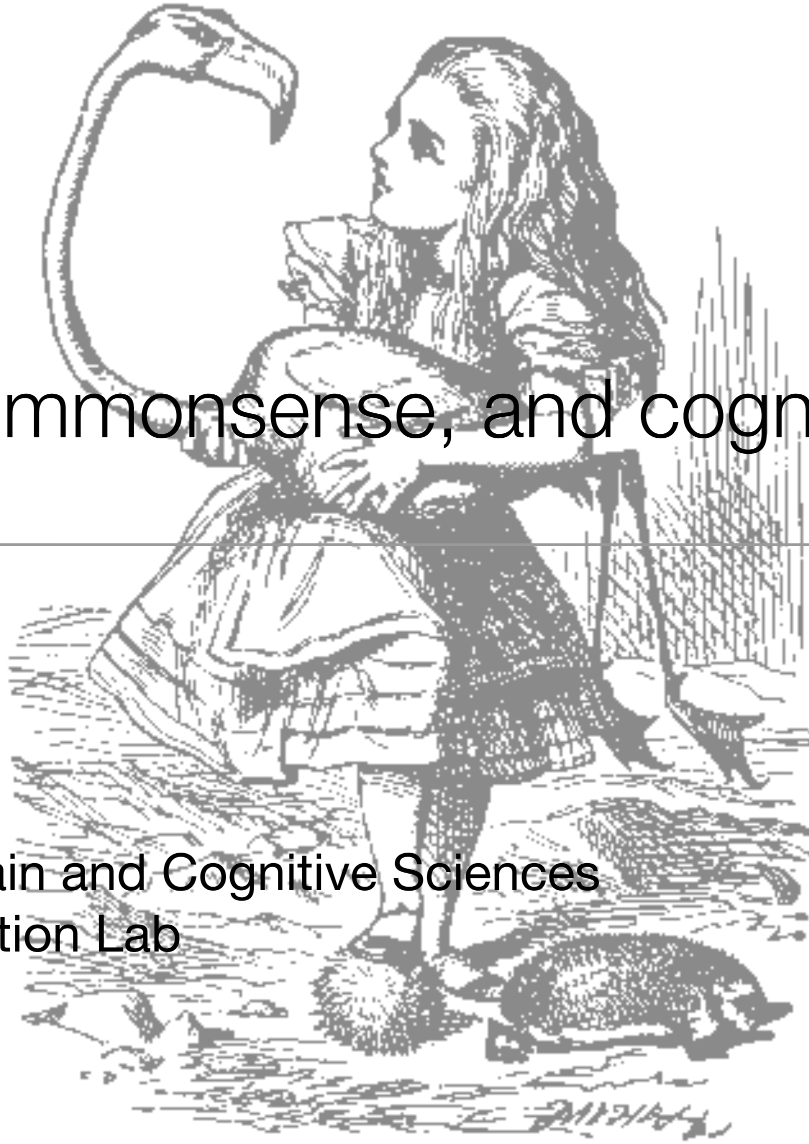
Intelligence, commonsense, and cognitive development



Laura Schulz
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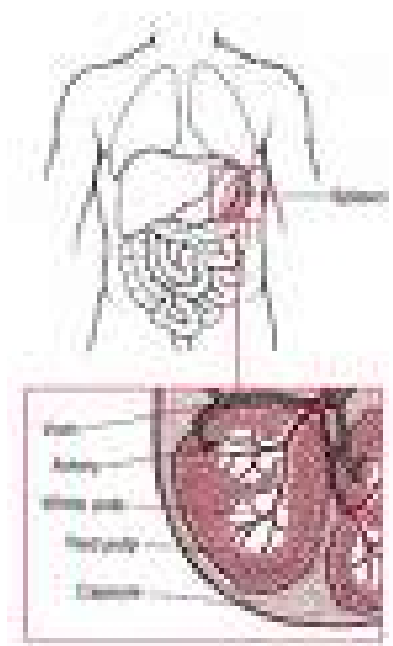
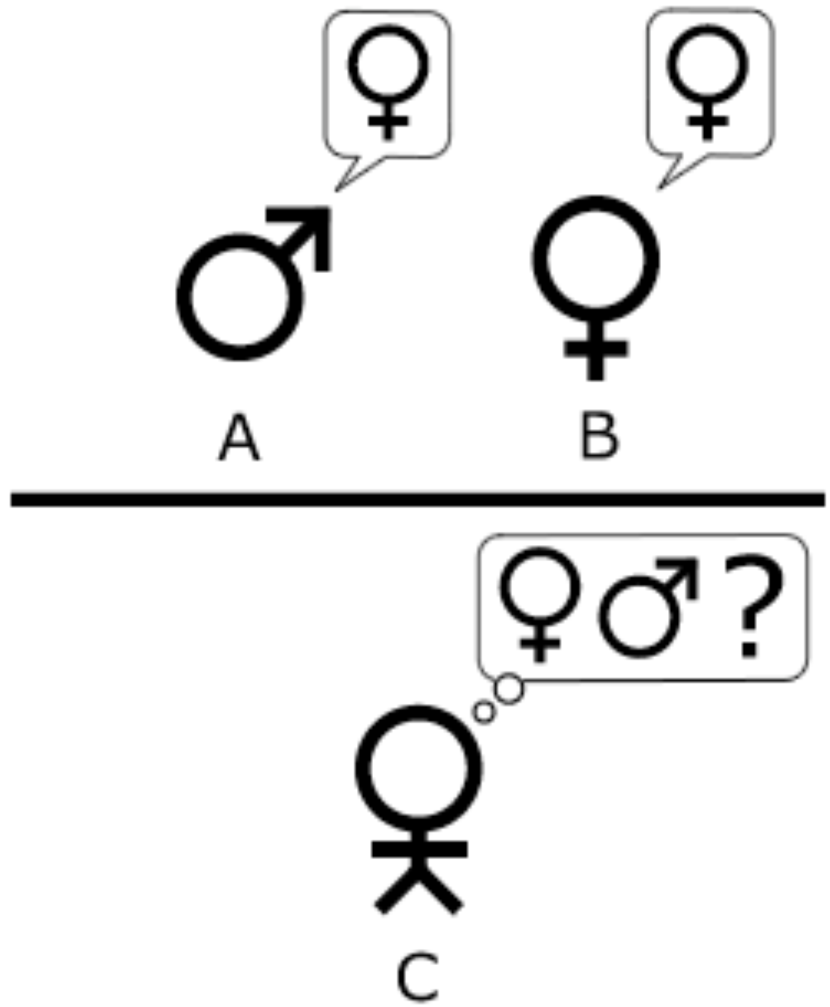
Early Childhood Cognition Lab

Spleen (n)

- 1. a vascular ductless organ in the left upper abdomen of humans and other vertebrates that helps to destroy old red blood cells, form lymphocytes, and store blood



Alan Turing


♀
♀
A
B
♀♂?
C

Underestimating the challenge of common sense intelligence

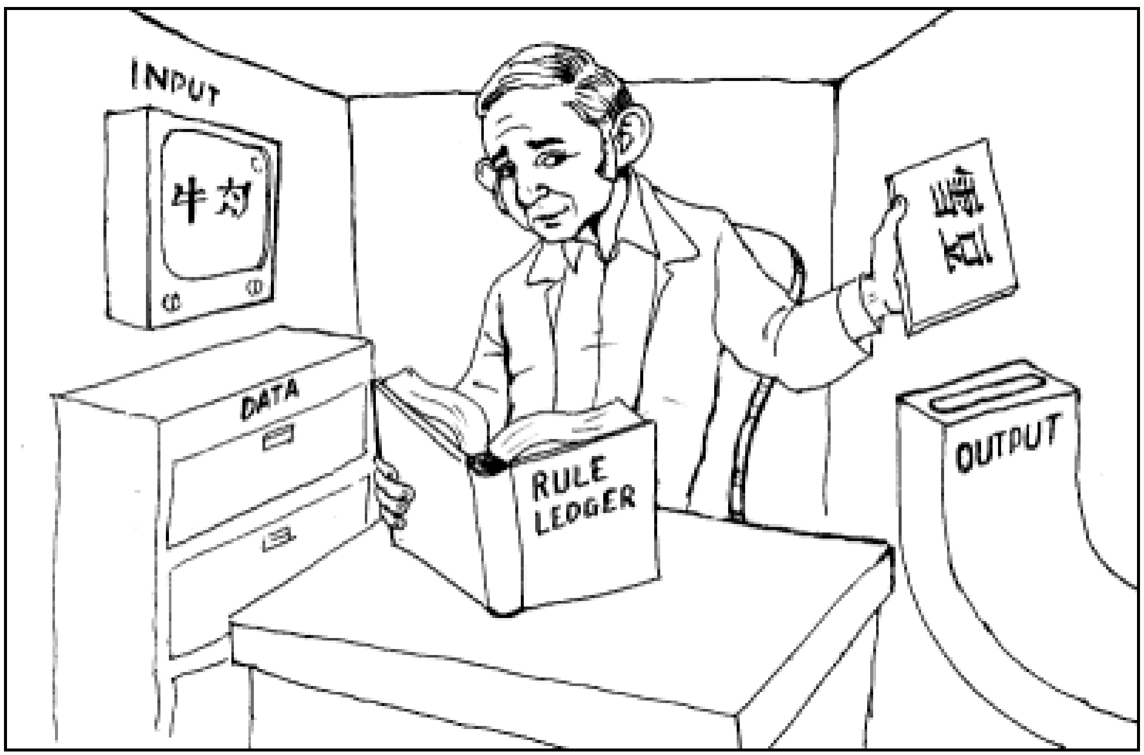
- Turing test

Underestimating the challenge of common sense intelligence

"I believe that in about fifty years' time it will be possible to program computers … to make them play the … game so well that an average interrogator will not have more than 70 percent chance of making the right identification after five minutes of questioning" (Turing, 1950)

Is this a good test of intelligence?

- Searle's Chinese room … maybe not.



Underestimating the challenge of common sense intelligence

RECENT WINNERS OF THE LOEBNER PRIZE

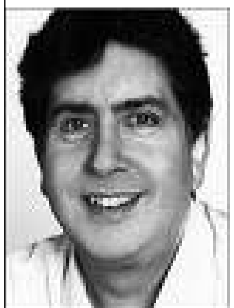
Can you read?
Yes -- what's your favorite novel?
There's no such thing.
Meaning you don't have a favorite novel or novels don't exist?
No
What's your favorite book then?
Are you serious? I don't have a favorite book. My favorite color is transparent.

Underestimating the challenge of common sense intelligence

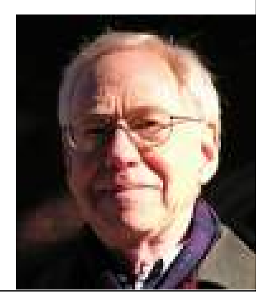
RECENT WINNERS OF THE LOEBNER PRIZE

Do you have a pet?
No but I like cats very much.
Why don't you have a cat?
Do I need one?
Only if you think you do.
I think I do.
Well then get one by God!
Good reasoning! Where can I get one by God?

Commonsense as the hard problem of cognitive science



- Suppose you wanted to engineer commonsense how would you do it?
- Douglas Lenat: maybe the trick is just to give computers a bunch of facts about the world
- But if knowledge is organized as individual facts, you would have to know that if Barack Obama is in Washington, so is his eyebrow, his big toe, his spleen …
- Hubert Dreyfus: “If you got all that knowledge into a computer you would not know how to retrieve it.”



Or not ...

- Watson (16:48-16:50)
- So Dreyfus' problem turns out not to be the problem
- The hard problem may be that even having massive world knowledge is neither necessary nor sufficient for passing the Turing test.
- "Hedgehogs are covered with quills or spines which are hollow hairs made stiff by this protein ..."
- Keratin = 99%, Porcupine = 36%

Common sense as the hard problem of cognitive science

- “Is it easier to walk forwards or backwards?”
- “If President Obama is in Washington, is his spleen in Washington?”
- “Do doctors wear pants?”

Everything you needed to know to pass the Turing test you learned before kindergarten.

Most of the hard problems of cognitive science …

- natural language understanding
- scene understanding
- face recognition
- motor planning
- causal reasoning
- theory of mind
- moral reasoning
- Are readily solved by young children.

We would like to know

- What causes this knowledge to emerge.
- How the knowledge is represented.
- Whether this knowledge changes and if so why.
- How knowledge in one area interacts with knowledge in other areas.
- Not just a hard problem of cognitive science but an old problem of philosophy …

Background

- From the beginning of Western philosophy: two competing traditions.
- **Rationalism** -- Knowledge of that which is necessarily true is innate. (Plato)
- **Empiricism** -- "Nothing is in the intellect which was not first in the senses." (Aristotle)
- But the puzzle of common sense is how we can be we so confident about knowledge that is neither
  - innate (e.g., about spleens)
  - nor necessarily true (you can actually live without a spleen -- although I don't recommend it)
- Bothered a lot of philosophers (Kant: "How are synthetic a priori truths possible?")
- Today -- how is inductive inference possible?

Common sense intelligence

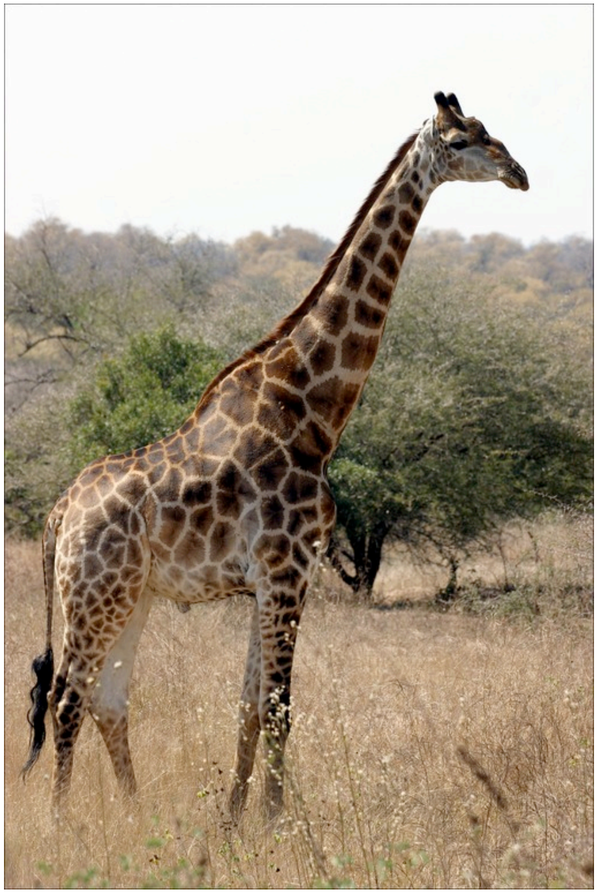
- We need to explain the gap between experience and our understanding of it
- By now you may have already forgotten again why this is a hard problem ...

What gap? Try this multiple choice quiz

- A speaker of Quinian points to this and says "Gavagi." What does Gavagai mean?

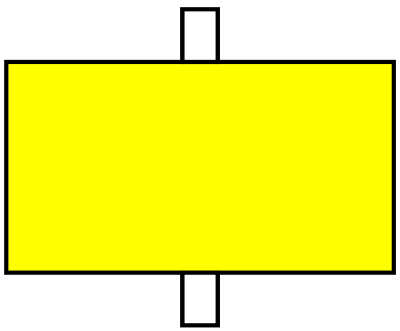
What gap? Try this multiple choice quiz

- Complete the sentence: “The giraffe has a very long ...”



What gap? Try this multiple choice quiz

- What's behind the rectangle?



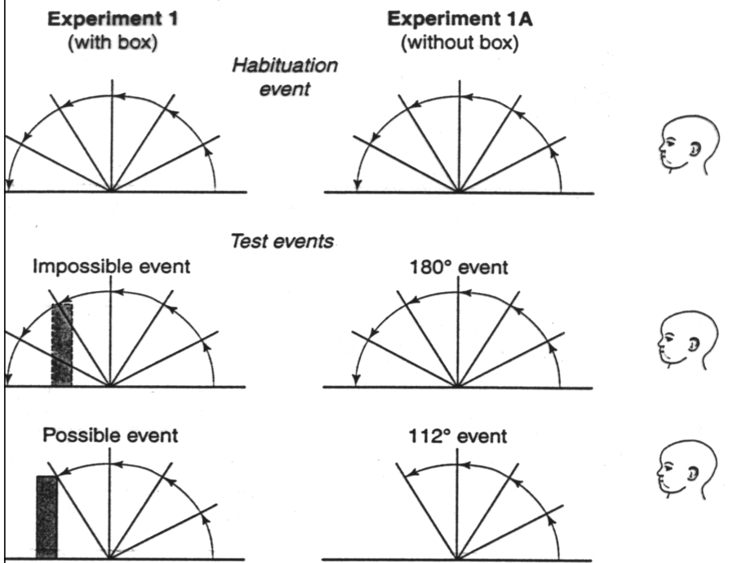
The problem of common sense intelligence

- Most of what we know is massively underconstrained by the data.

- Inductive inference as a chicken and egg problem ...
- we need abstract knowledge to constrain our interpretation of evidence
- but how do we get that abstract knowledge in the first place?

Core knowledge

Infancy revolution



ORIGINS OF KNOWLEDGE

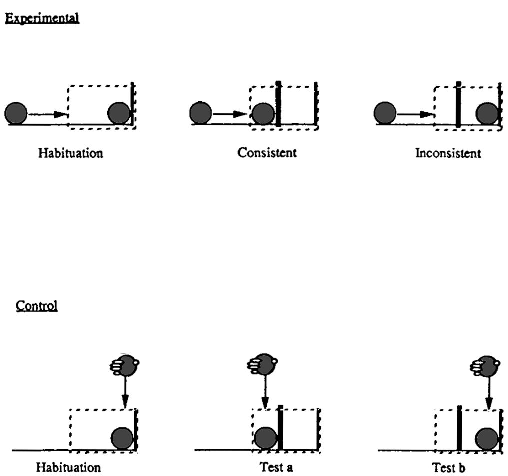


Figure 6. Schematic depiction of the events from Experiment 3.

■ FIGURE 5.9
Imitation of Facial Expressions in Newborns

Sample photographs from videotape recordings of two- to three-week-old infants imitating (a) tongue protrusion, (b) mouth opening, and (c) lip protrusion demonstrated by an adult experimenter.

SOURCE: A. Meltzoff and W. Moore. Imitation of facial and manual gestures by human neonates. *Science*, 1977, *198*, 7578. Copyright 1977 by the American Association for the Advancement of Science. Reprinted by permission of the publisher and the author.

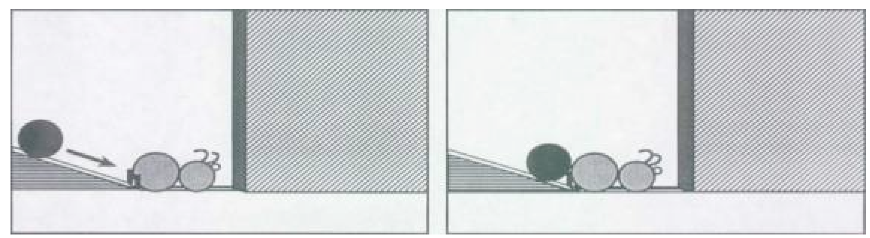


Figure 3A

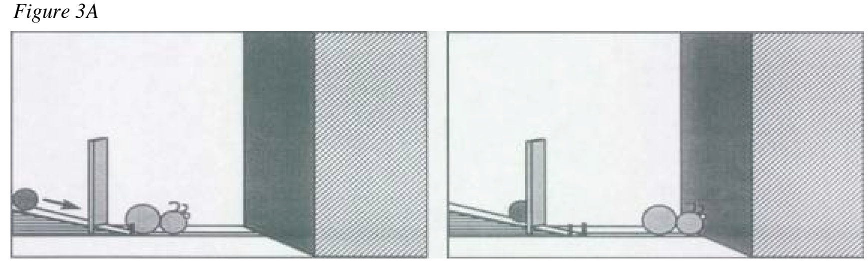


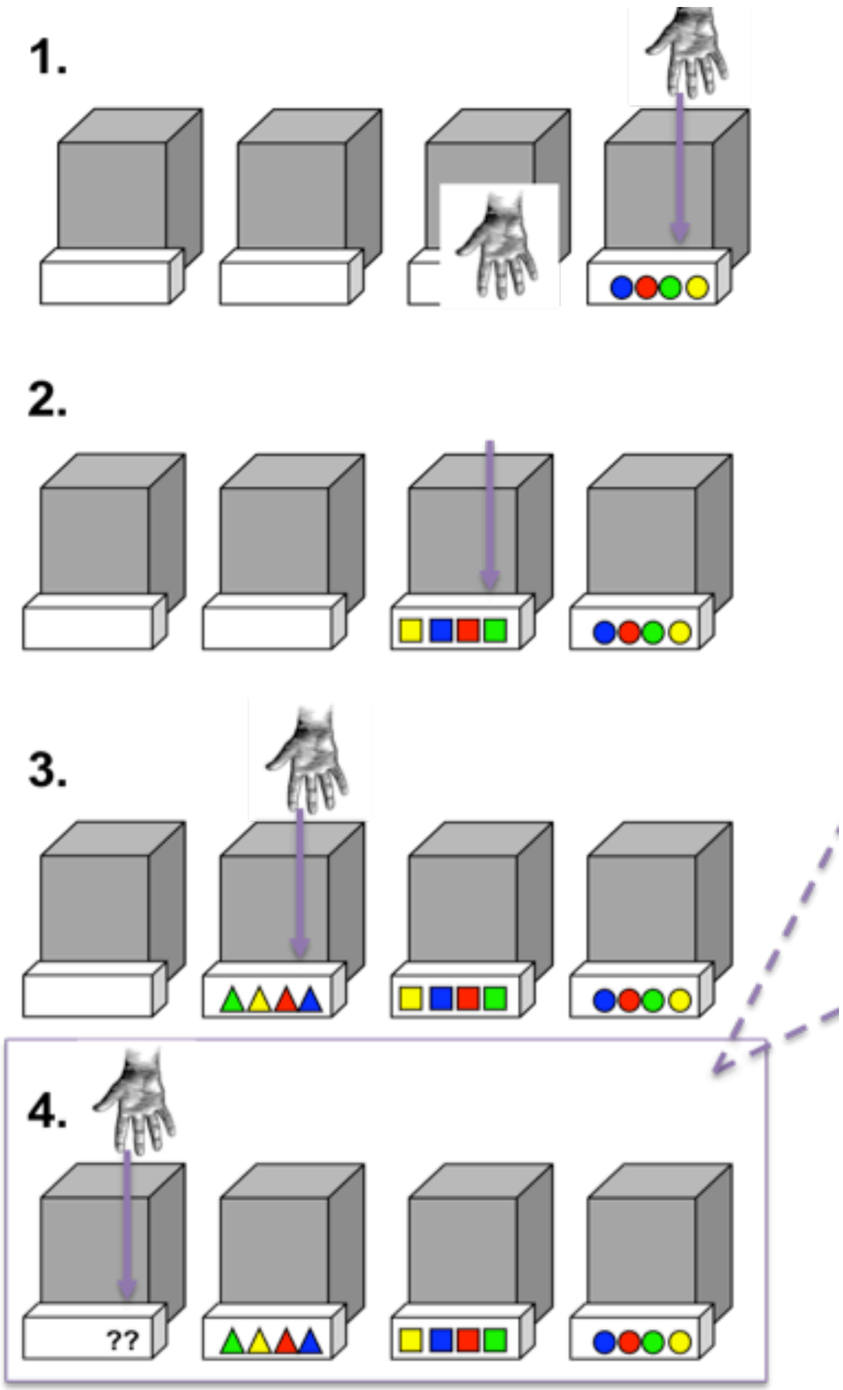
Figure 3B

But abstract constraints don’t necessarily have to be innate

The blessing of abstraction suggests that this is
not a necessary order for the construction of knowledge, but
that abstract knowledge can become available before specific
knowledge in any of the systems that it depends on.

Noah D. Goodman, Tomer D. Ullman, Joshua B. Tenenbaum

Induction, Overhypothesis, and the Origin of Abstract Knowledge: Evidence from 9-month-old Infants
Kathryn M. Dewar1 & Fei Xu2



Child as scientist

How do scientists learn?

- Scientists learn from statistical evidence
- Scientists beliefs affect their interpretation of statistical evidence
- Scientists distinguish genuine causes from spurious associations
- Scientists selectively explore ambiguous or confounded evidence
- Scientists introduce unobserved variables to explain data otherwise anomalous with respect to their prior beliefs
- Scientists' generalizations depend on how evidence is sampled
- Scientists infer the relative probability of competing hypotheses and choose interventions most likely to achieve desired outcomes
- Scientists isolate variables to distinguish competing hypotheses
- Scientists rely on expert knowledge and trade-off instruction and exploration

Rational inference in early childhood

- Children learn from statistical evidence
- Children’s beliefs affect their interpretation of statistical evidence
- Children distinguish genuine causes from spurious associations
- Children selectively explore ambiguous or confounded evidence
- Children introduce unobserved variables to explain data otherwise anomalous with respect to their prior beliefs
- Children’s generalizations depend on how evidence is sampled
- Children infer the relative probability of competing hypotheses and choose interventions most likely to change target outcomes
- Children isolate variables to distinguish competing hypotheses
- Children rely on expert knowledge and trade-off instruction and exploration

It’s not that children are little scientists ...

It’s that science is possible because of the type of learning that is necessary in early childhood ...

Rational inference in early childhood

- Children learn from statistical evidence
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- Children distinguish genuine causes from spurious associations
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- Children isolate variables to distinguish competing hypotheses
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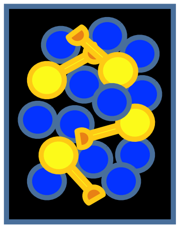
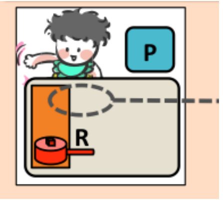
Four quick examples

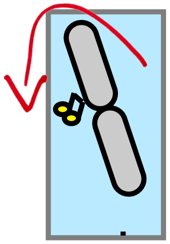
- Infants' generalizations depend on how evidence is sampled



- Infants infer the relative probability of hypotheses and choose interventions most likely to achieve desired outcomes.



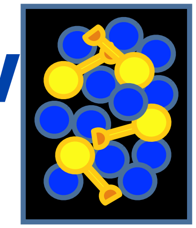
- Preschoolers' isolate variables to distinguish competing hypotheses



- Preschoolers rely on expert knowledge and trade-off instruction and exploration

Four quick examples

- **Infants' generalizations depend on how evidence is sampled**



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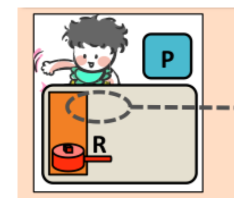

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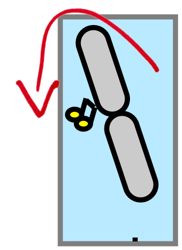
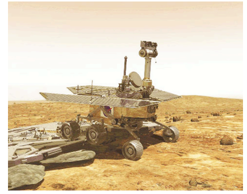


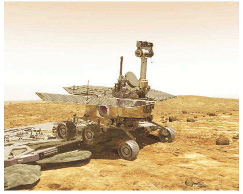
- Preschoolers rely on expert knowledge and trade-off instruction and exploration

Child as scientist?

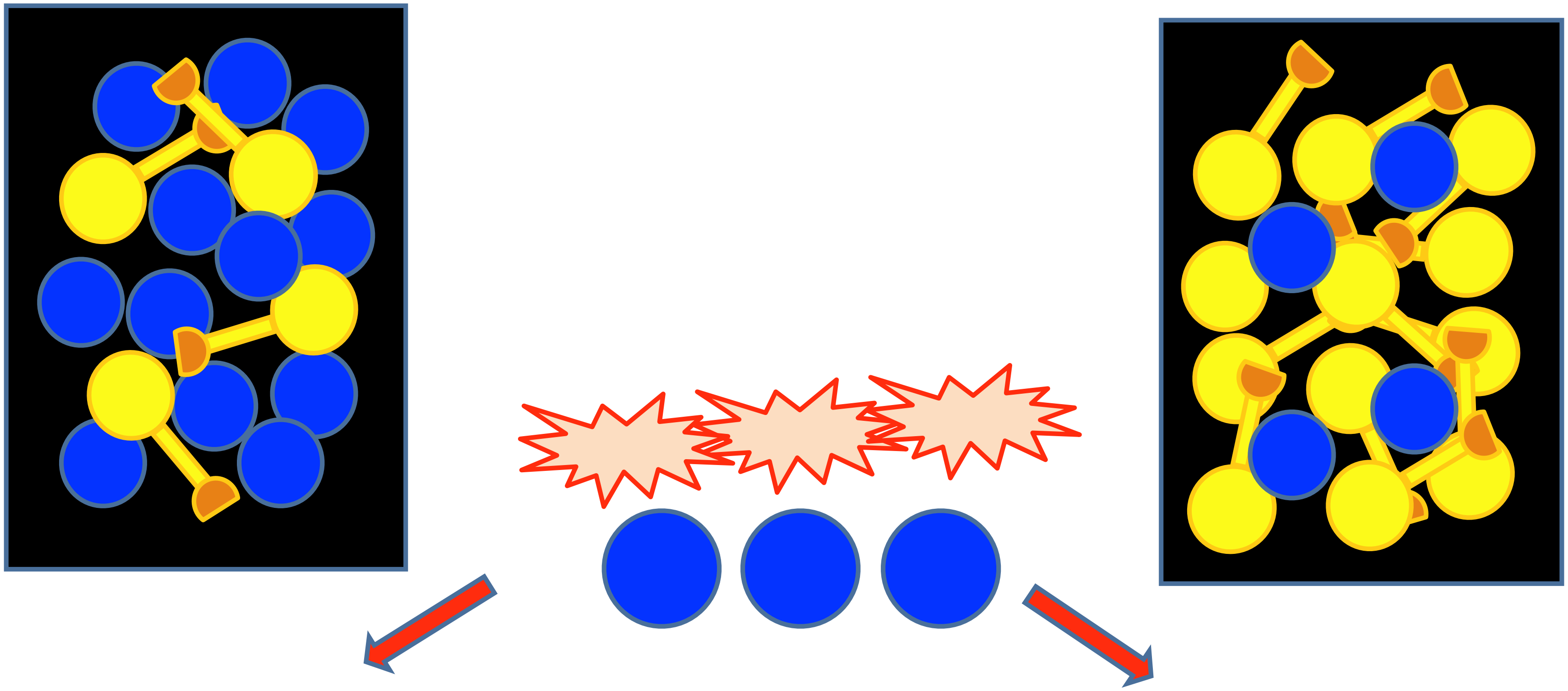


- Science requires generalizing properties from a small sample to a population.
- Can use category membership and feature similarity to infer that things that look alike will share properties
- If you know that this sample of Martian rocks has a high concentration of silica, can infer that other Martian rocks may have a high concentration of silica.
- If you know that this sample of needles from a Pacific silver fir lie flat, can infer other Pacific silver fir needles lie flat.

Child as scientist?



- But as scientists we may know something about the sampling process that affects our inferences.
  - Do all Martian rocks have high concentrations or silica or only dusty rocks on the surface?
  - Do all Pacific silver fir needles lie flat or just those low on the canopy?
- How far we extend our generalizations depends on whether we think the sampling process was random or selective.
- Do infants' generalizations also take the sampling process into account?



Consistent with sampling from whole box

Unlikely to have been sampled from whole box

More likely that evidence was sampled selectively

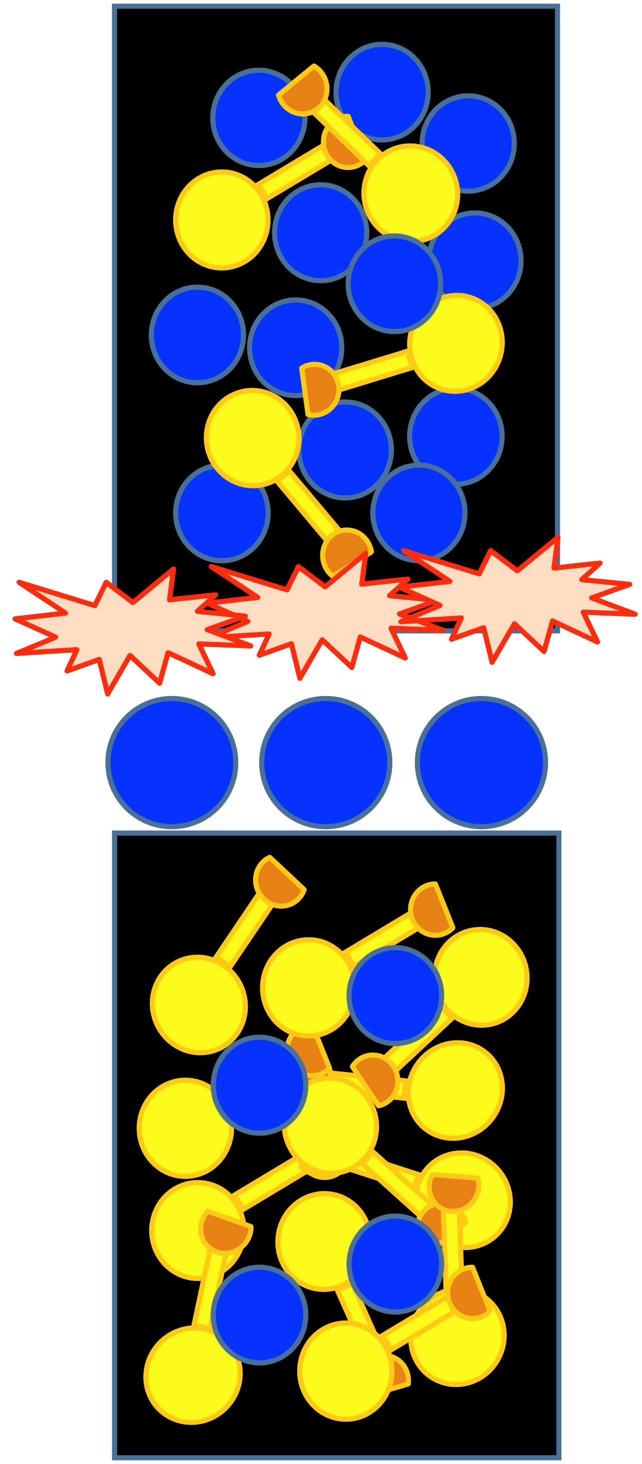
Prediction: Many children try to squeak and squeak persistently

Prediction: Few children try to squeak and children do not squeak often

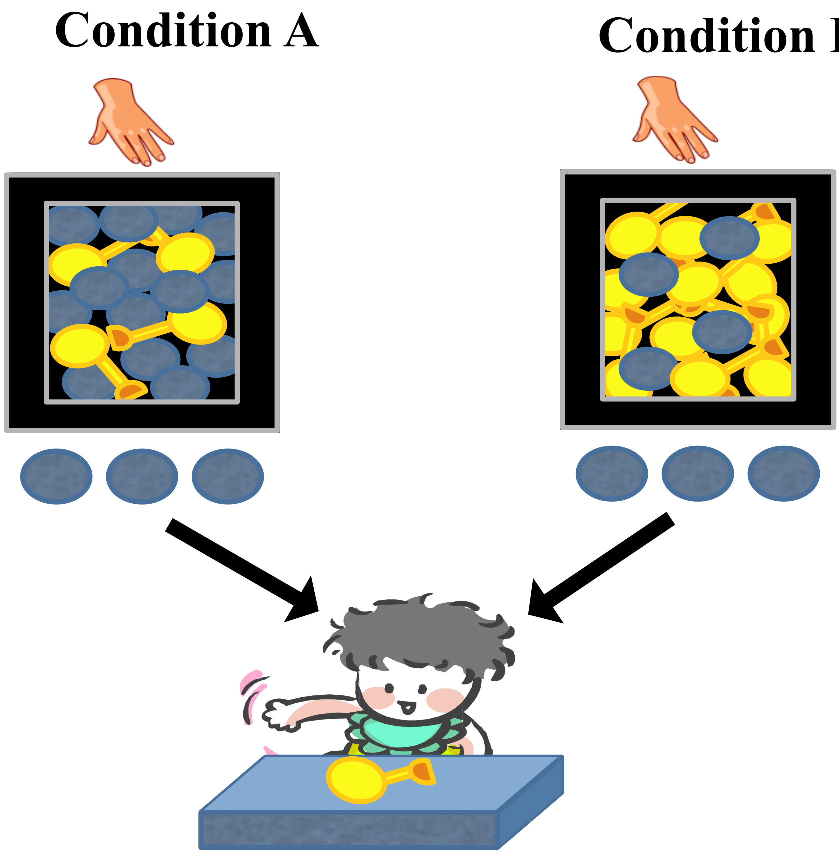
The yellow ball probably doesn't squeak

[redacted]

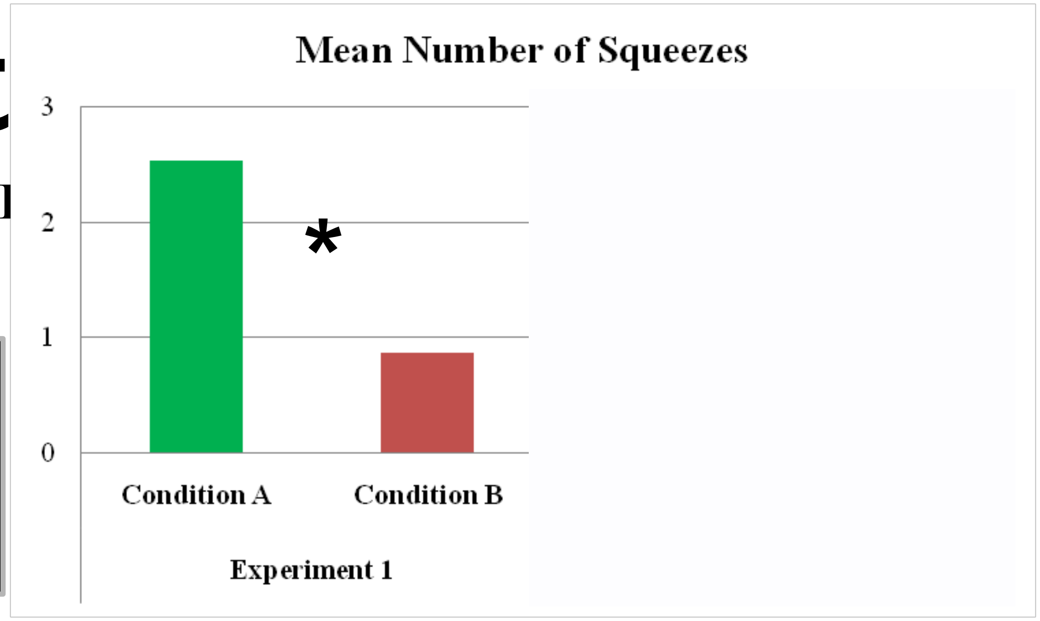
[redacted]

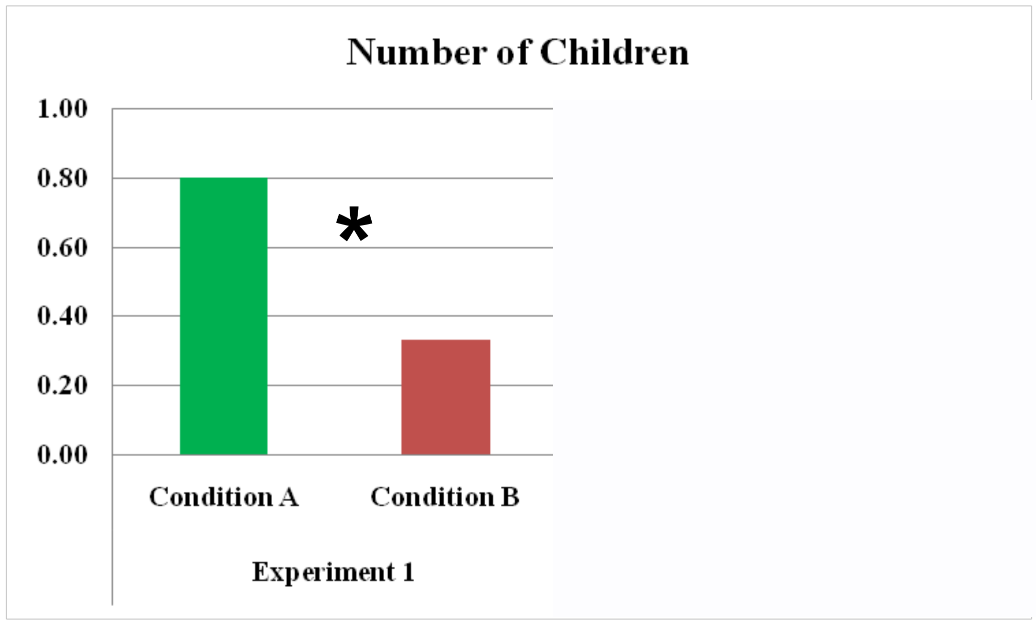


Result



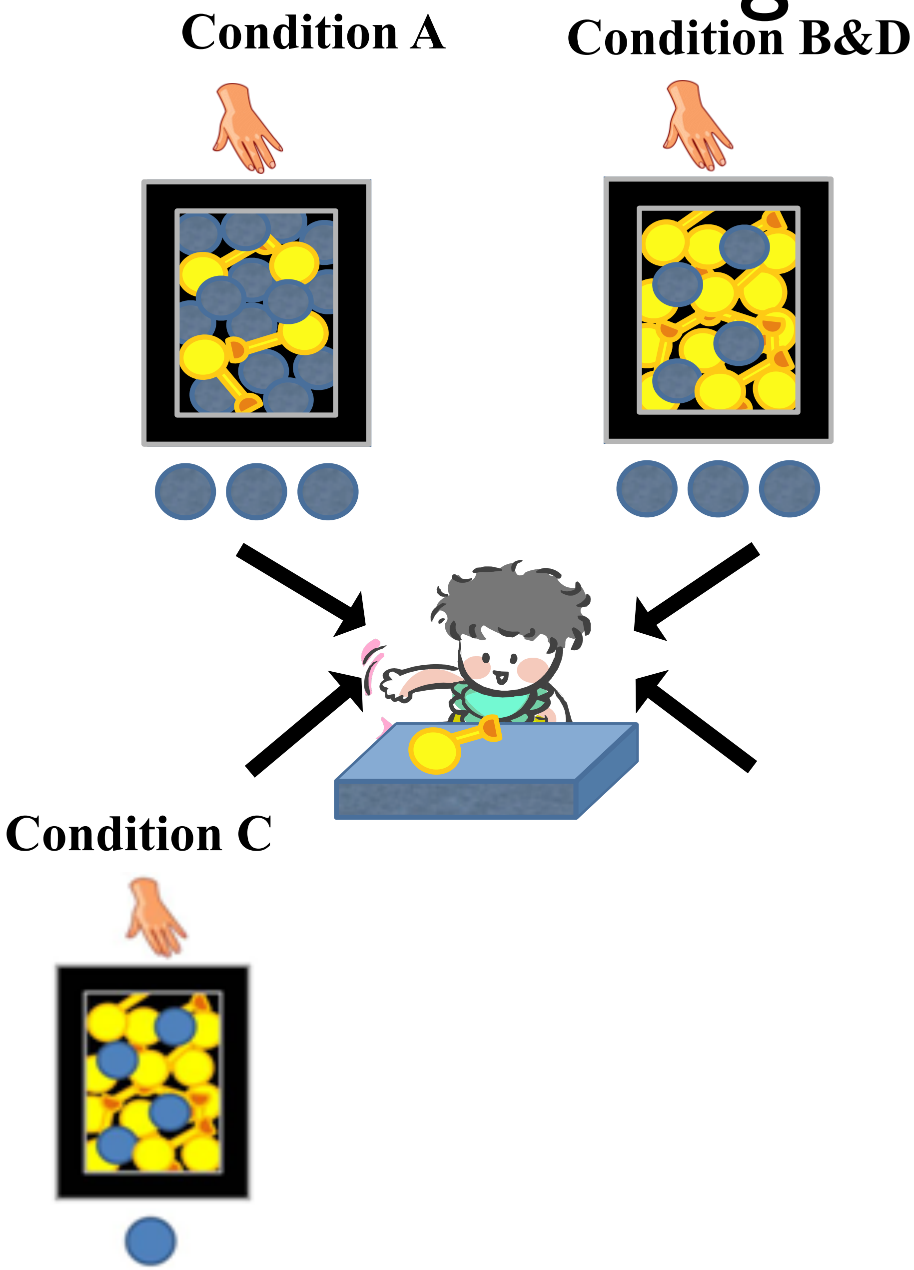
Toddlers: 13 -18 months; mean 15 months





Gweon, Tenenbaum, & Schulz, PNAS, 2010

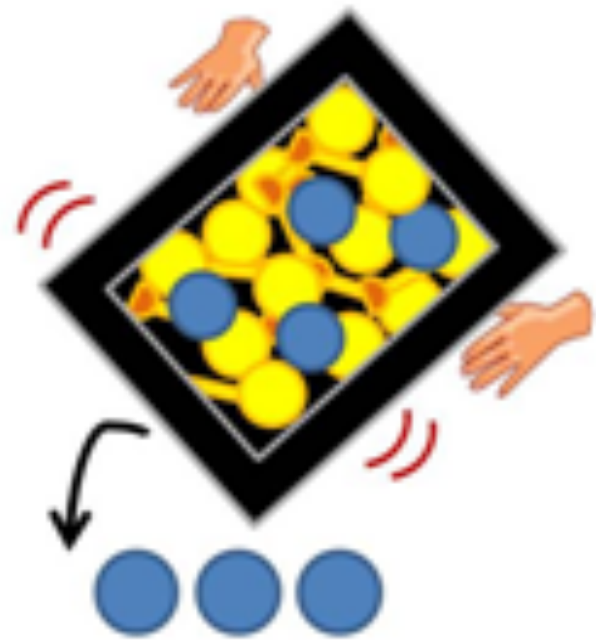
Design



Gweon, Tenenbaum, & Schulz, PNAS, 2010

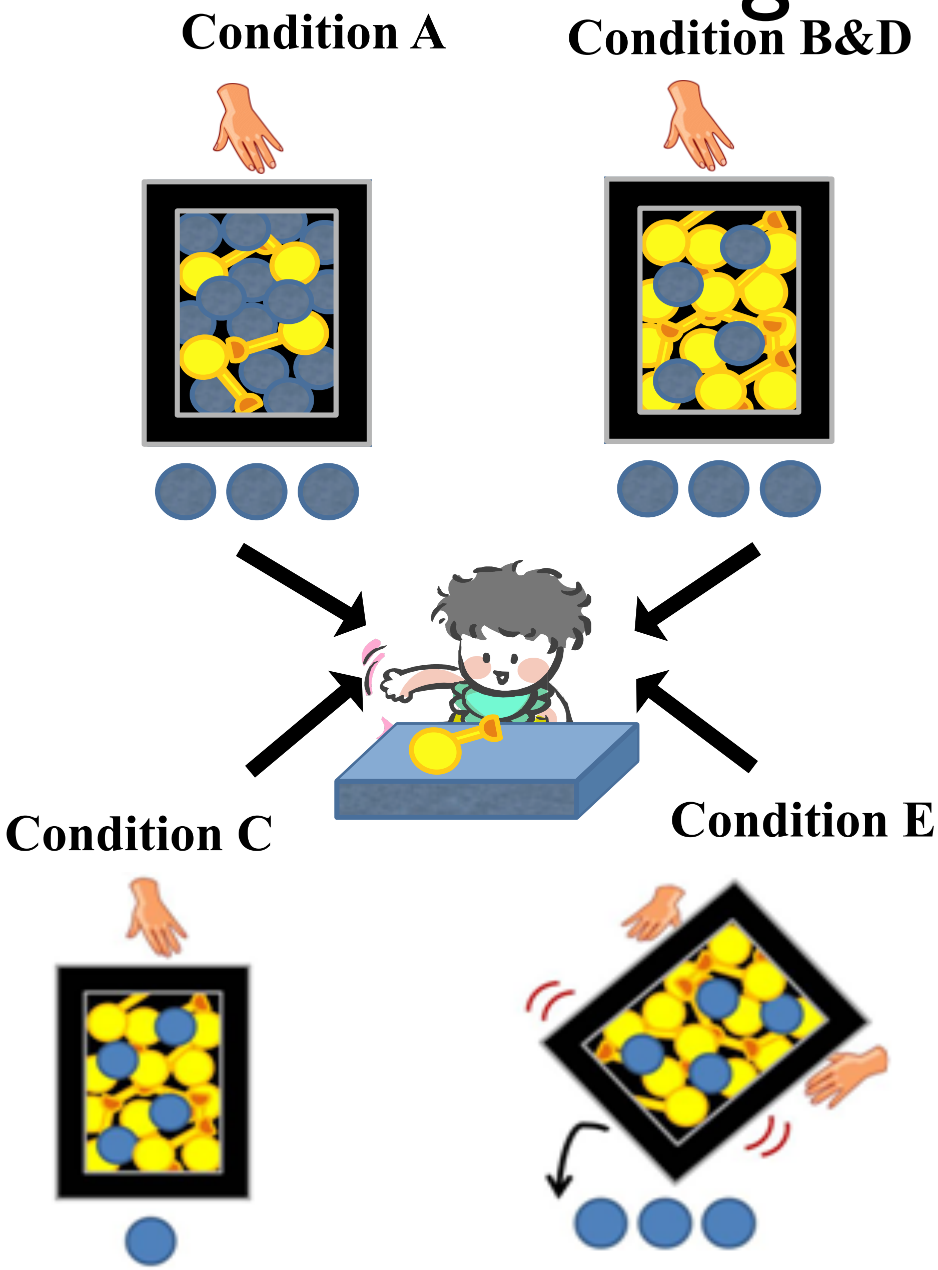
What if…

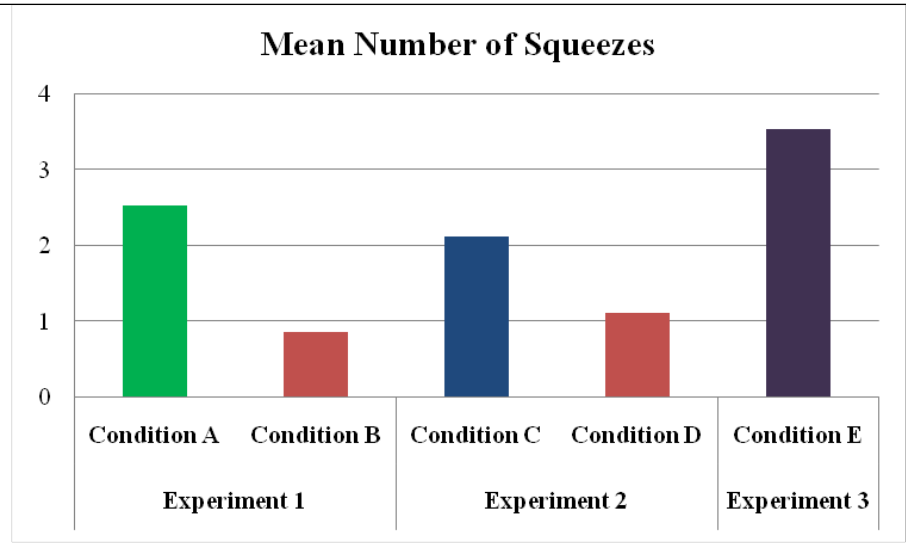
- Shake the box upside down
  - And three blue balls fall out?

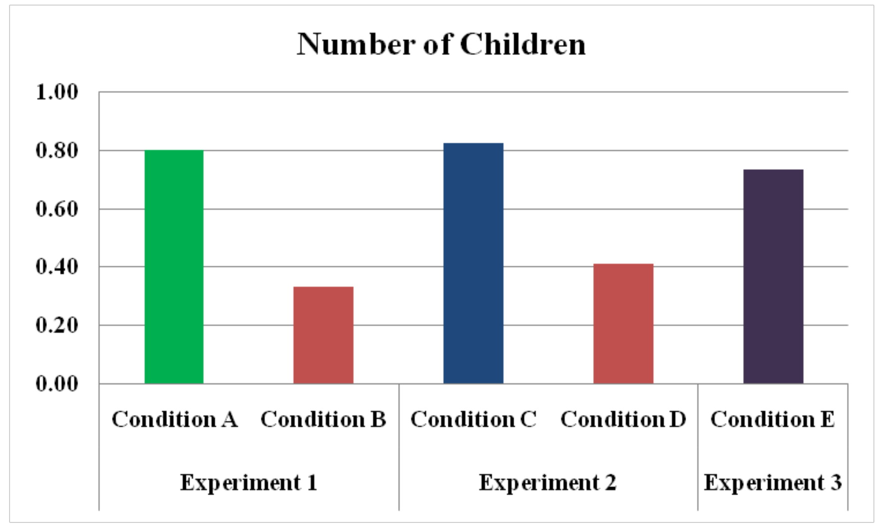


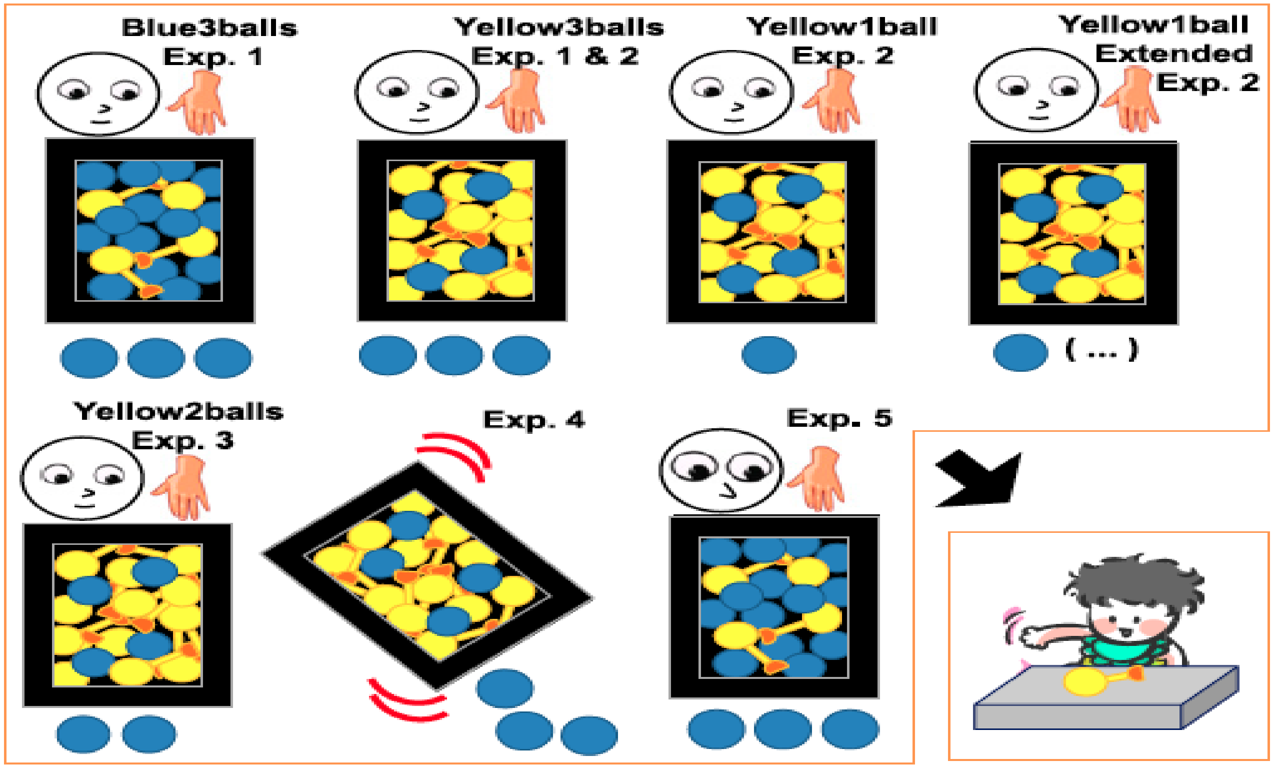
- Specifies that the balls had to be randomly sampled from the whole box.
  - Even though the sample is improbable, should generalize to whole box

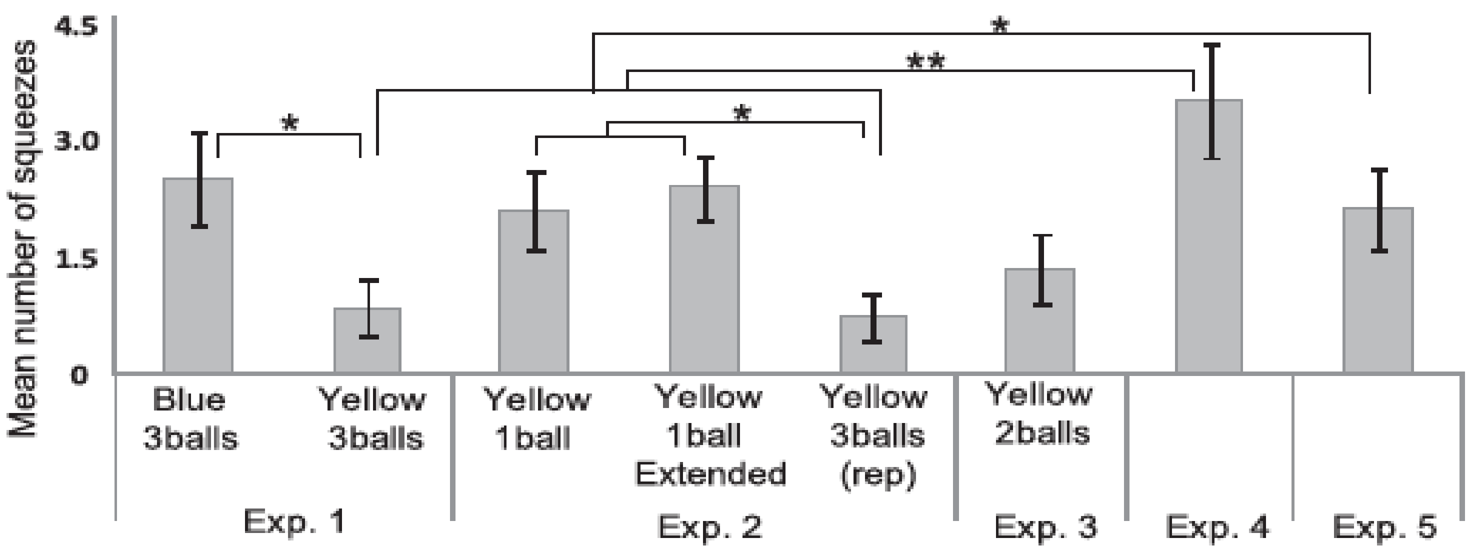
Design


Condition A
Condition B&D
Condition C
Condition E


Mean Number of Squeezes
0
1
2
3
4
Condition A
Condition B
Condition C
Condition D
Condition E
Experiment 1
Experiment 2
Experiment 3


Number of Children
0.00
0.20
0.40
0.60
0.80
1.00
Condition A
Condition B
Condition C
Condition D
Condition E
Experiment 1
Experiment 2
Experiment 3

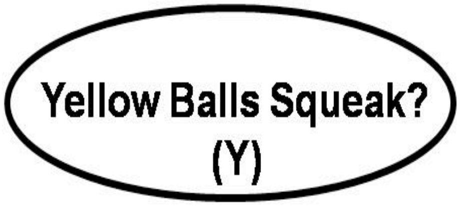




Gweon, Tenenbaum, & Schulz, PNAS, 2010

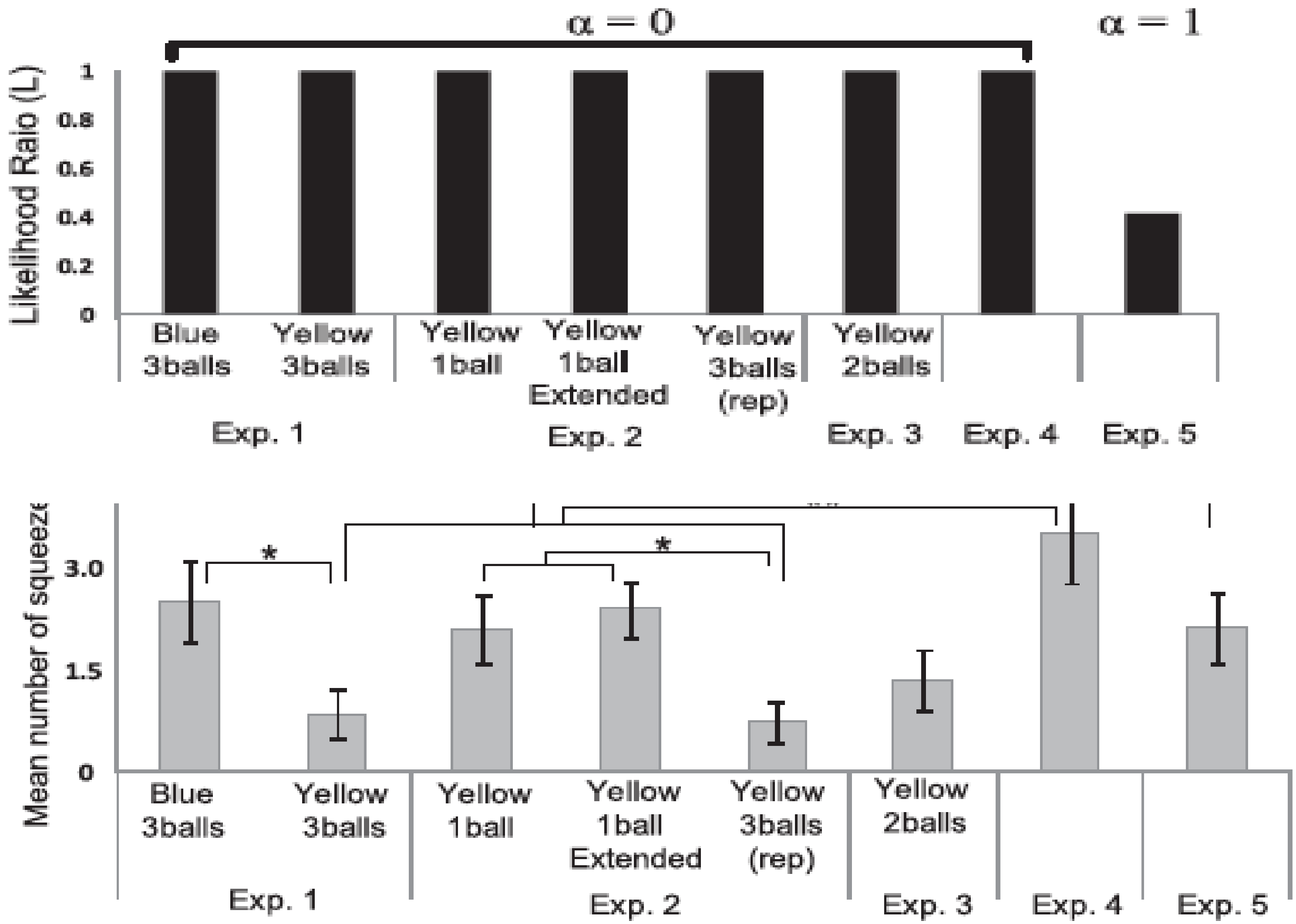
The inference problem

- Sampling process & Property extension



Gweon, Tenenbaum, & Schulz, PNAS, 2010

Model assuming weak sampling (agents choose at random from the whole population)



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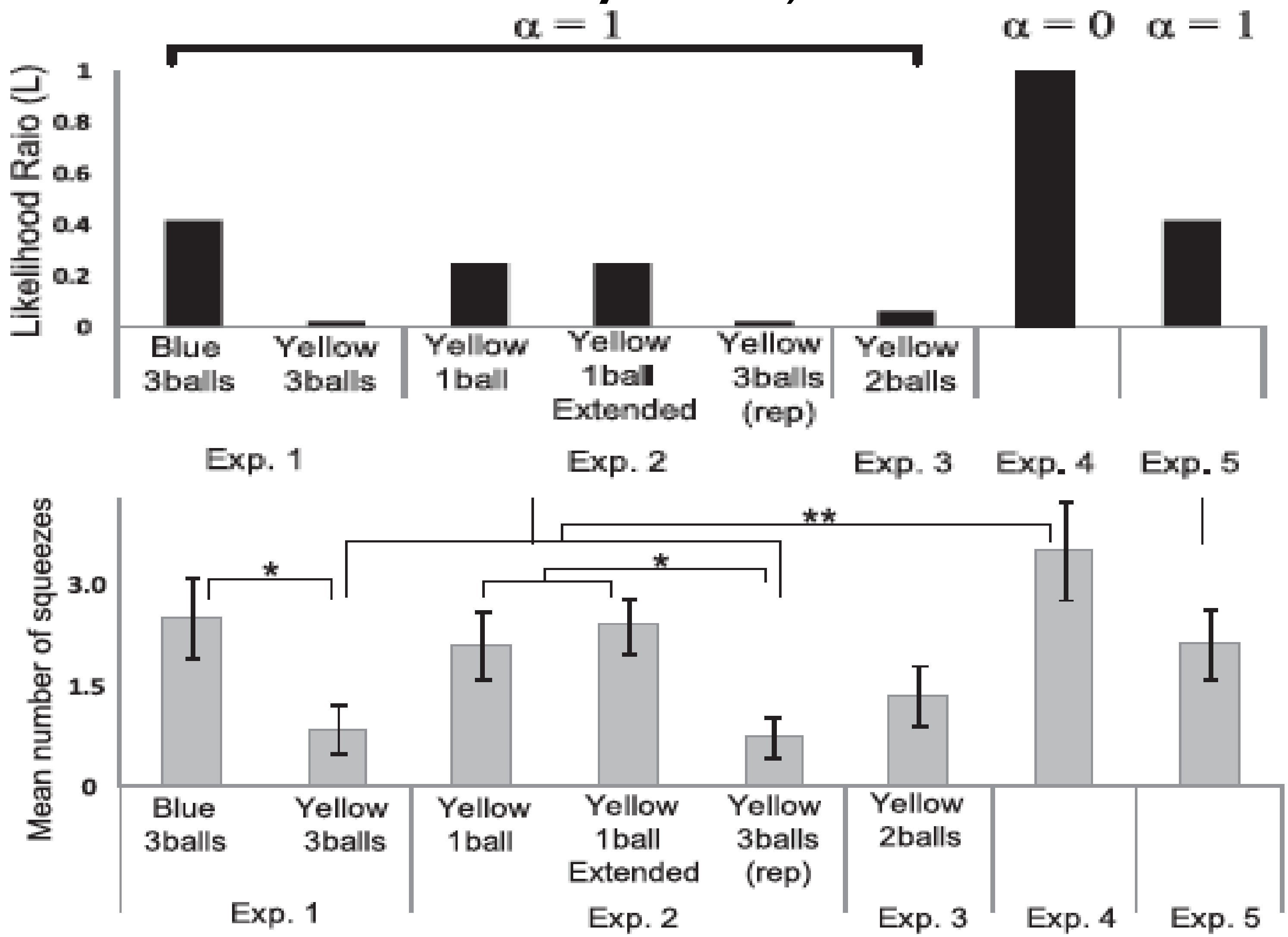
Model assuming strong sampling (agents sample items selectively depending on the properties they have)



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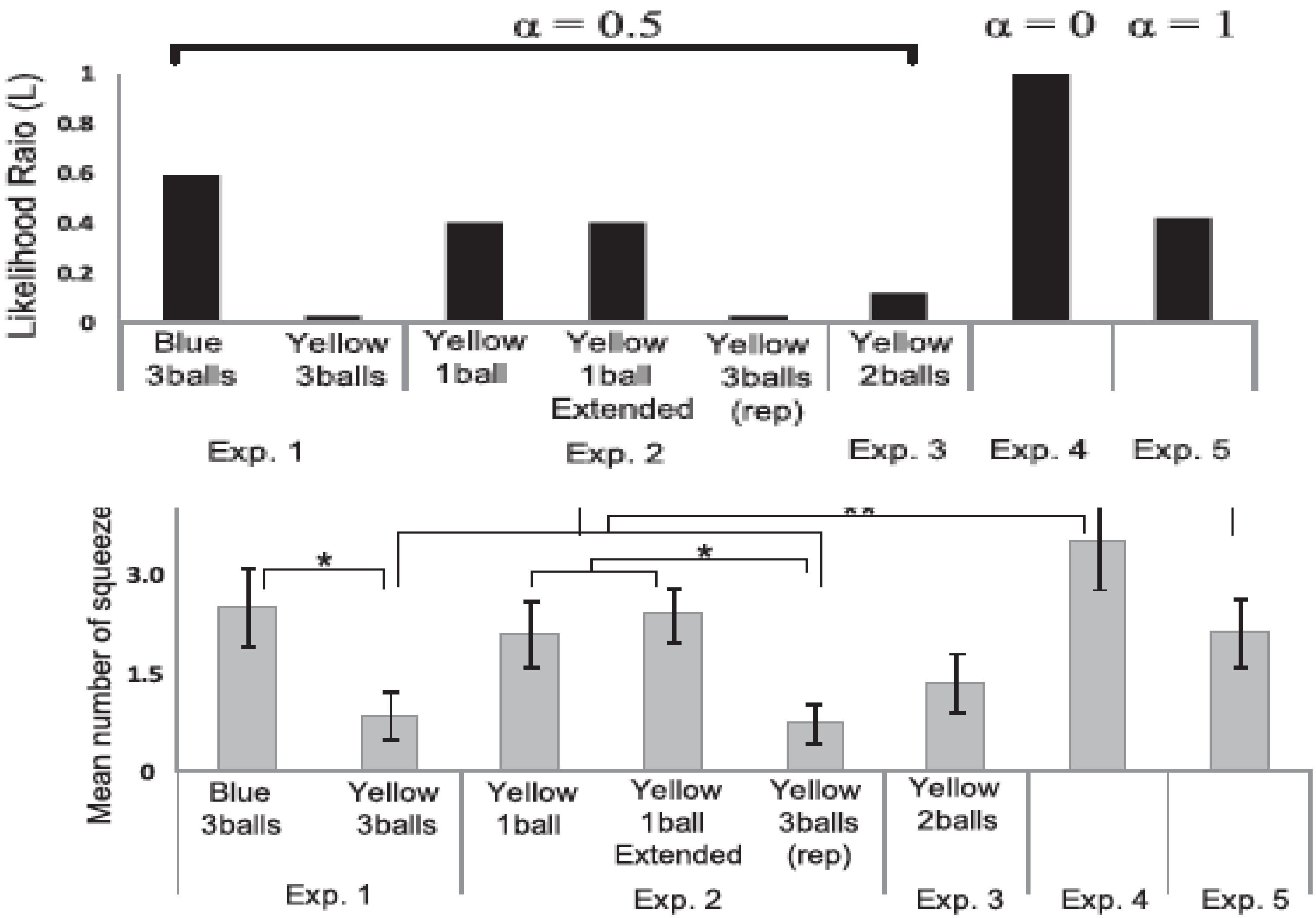
Model assuming joint inference



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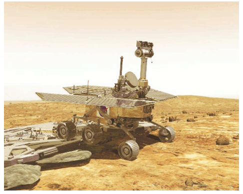
Child as scientist?

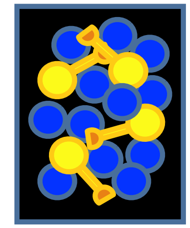


- 15-month-olds attend to more than the perceptual similarity of objects.

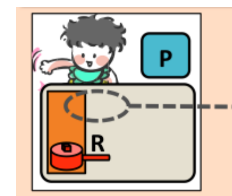
- Infants make graded inferences that are sensitive to both the amount of evidence they observe and the process by which the evidence is sampled.

Today's talk

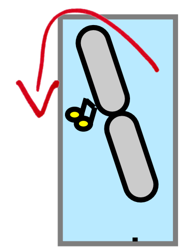
- Infants' generalizations depend on how evidence is sampled



- **Infants infer the relative probability of hypotheses and choose interventions most likely to achieve desired outcomes.**

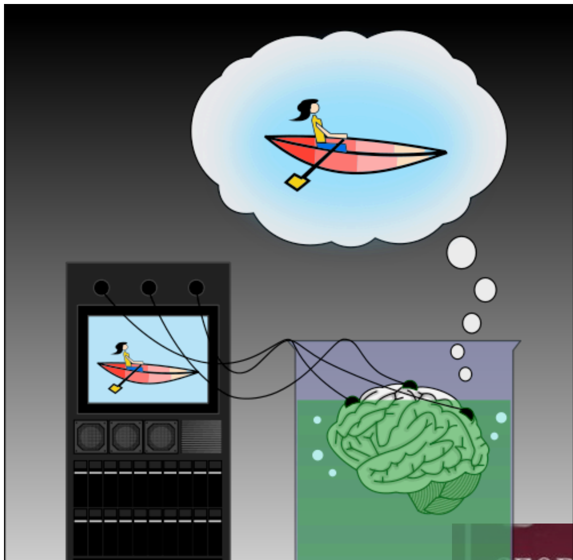


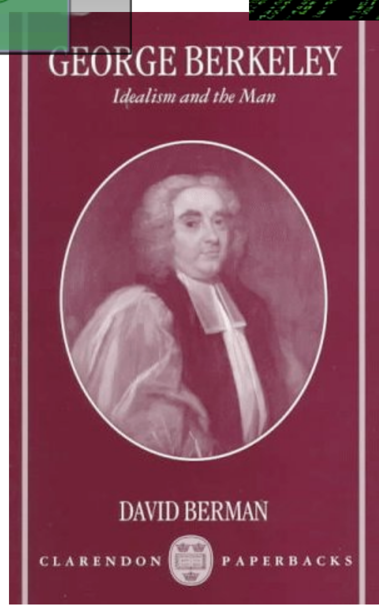
- Preschoolers' isolate variables to distinguish competing hypotheses



- Preschoolers rely on expert knowledge and trade-off instruction and exploration

Fundamental problem of confounding: us and the world

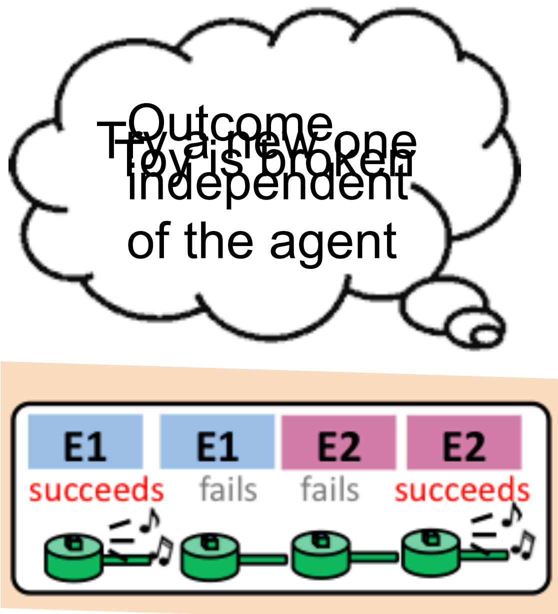


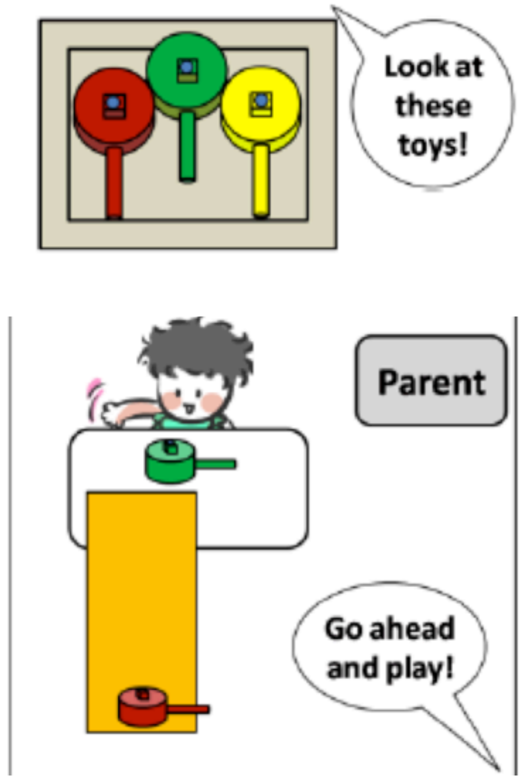


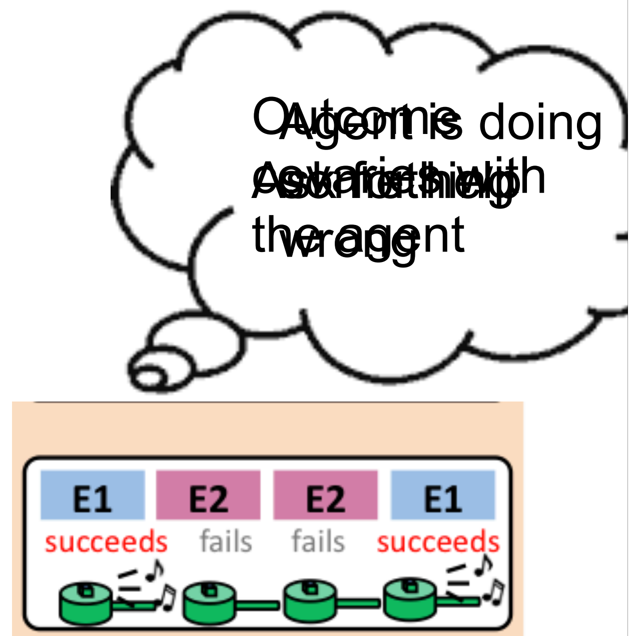
Samuel Johnson

Fundamental problem of confounding: us and the world

When you fail to achieve an expected outcome, did you do something wrong or is something wrong in the world?







Gweon & Schulz, 2011, Science

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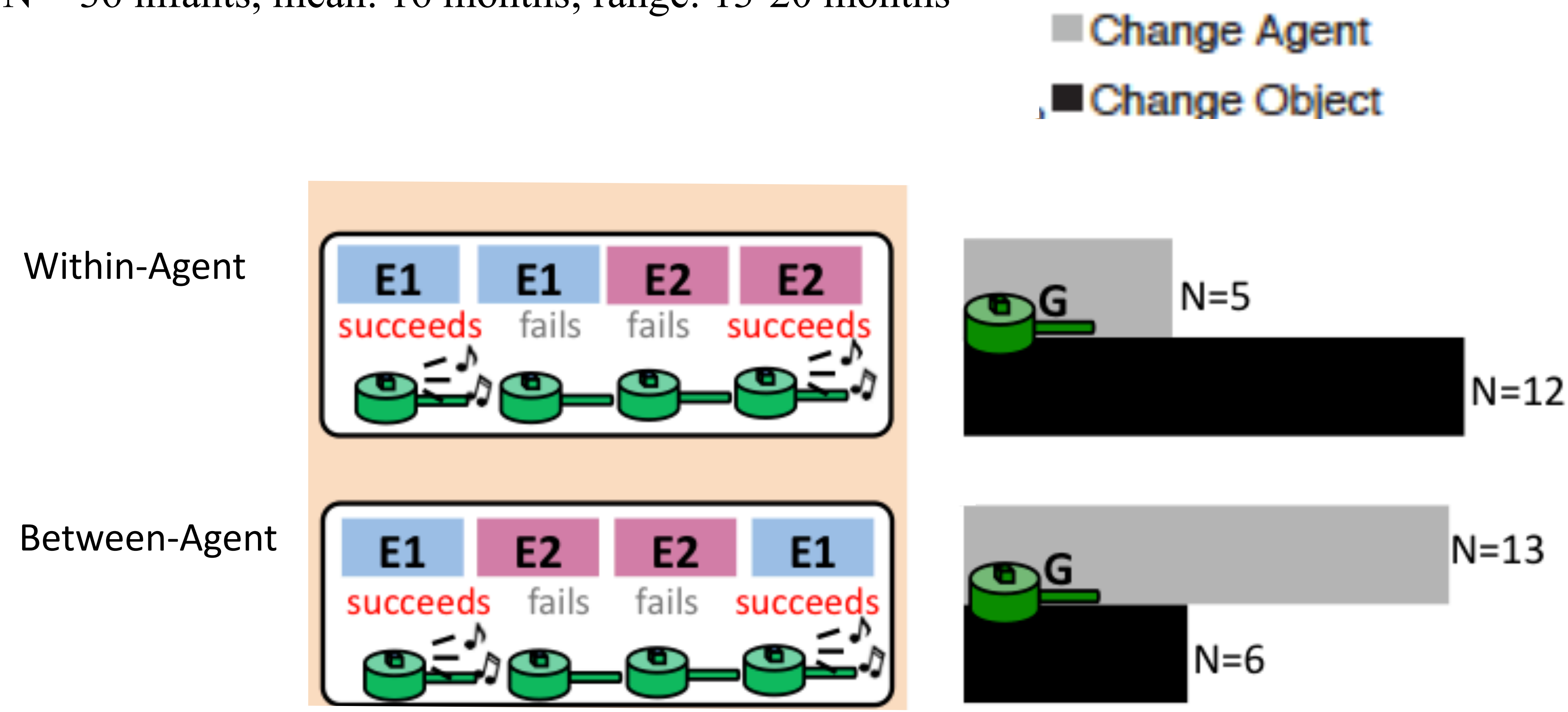
Results

N = 36 infants, mean: 16 months; range: 13-20 months



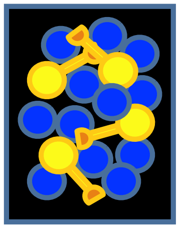
Gweon & Schulz, 2011, Science

Rational causal inference in infants

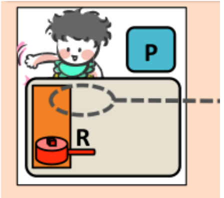
- 16-month-olds…
  - track the statistical dependence between agents, objects, and outcomes
  - can use minimal data to make rational attributions about the cause of failed goal-directed actions
- These distinct explanatory attributions (self vs. world) help them choose between two different strategies for learning
  - seeking instruction from others
  - self-guided exploration

Four quick examples

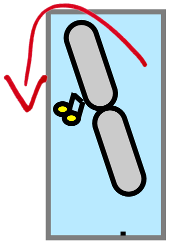
- Infants' generalizations depend on how evidence is sampled



- Infants infer the relative probability of hypotheses and choose interventions most likely to achieve desired outcomes.

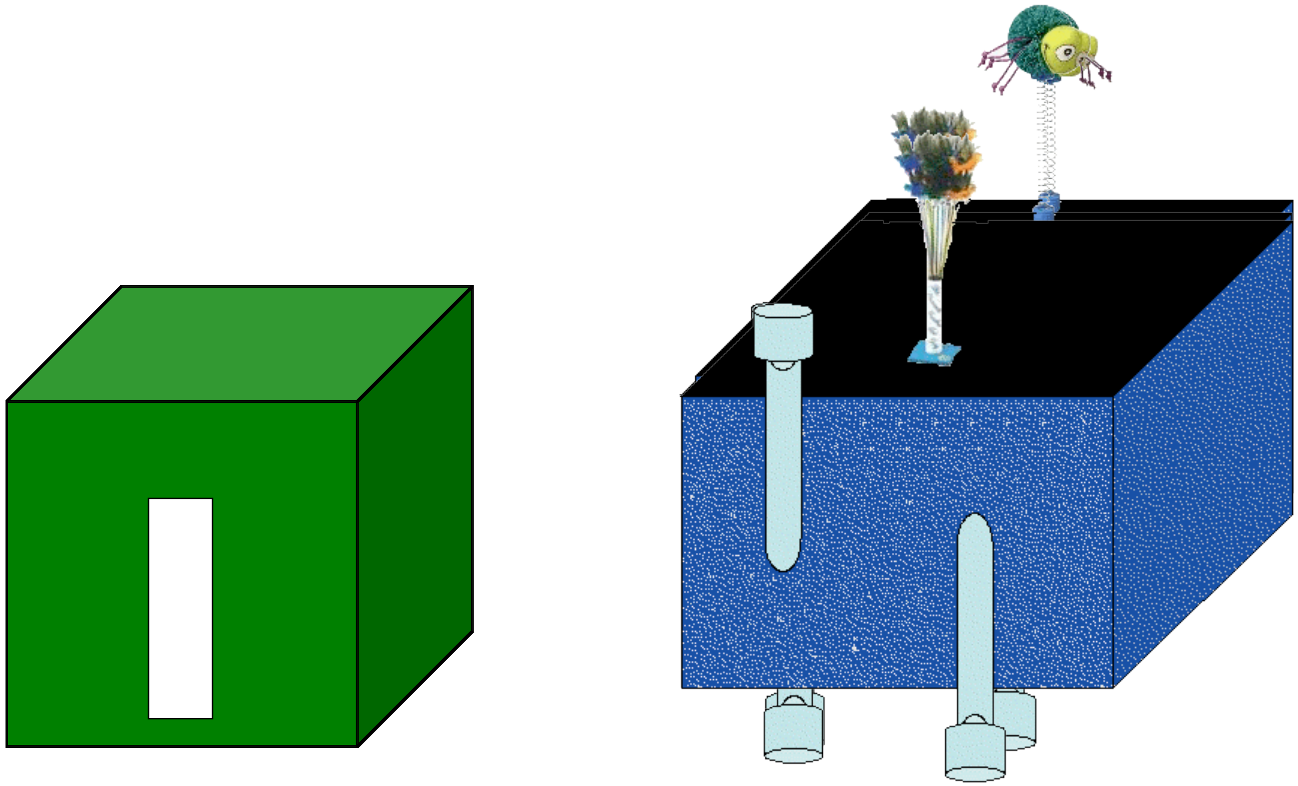


- **Preschoolers' isolate variables to distinguish competing hypotheses**



- Preschoolers rely on expert knowledge and trade-off instruction and exploration

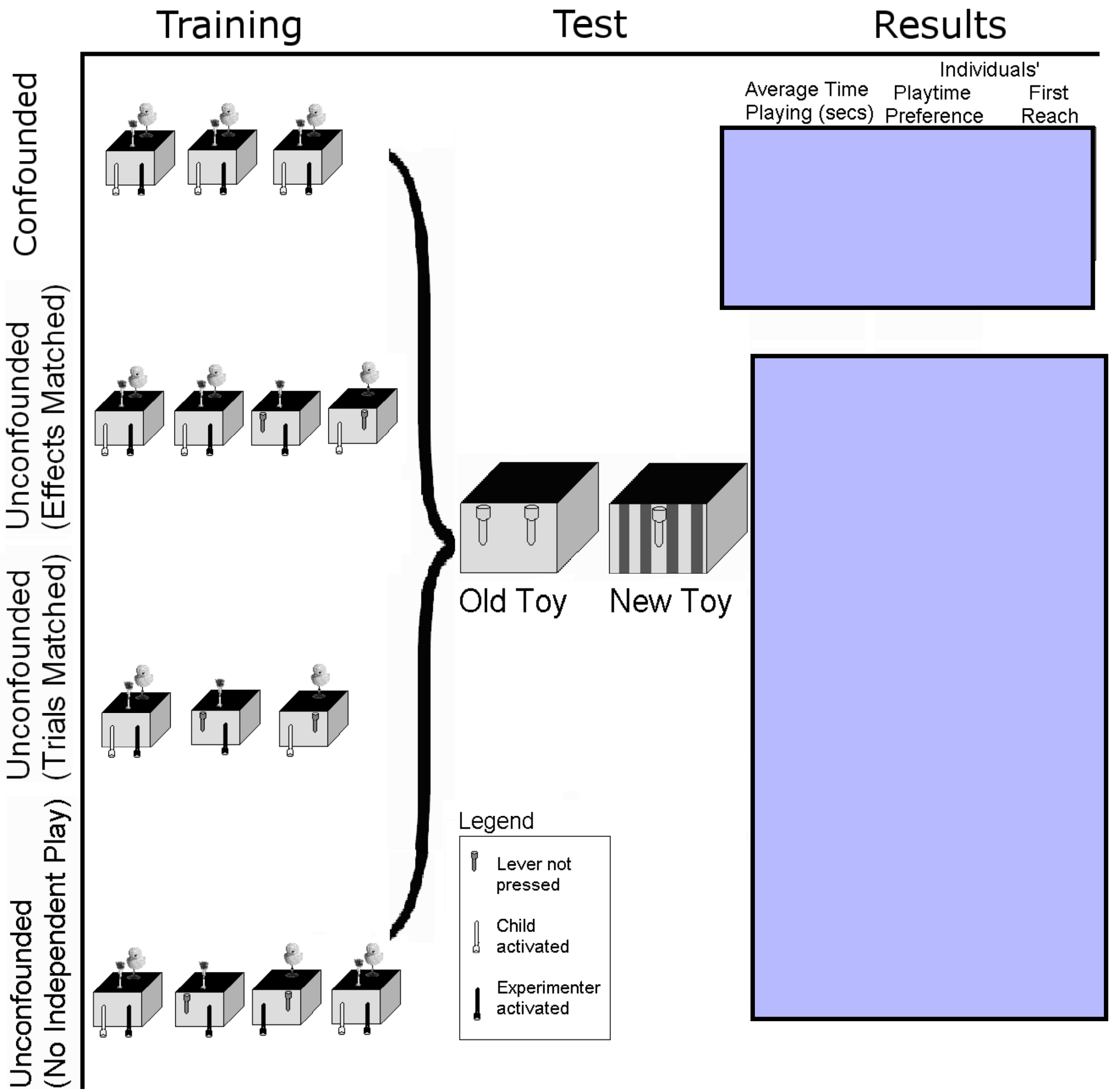
Children selectively engage in exploratory play when evidence fails to distinguish competing hypotheses (e.g., when evidence is confounded)



Unconfounded evidence

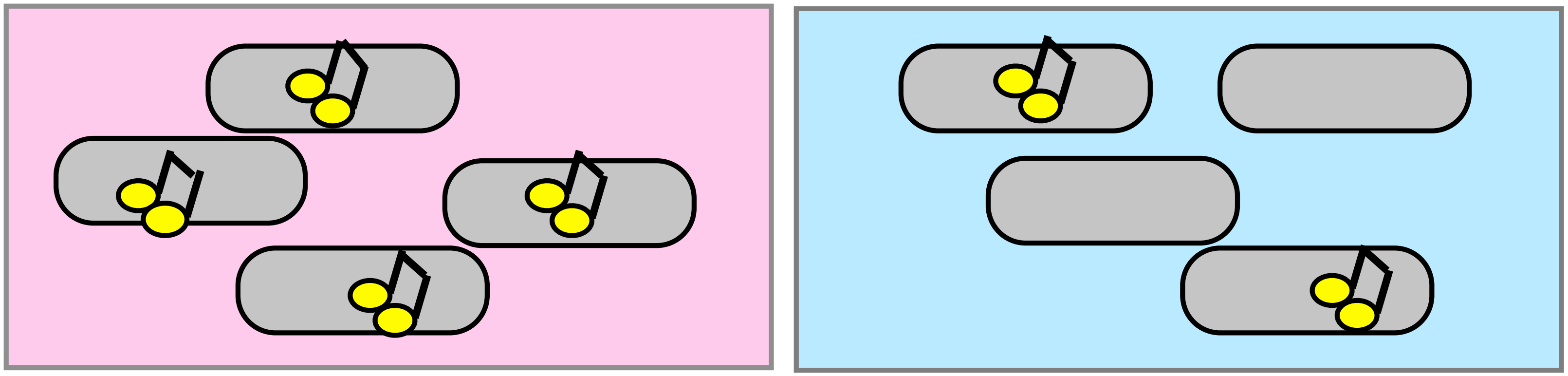
Confounded evidence

n = 16/condition
four & five-year-olds
mean: 57 months



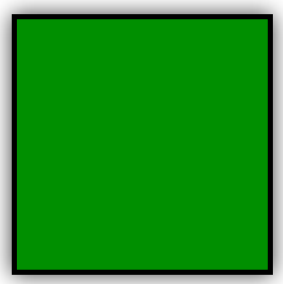
Schulz & Bonawitz, 2007, Developmental Psychology

Children assigned to one of two training conditions



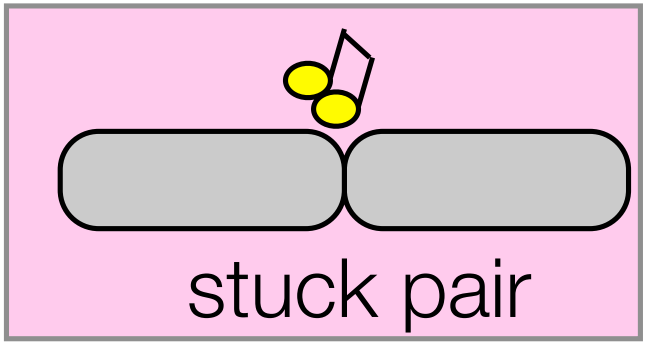
all beads condition

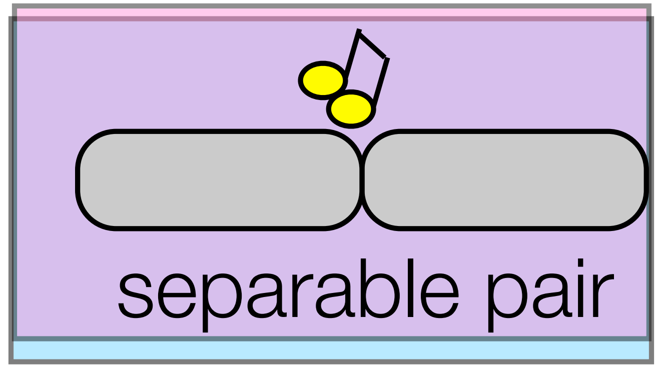
some beads condition



Cook, Goodman, & Schulz (in press) Cognition

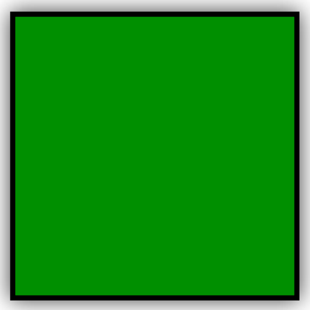
All children given the same test condition





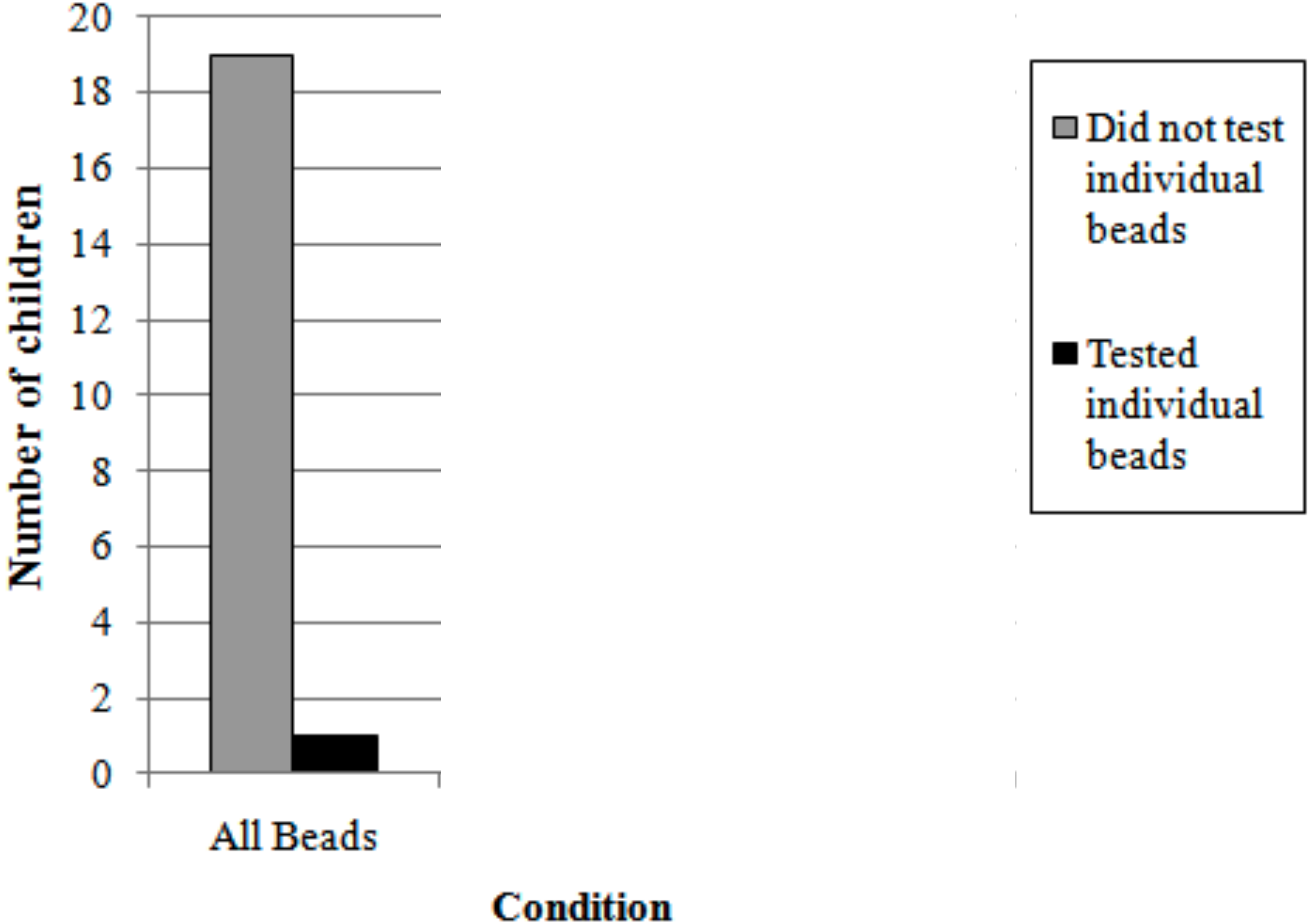
some beads condition

all beads condition



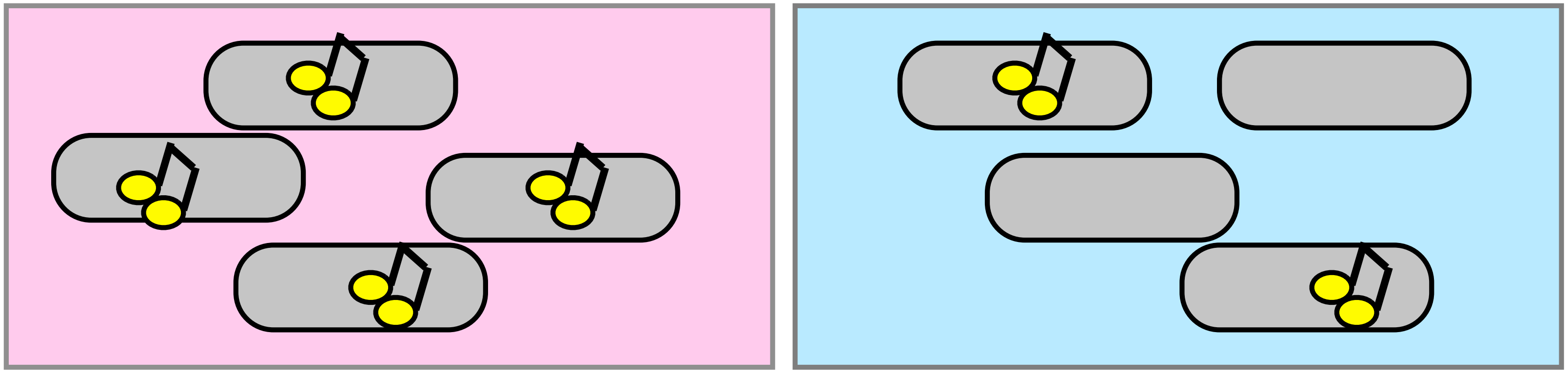
Cook, Goodman, & Schulz (in press) Cognition

n = 20/condition, mean: 54 months; range: 46-64 months



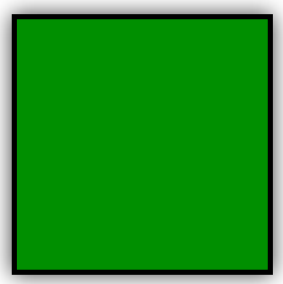
Cook, Goodman, & Schulz (in press) Cognition

Children assigned to one of two training conditions



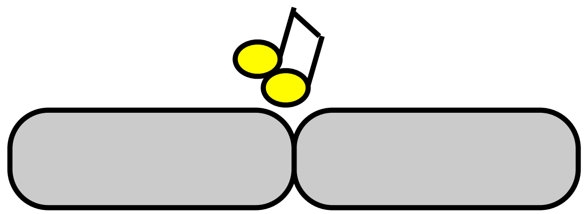
all beads condition

some beads condition

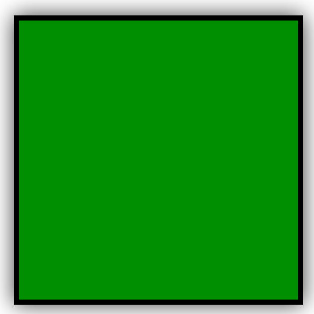


Cook, Goodman, & Schulz (in press) Cognition

All children given the same test condition

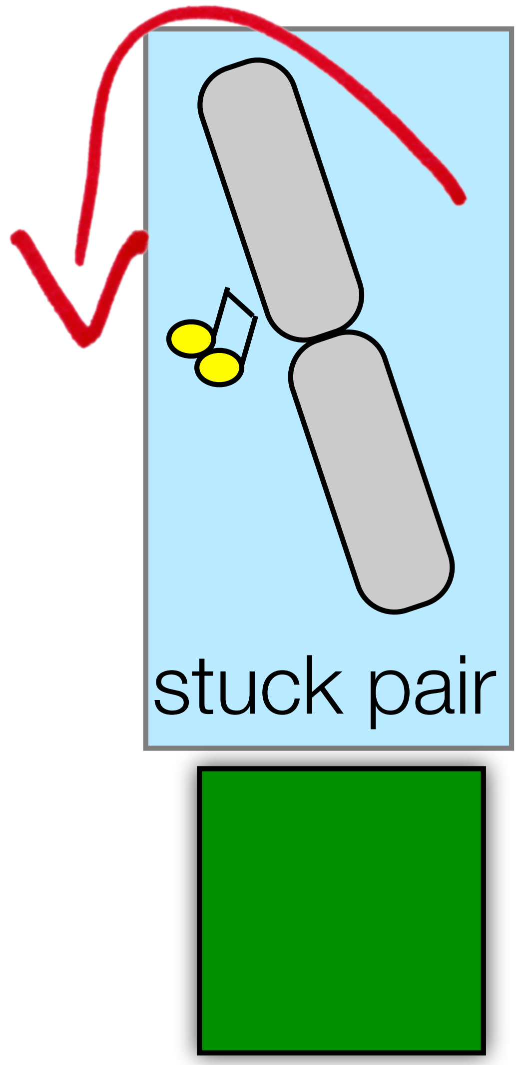


stuck pair



Cook, Goodman, & Schulz (in press) Cognition

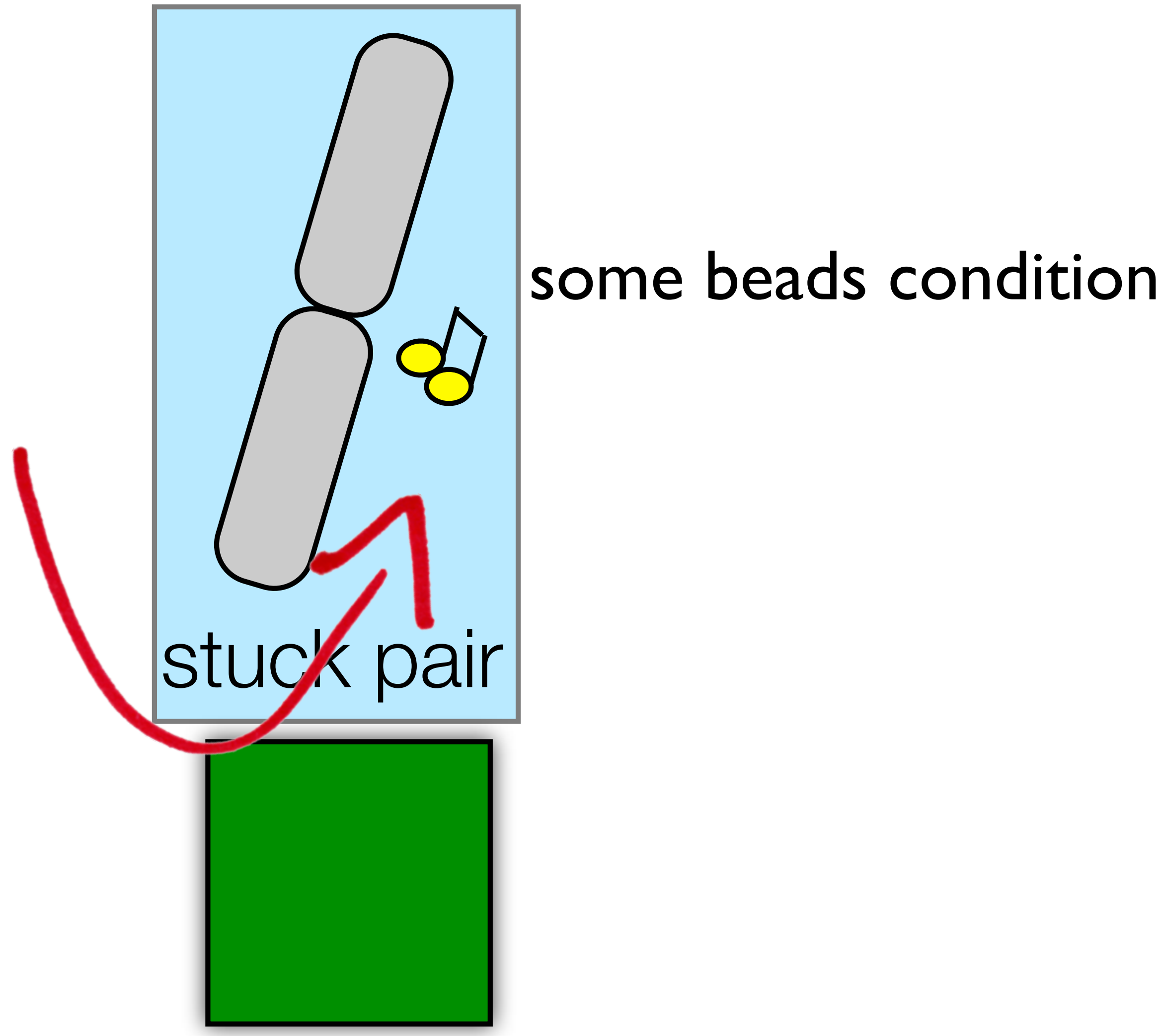
All children given the same test condition



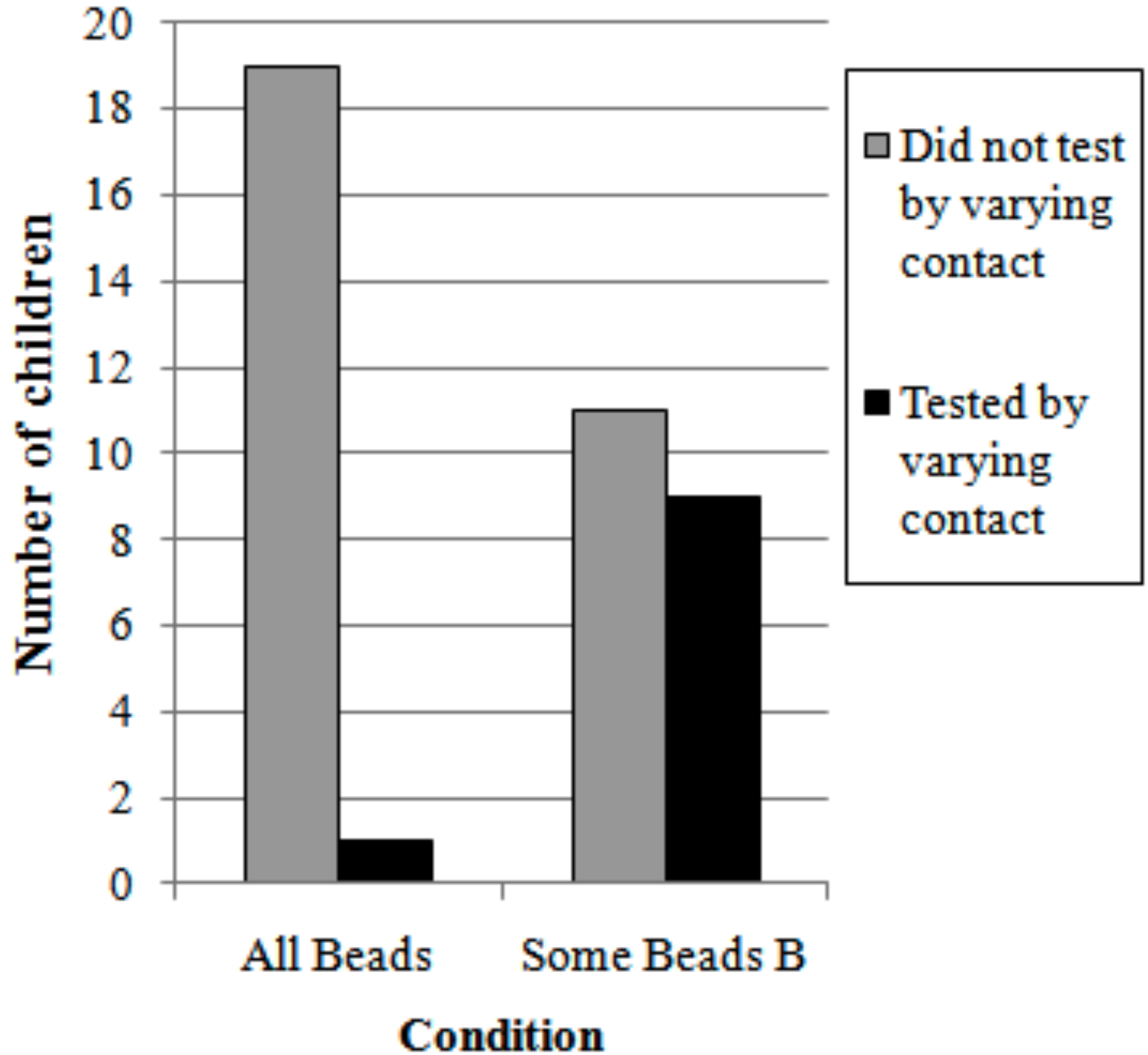
some beads condition

Cook, Goodman, & Schulz (in press) Cognition

All children given the same test condition



Cook, Goodman, & Schulz (in press) Cognition



Cook, Goodman, & Schulz (in press) Cognition

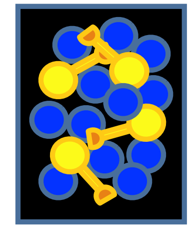
Conclusions

- Preschoolers can use information about the base rate of candidate causes to distinguish the relative ambiguity of evidence.

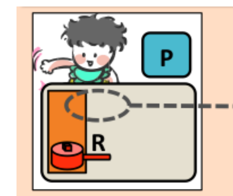
- Given ambiguous evidence, children select -- and design -- potentially informative interventions that isolate relevant causal variables.

Four quick examples

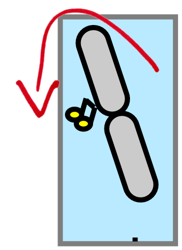
- Infants' generalizations depend on how evidence is sampled



- Infants infer the relative probability of hypotheses and choose interventions most likely to achieve desired outcomes.



- Preschoolers' isolate variables to distinguish competing hypotheses



- **Preschoolers rely on expert knowledge and trade-off instruction and exploration**

Assumptions about teaching

- Learner will rationally update her beliefs from evidence.
- The probability that a teacher will demonstrate some set of evidence is proportional to the probability that the learner will infer the target hypothesis given that evidence.

Bonawitz, Shafto, Gweon, Spelke, & Schulz (in press) Cognition

Assumptions about teaching

- If you assume that an adult is helpful and knowledgeable …
  - Can assume that evidence they show you is not only true
  - But helps distinguish the target hypothesis from other hypotheses.

Bonawitz, Shafto, Gweon, Spelke, & Schulz (in press) Cognition

Assumptions about pedagogy

- Thus for instance, if a knowledgeable teacher shows you n properties of a toy, should assume that there are not $n + 1$.
- If the same evidence is demonstrated by a naïve learner (or discovered by the child herself), should be much less likely to make this assumption (could well be more than n).
- Pedagogy strengthens the inference that absence of evidence is evidence of absence.

Bonawitz, Shafto, Gweon, Spelke, & Schulz (in press) Cognition

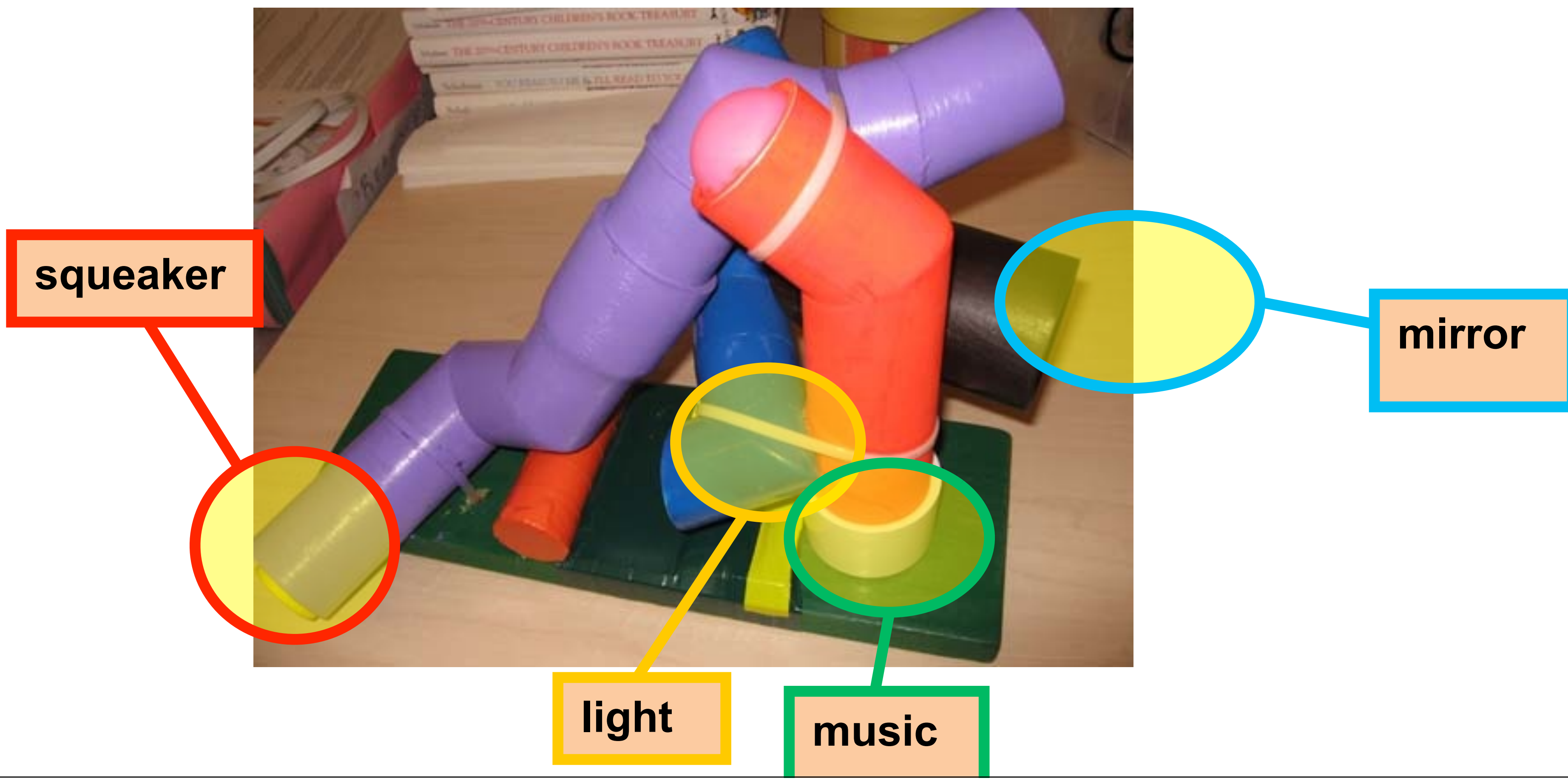
Predicts a trade-off between instruction and exploration

- If a knowledgeable teacher demonstrates properties of a toy, children should not engage in additional exploration.
- If a naïve learner demonstrates the same properties, children should make no such assumption and should explore broadly.

Bonawitz, Shafto, Gweon, Spelke, & Schulz (in press) Cognition

PEDAGOGICAL	ACCIDENTAL	NO DEMO	INTERRUPTED
"**Watch this**, I'm going to show you **my** toy." [**intentionally pull tube**] "Wow, see that?"	"Look at this neat toy I found here." [**accidentally pull tube**] "Wow, see that?"	"Look at this neat toy that I have." [rotate toy for child] "Wow, see that?"	Identical to Pedagogical except interrupted immediately after "Wow, see that?"

- Four interesting properties



Pedagogical Condition

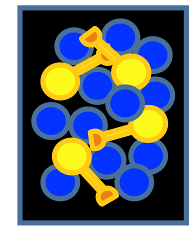
Rational (but challenging) trade-offs between instruction and exploration

The principal goal of education is to create men who are capable of doing new things, not simply of repeating what other generations have done - men who are creative, inventive and discoverers.

Jean Piaget.

Four quick examples

- Infants’ generalizations depend on how evidence is sampled



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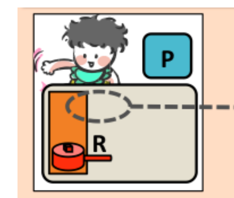
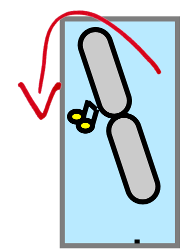


- Preschoolers’ isolate variables to distinguish competing hypotheses

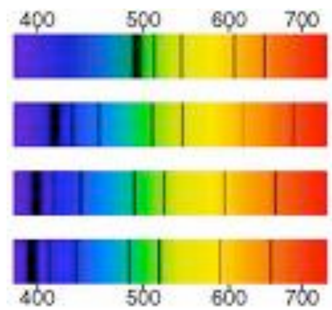


- Preschoolers rely on expert knowledge and trade-off instruction and exploration

Back to intelligence ...

- Big mysteries remain ... in particular, how do learners generate new hypotheses? Where do new ideas come from?
    - How do we know when we are on the right track?
    - How do we distinguish “good” wrong ideas from “bad” ones?
    - How do we sometimes know we’ve arrived at the solution to a problem even before we have access to new evidence?

"There is something fascinating about science, one gets such wholesale returns of conjecture out of such a trifling investment in fact" (Mark Twain, 1883)

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Thank you to co-authors Elizabeth Bonawitz, Claire Cook, Noah Goodman, Hyo Won Gweon, Pat Shafto, Elizabeth Spelke, and Josh Tenenbaum

members of the ECCL, many outstanding UROP's and participating parents and children at the Museum of Science, Boston and the Boston Children's Museum

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