“Instead of trying to produce a programme to simulate the adult mind, why not rather try to produce one which simulates the child's?”
Alan Turing, 1950.

AI Learning

- Deep learning, reinforcement learning, Supervised learning
- Needs lots of data
- Not much (or right) generalization
- Computationally tractable

2-year-olds' learning

- Very little data
- Excellent generalizations
- Search and sampling
- Computationally intractable

DARPA Machine Common Sense: MESS Model-building, exploratory, social learning systems

- **Abstract causal models from statistical evidence**
- **Active learning through exploratory play**
- Social learning through imitation and testimony

Probabilistic Causal Models in Children (Pearl, 2000, Spirtes et al. 2001, Gopnik & Wellman, 2012, Gopnik 2020)

Four-year-olds (and younger) can rationally

- Infer complex causal structure (chains versus common effects vs common causes) from conditional probabilities (Schulz et al. 2007)
- Integrate and override prior causal knowledge in the face of new evidence (Kushnir & Gopnik, 2007, Griffiths et al. 2011)
- Infer unobserved causal structure (Gopnik et al. 2004)
- Infer causal theories of the physical, biological, psychological and social domains (Schulz & Gopnik, 2004, Kushnir et al. 2010, Seiver et al. 2013, Vasilyeva et al. 2018)
- Infer and use counterfactuals (Buchsbaum et al. 2012)
- Infer abstract over-hypotheses (Lucas et al. 2014, Gopnik et al. 2017)

Variable Selection and Analogical Reasoning

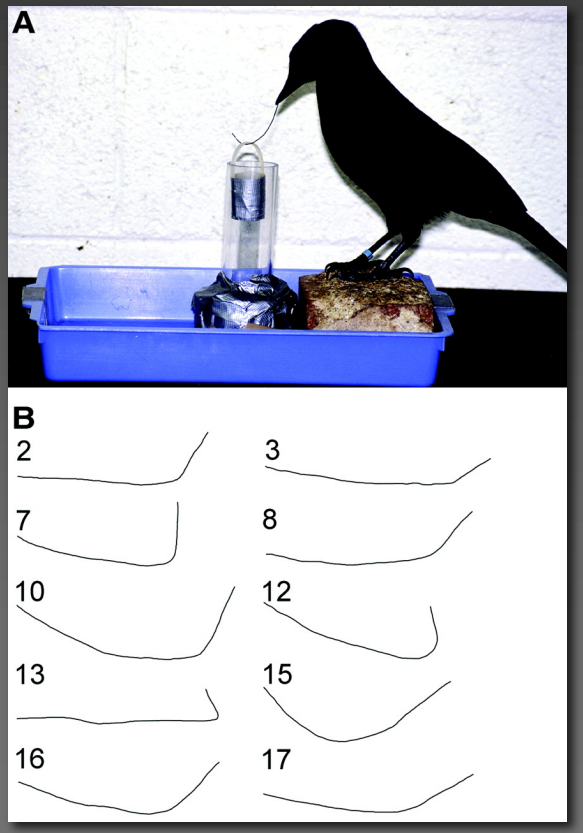
- M. Goddu, & A. Gopnik. (2020) Learning what to change: Young children use 'difference-making' to identify causally relevant variables. *Developmental Psychology, 56, 2, 275* ***DOI****:10.1037/dev0000872*
- M. Goddu, T. Lombrozo, & A. Gopnik. (2020). Transformations and transfer: Preschool children understand abstract relations and reason analogically in a causal task. *Child Development. 91, 6, 1898-1915, DOI: 10.1111/cdev.13412*

Intervention, Exploration and Active Learning

- Schulz et al. 2007
- Schulz & Bonawitz, 2007
- Bonawitz et al. 2012
- Ruggieri et al. 2015, 2019

The Explore-Exploit Problem

Longer Childhood, Larger Brain, Smarter Animal



Hypothesis

Childhood is evolution's way of resolving explore/exploit trade-offs and performing simulated annealing.

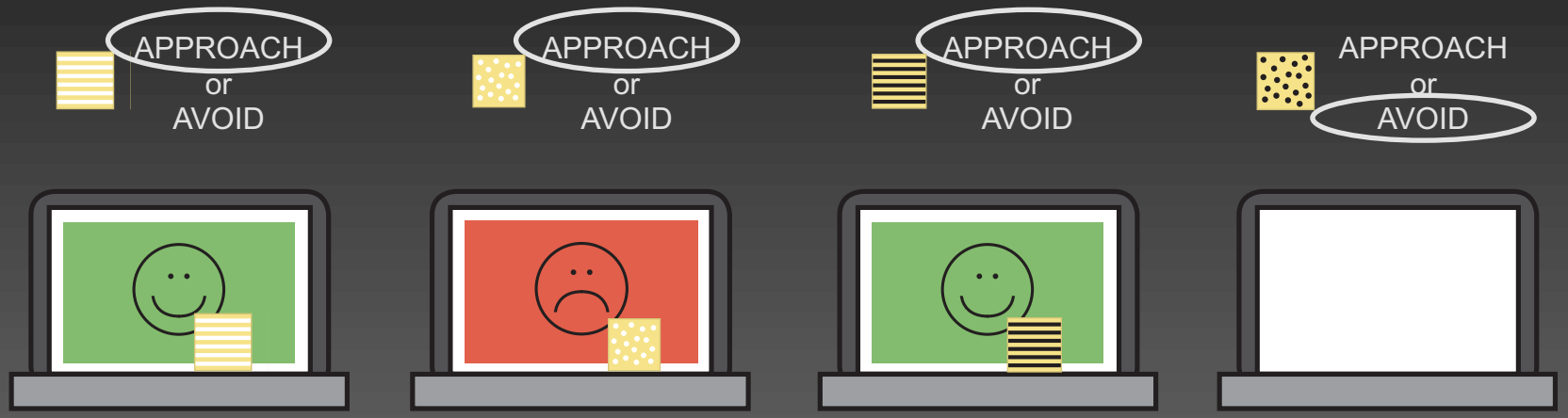
Gopnik et al. 2017, PNAS, Gopnik, Philosophical Transactions of the Royal Society B, 2020

Explore Features, Exploit Bugs

- Noisiness, variability, randomness
- Risk-taking
- Impulsivity
- Play
- Curiosity

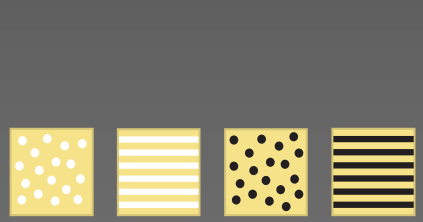
The Blicket Detector

Liquin & Gopnik: Children are more exploratory and learn more than adults in an approach-avoid task. *Cognition,* Volume 218, January 2022, 104940 Cognition 2021

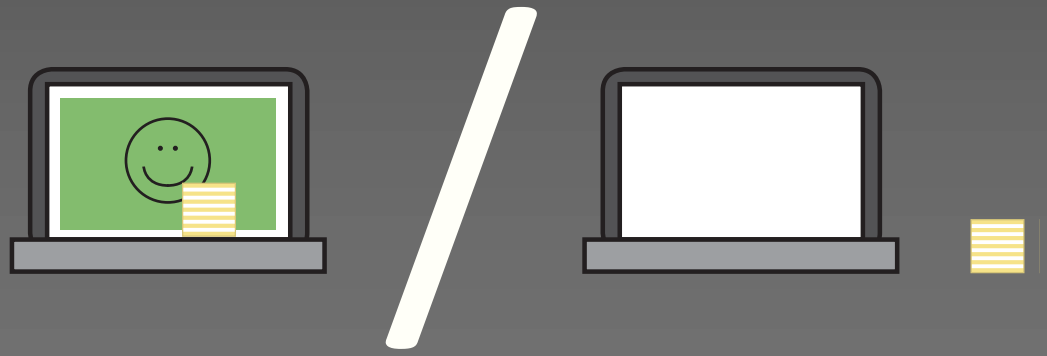


Actual Outcome:

Stickers:



x 4 sets

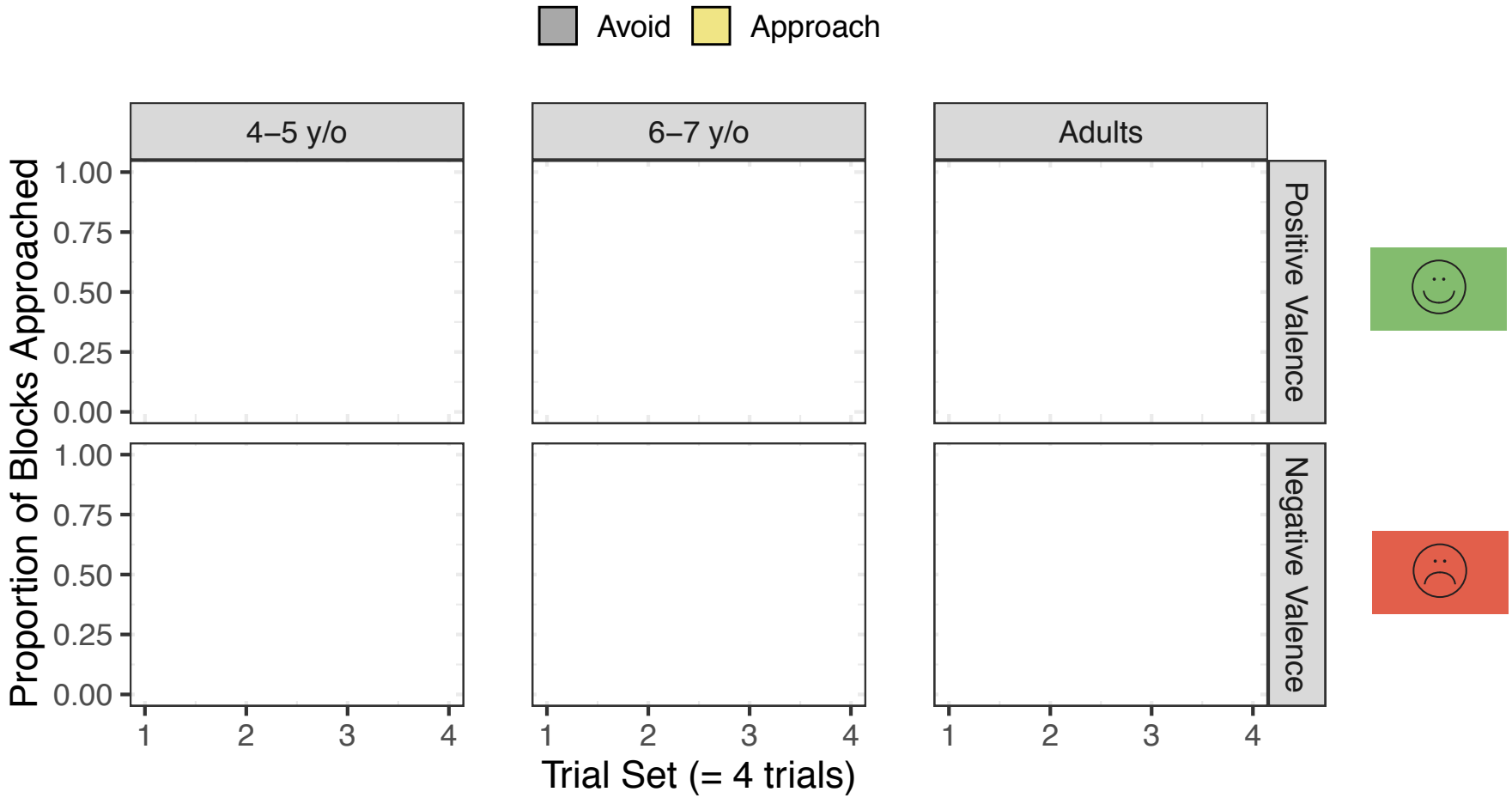


"Approach"

"Avoid"

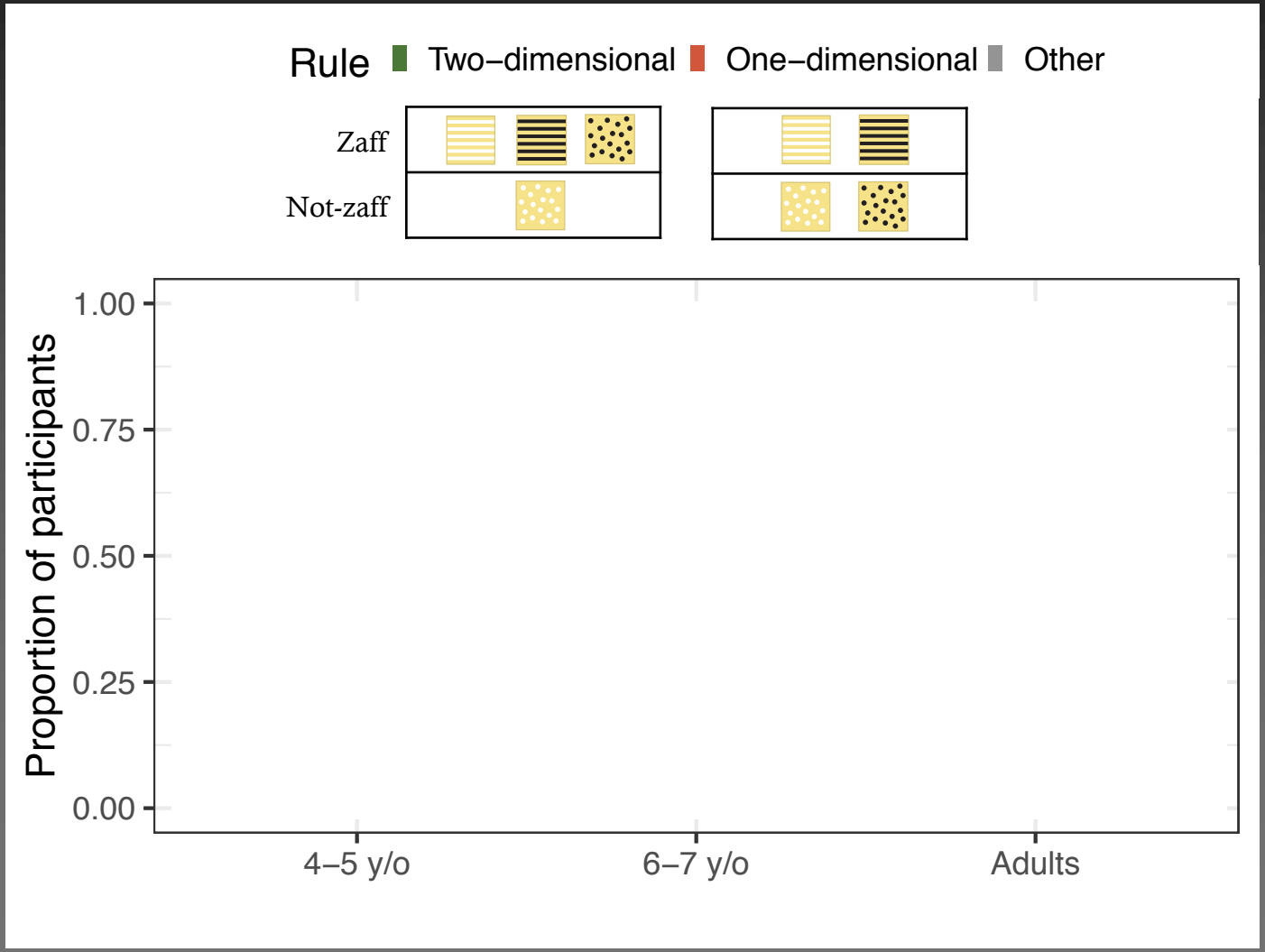
(Rich & Gureckis, 2018)

Approach/Avoid Decisions



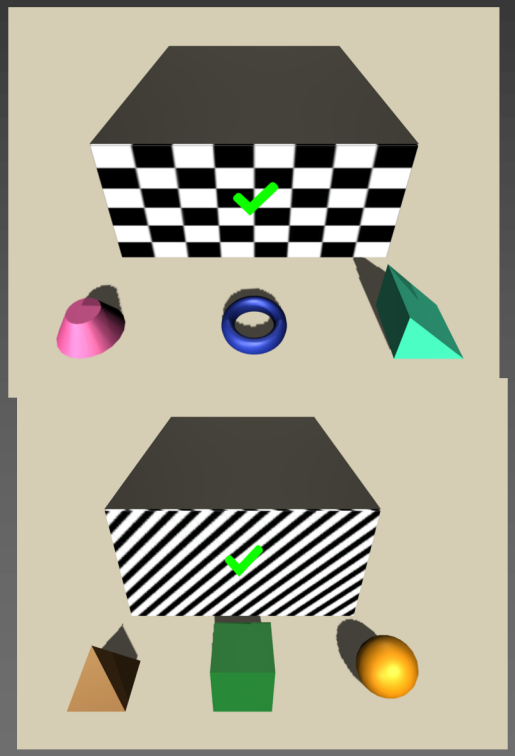
Positive Blocks: Age Group $F(2,106) = 28.41$, $p < .001$***
Negative Blocks: Age Group $F(2,105) = 14.05$, $p < .001$***

Is this reflected in learning?



$\chi^2(2) = 17.33, p < .001^{***}$

EXP outline:

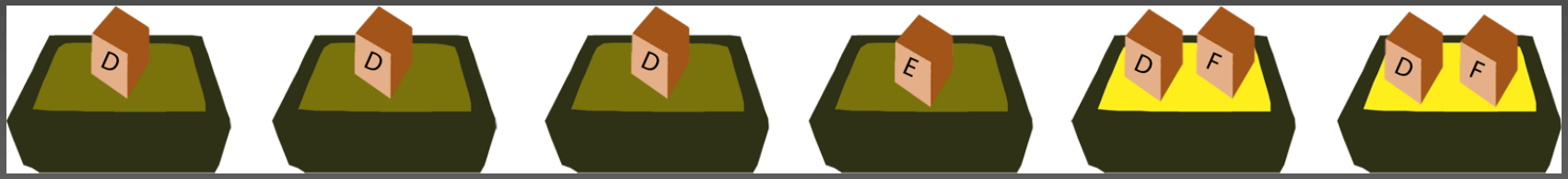


	CONJUNCTIVE	DISJUNCTIVE
GIVEN HYPOTHESIS SPACE	**A3:** Blocks DEF Blickets are D&E **N: 22** Turns on: DE, DEF Does not turn on: D,E,F,DF, EF *Predictions: kids will try objects 1 by 1 until they see that non make it go, then do they switch to try combinations of blocks, might do it here since we gave them evidence*	**A4:** Blocks DEF Blickets are D'or'E **N: 23** Turns on: D,DE,DEF,E,EF,DF Does not turn on:F *Predictions: they try objects 1 by 1, see it works, stop there*
NOT GIVEN HYPOTHESIS SPACE	**B3:** Blocks DEF Blickets are D&E **N:20** Turns on: DE,DEF Does not turn on: D,E,F,DF,EF *Predictions: kids will try objects 1 by 1 until they see that non make it go, then do they switch to try combinations of blocks, might do it here since we gave them evidence*	**B4:** Blocks DEF Blickets are D 'or' E **N:20** Turns on:D,DE,DEF,E,EF,DF Does not turn on:F *Predictions: they try objects 1 by 1, see it works, stop there*

When Younger Learners are More Exploratory

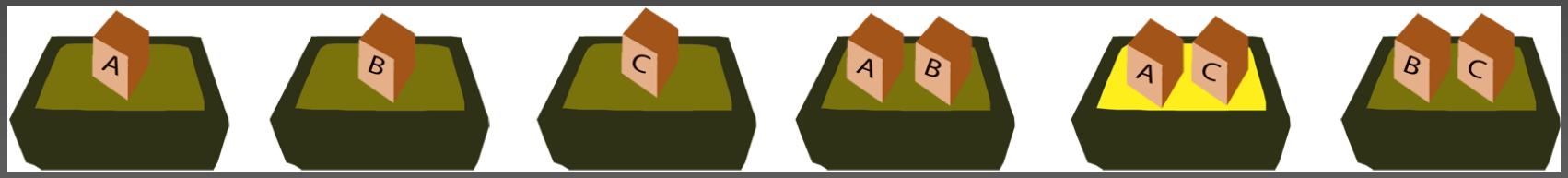
- A. Gopnik, T. Griffiths, & C. Lucas (2015). *Current Directions in Psychological Science*, *24* (2), 87-92
- C. Lucas, S. Bridgers, T. Griffiths, & A. Gopnik (2014). *Cognition*. 131, 2, 284–299.
- A. Gopnik, S. O'Grady, C. Lucas, T. Griffiths A. Wente, S. Bridgers, R. Aboody, H. Fung, R. E. Dahl, (2017). *PNAS*.

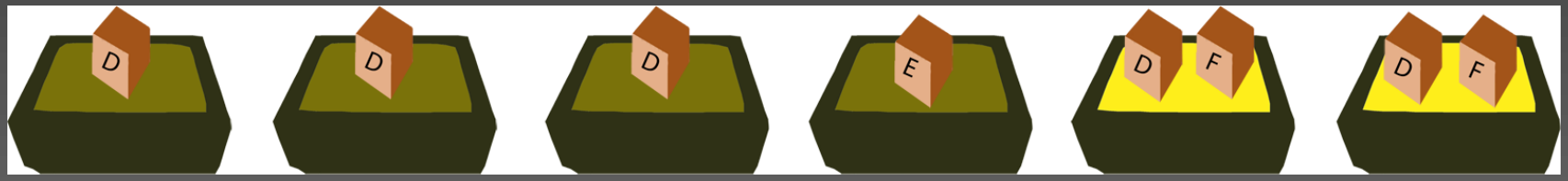
Which objects are blickets?



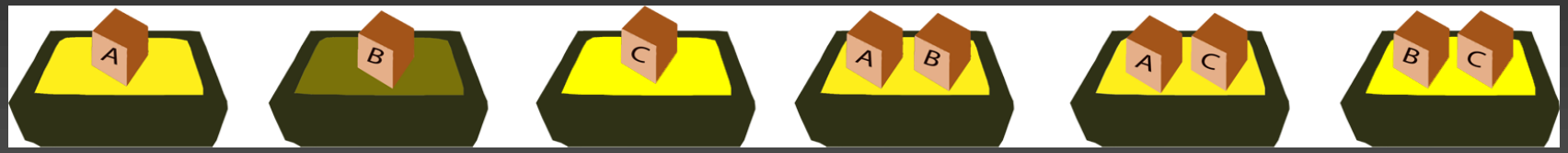
Is D a blicket? Is E a blicket? Is F a blicket?

What if you also saw these events?

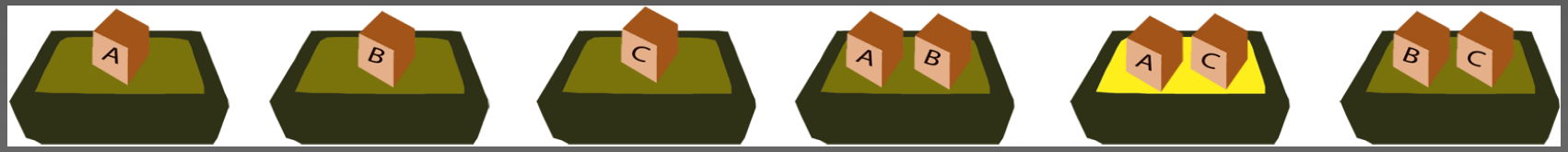



D
D
D
E
D
F
D
F

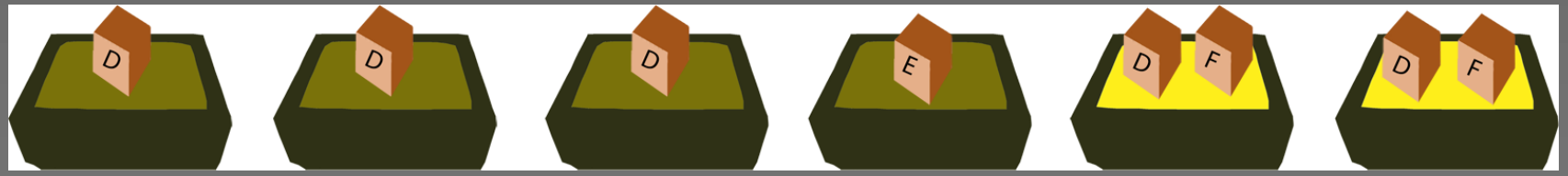
Disjunctive Training



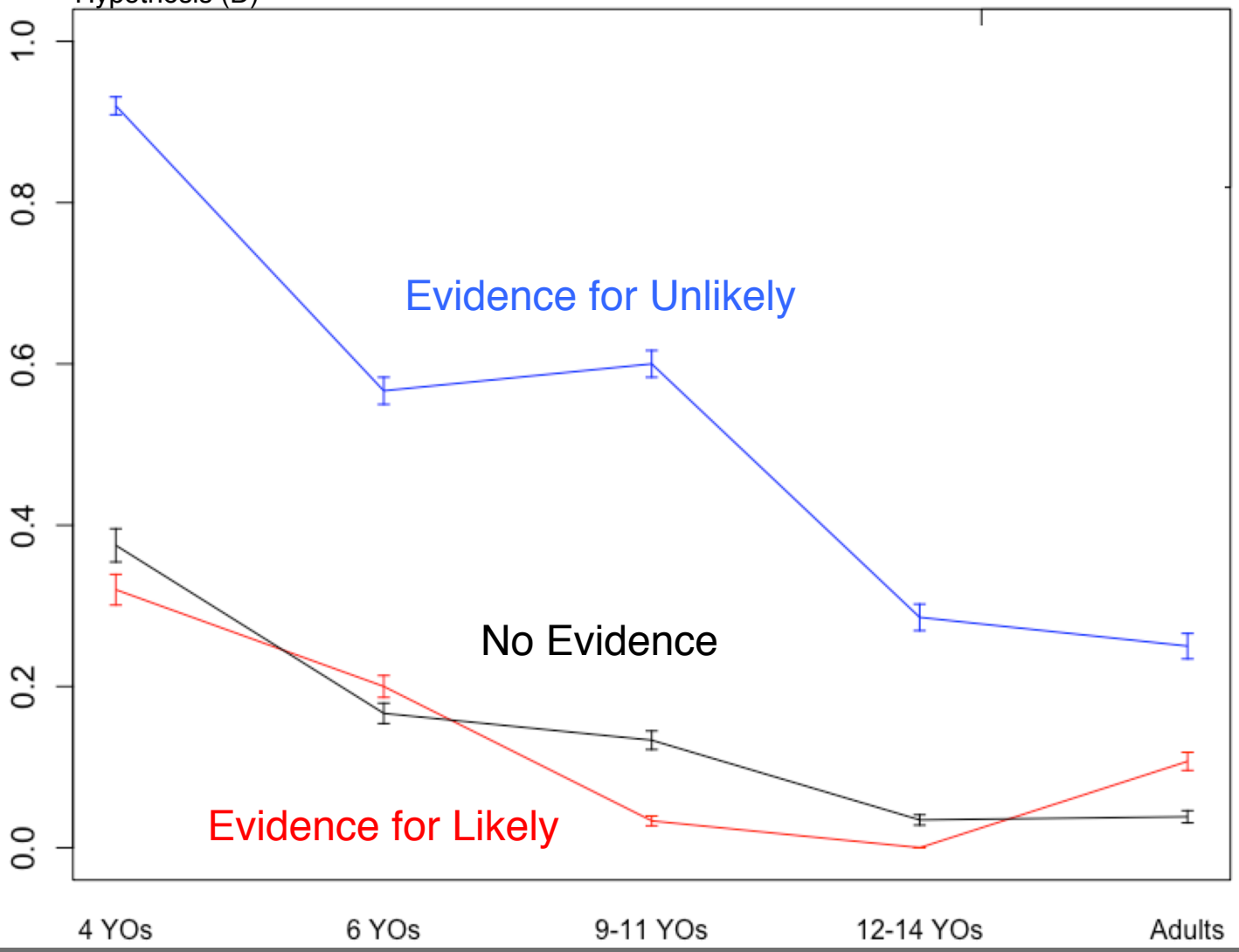
Conjunctive Training



Test

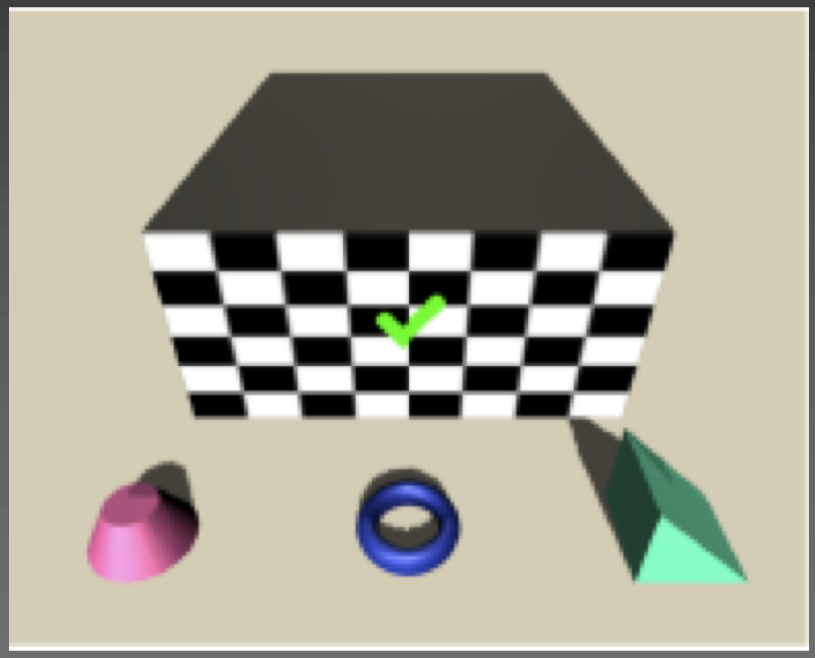


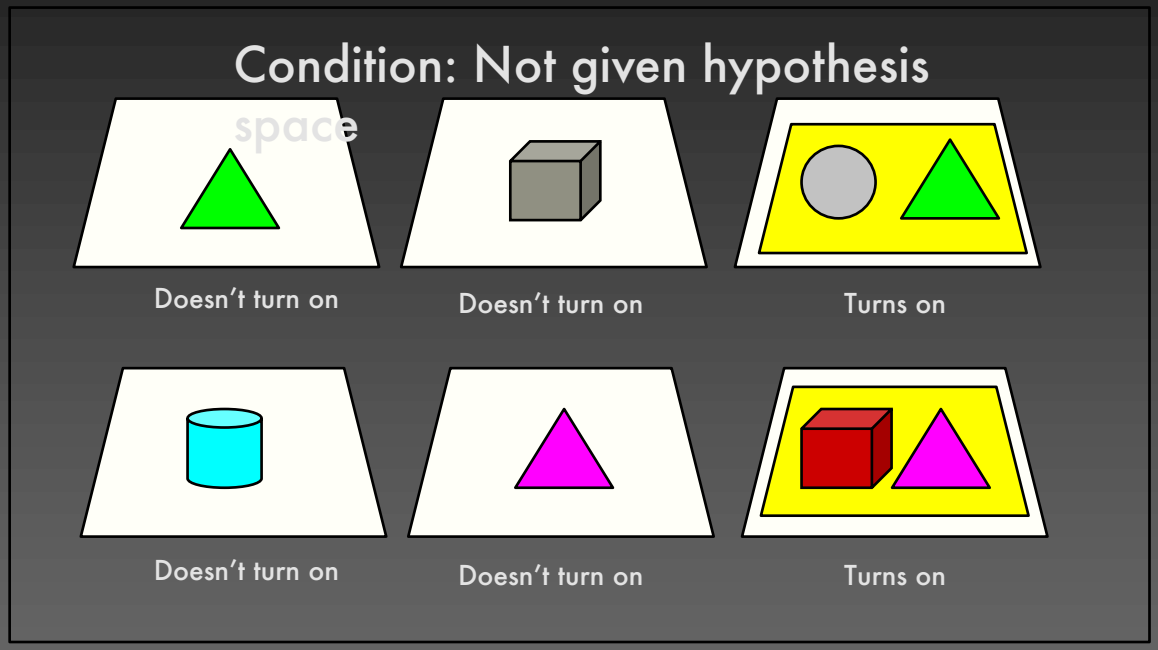
Gopnik et al. PNAS, 2017 Proportion of Participants Choosing the Unlikely Physical Hypothesis (D)



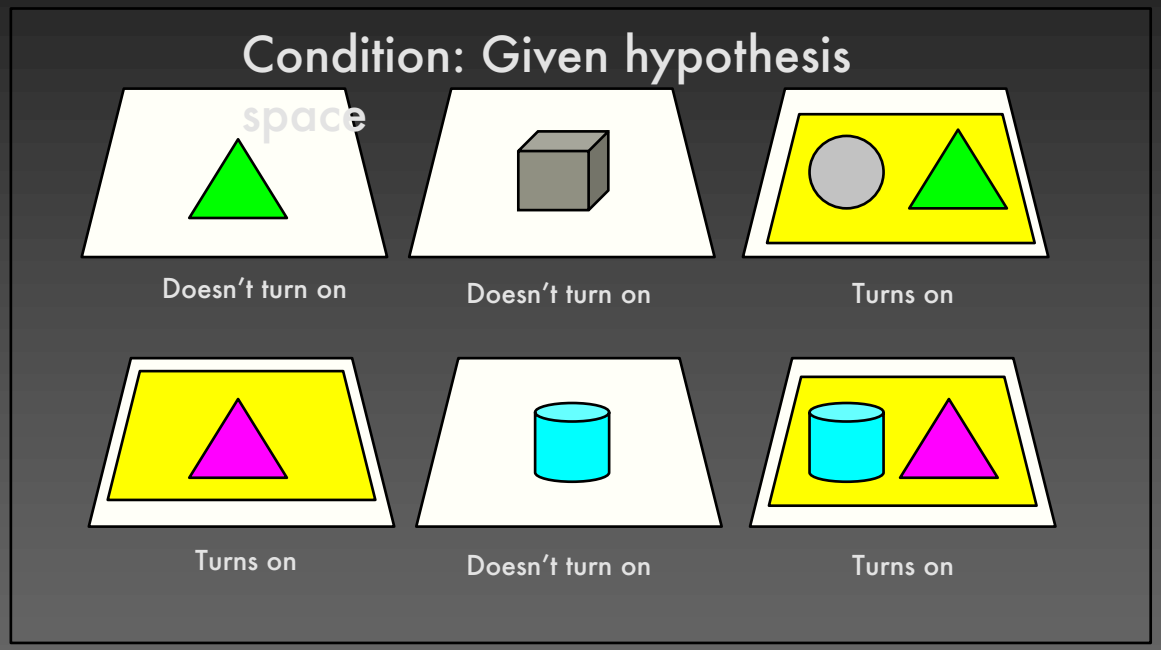
Exploration of Causal Structure

- **Learning Casual Overhypotheses through Exploration in Children and Computational Models ,**
- **Rosemary Ke, Eliza Kosoy, Jessica Hamrick, Jasmine Collins, David Chan, Sandy Huang, Adrian Lu**





Visualizations for paper:



Visualizations for paper:

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