Babies and Bayes nets: A computational theory of human theory-formation

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Collaborators

- Clark Glymour
- Laura Schulz
- Tamar Kushnir
- David Sobel
- David Danks

Gopnik,Glymour,Sobel,Schulz,Kushnir,& Danks, Psychological Review, 2004.

Gopnik & Schulz, Trends in Cognitive Science, 2005

The Theory Theory

- Intuitive theories of biology (Carey) physics (Gopnik & Meltzoff) psychology, (Wellman, Perner, Theory of Mind)
- Cognitive development as intuitive theory formation
- The scientist as child
- Common representations and learning mechanisms underlying science and cognitive development.

The Spatial Analogy

- Cognitive maps
- The spatial inverse problem
- Implicit assumptions for solving the problem

Theories as Causal Maps

- General
- Coherent
- Non-egocentric
- Learned
- Support new predictions
- Support new interventions

The Causal Inverse Problem

- Causal structure is not directly perceived
- Causal structure is probabilistic
- Causal structure is complex

Assumptions for Solving the Inverse Problem

- **Substantive Assumptions**
- Space, Time, Movement-Michotte, Leslie, Bullock & Gelman
- Events following intentional actions-Watson, Meltzoff

Assumptions for solving the inverse problem

- **Formal Assumptions**
- Conditional dependence
- In adults - Cheng, Shanks, Causal Rescorla-Wagner
- In animals - Blocking in classical conditioning

Approaches to Causation

- “Kant”, Michotte, Leslie, Intuitive Physics Mechanism
- “Hume”, Classical Conditioning, Shanks Association
- Spirtes, Glymour, Scheines; Pearl, Woodward; Bayes nets -- Interventions & Observations

  The causal markov assumption, the faithfulness assumption, the intervention assumption

Normative Mathematical Models in Psychology

- **Vision**
- 3-d object representations (geometry)
- Projections from 3-d objects to the retina (optics)
- Assume projections are caused by objects (ideal observer theory)

- **Causation**
- Representations of causal structure (directed acyclic graphs)
- Projections from causal structure to conditional dependencies and interventions (the causal markov assumption)
- Assume dependencies and interventions are caused by structure (faithfulness)

Screening-Off

- A and B are potential causes of E
- A, B and E are correlated
- E is independent of B conditional on A
- E is not independent of A conditional on B
- A causes E and B does not
- In adults Cheng, Shanks
- In animals with classical conditioning
- In children with novel interventions?

Screening-off and Blickets

Some blocks are blickets. Blickets make the blicket detector light up and play music.

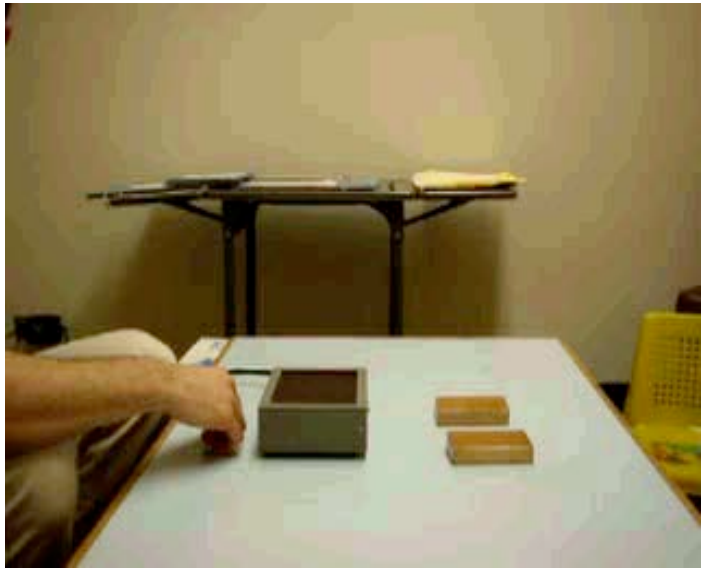
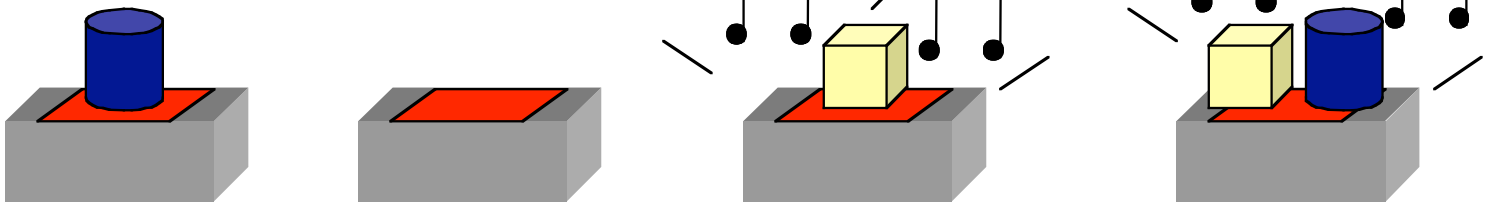


Figure 12: Procedure used in Gopnik et al. (2001), Experiment 3

One-Cause Condition



Object B is placed on the detector and nothing happens

Object B is removed

Object A is placed on the detector by itself and the detector activates

Object B is added to the detector with Object A. The detector continues to activate. Children are asked to make it stop

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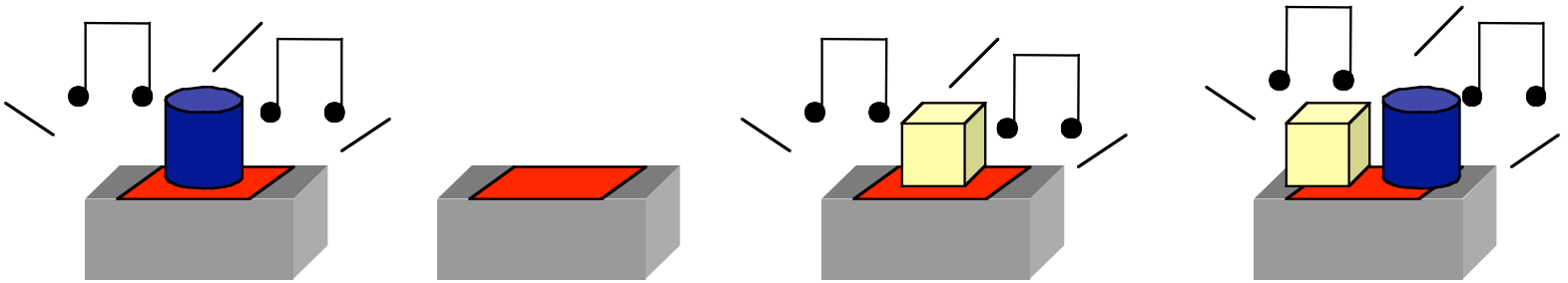
Two-Cause Condition



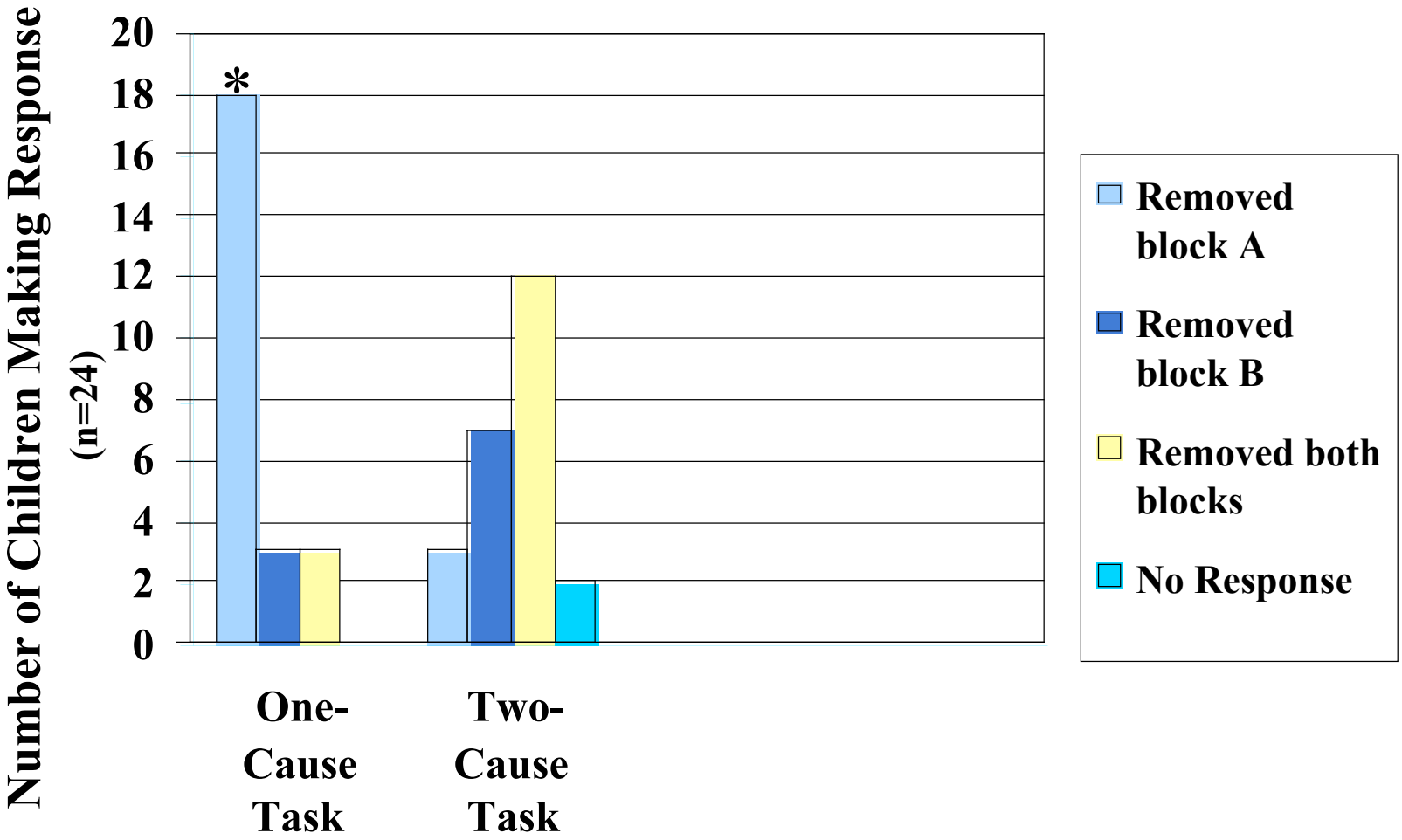
Object B is placed on the detector and the detector activates

Object B is removed. The detector stops activating

Object A is placed on the detector by itself and the detector activates

Object B is added to the detector with Object A. The detector continues to activate. Children are asked to make it stop

Can you make it stop?



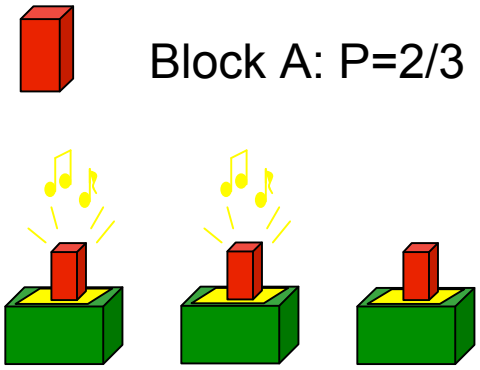
Probabilistic Strength = Causal Strength?

- Adults make inferences about causal *strength* based on probabilistic evidence (Cheng, 1997; Waldman & Hagmayer, 2001).

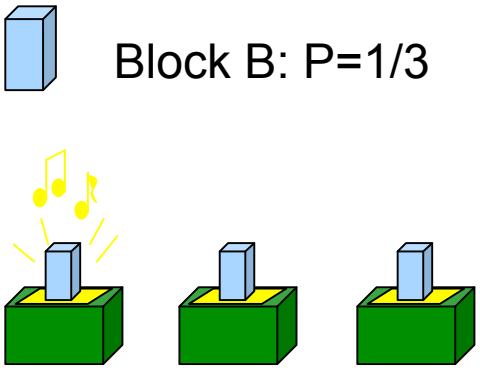
- Children make inferences about causal *structure* based on deterministic evidence (Bullock, Gelman & Baillargeon, 1982; Gopnik, Sobel, Schulz & Glymour, 2001).

- Do children use probabilities to infer causal strength?

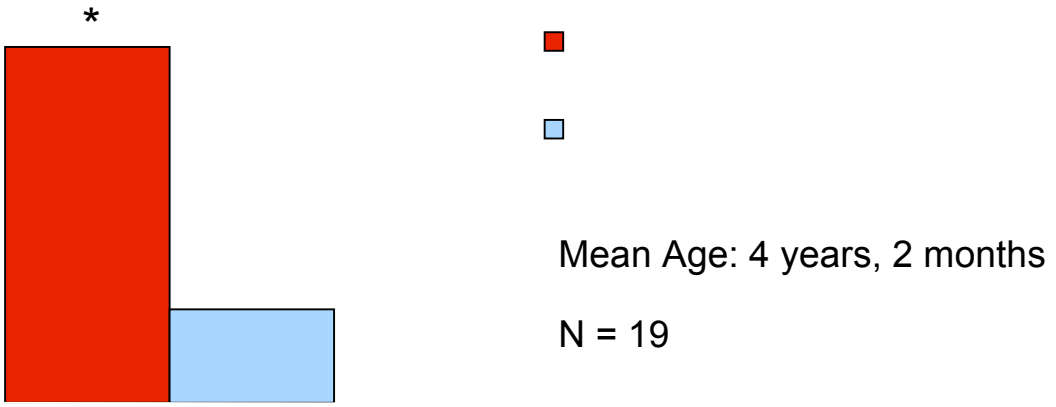
Probabilistic Strength = Causal Strength?



Block A: P=2/3



Block B: P=1/3



Intervention Question: “Pick the best one and make the toy go.”

Simultaneous Causes:Inferring causal direction

- Intervention→Insomnia →Anxious Thoughts
- Intervene on insomnia, anxious thoughts
- Intervention→Insomnia←Anxious Thoughts
- Intervene on insomnia, no anxious thoughts
- No work with adults or children (though since then Steyvers et al, 2003, Sobel & Kushnir in press).

Pretest

- This is my puppet machine. Some of these puppets are special. Special puppets almost always make other puppets go.
- Look X is moving and its making Y go. See?

- Is X special? Is X moving Y?

Interventions to resolve simultaneous causes

Common Effects

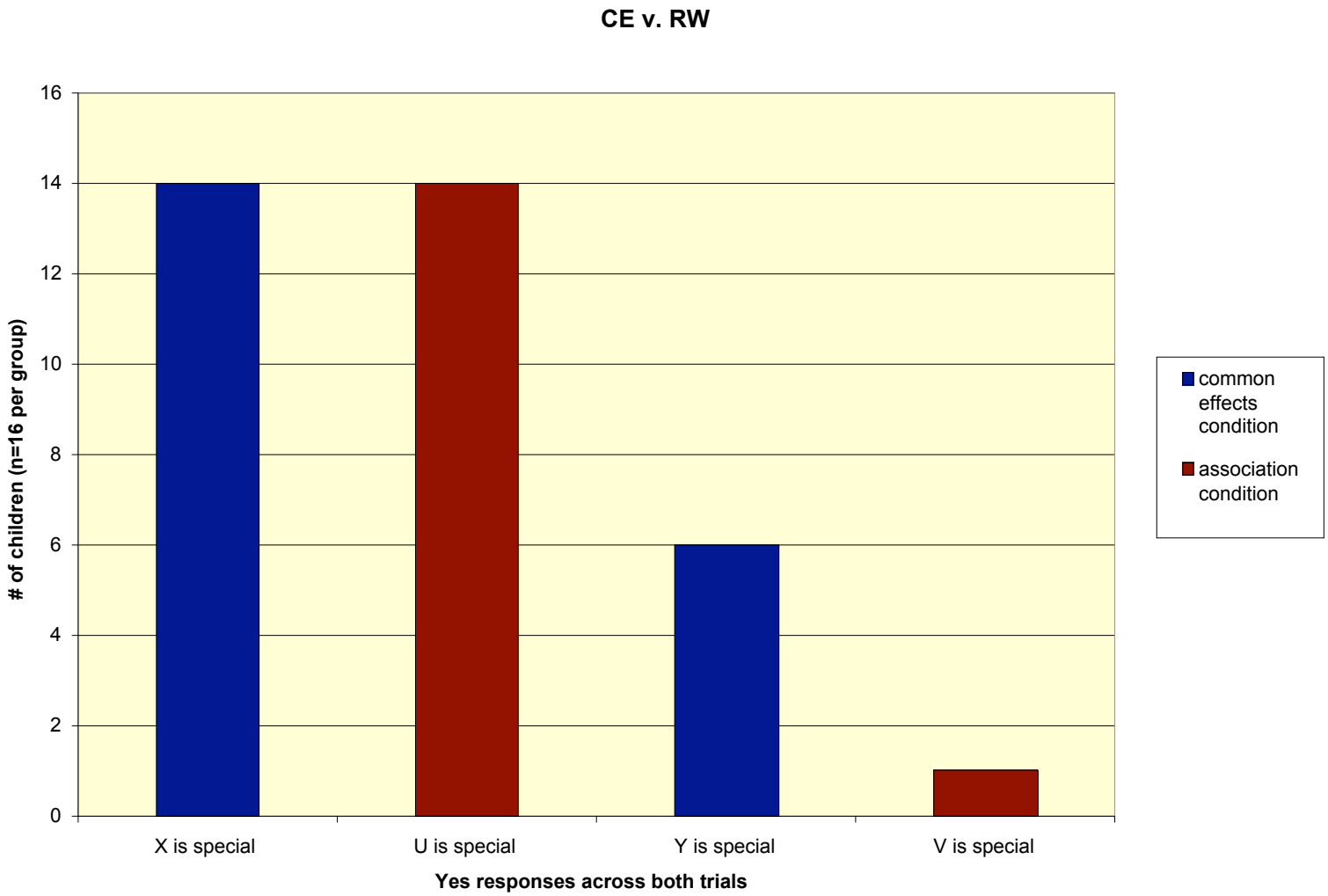
Y and X move together (3times)

E. Moves Y and X doesn't move

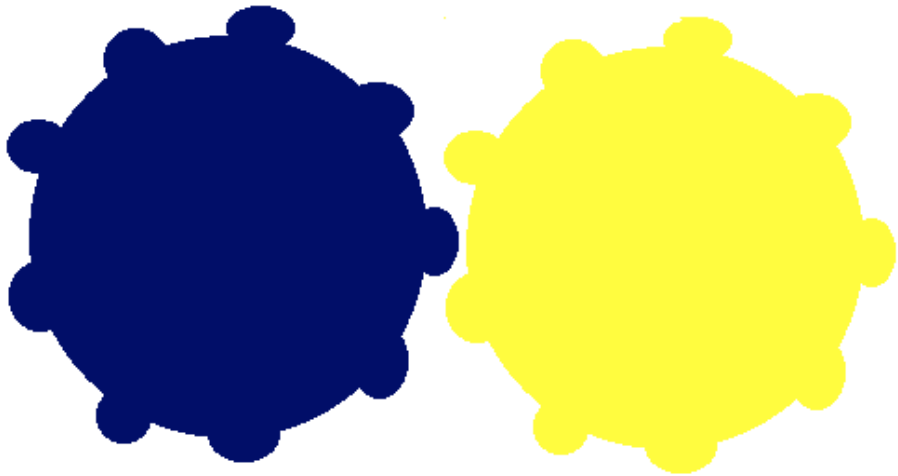
Y and X move together (2 times)

Does Y make X move?

Does X make Y move?

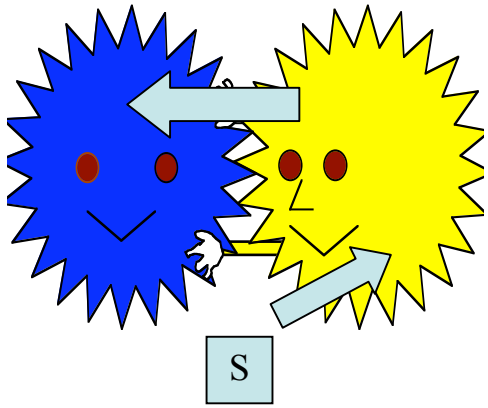

CE v. RW
16
14
12
10
8
6
4
2
0
# of children (n=16 per group)
X is special
U is special
Y is special
V is special
Yes responses across both trials
common effects condition
association condition

Inferring more complex causal structure: Chains versus common effects versus conjunctions



The Causal Possibilities

1



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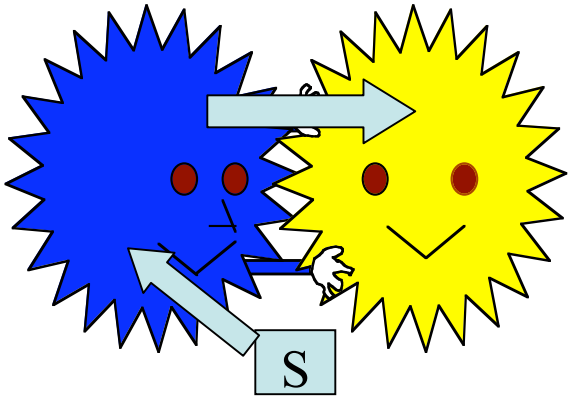

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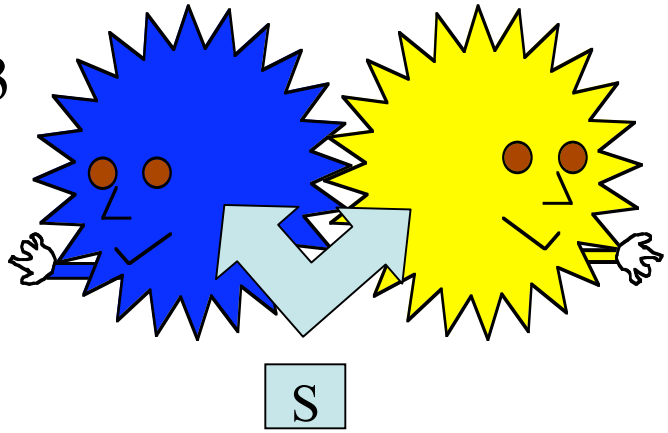

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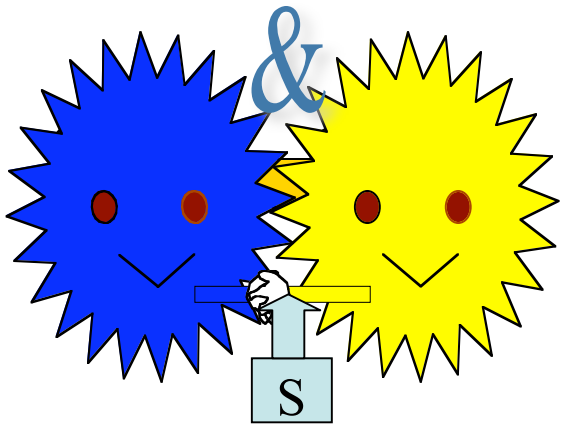
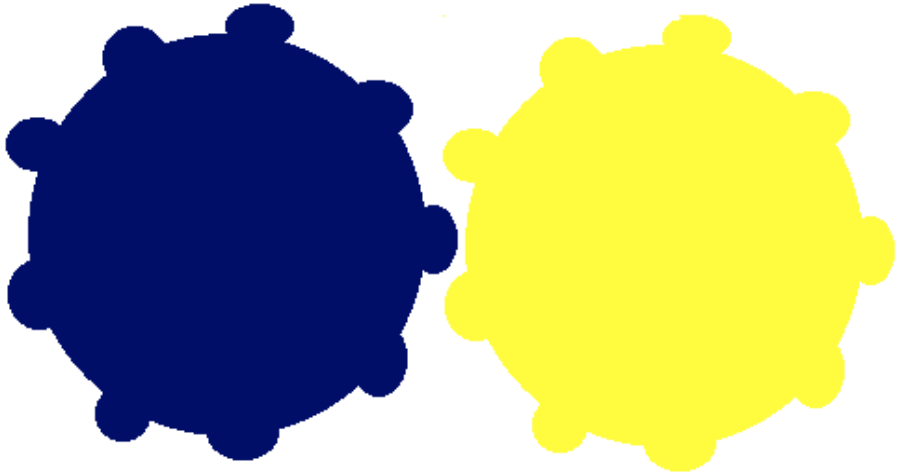
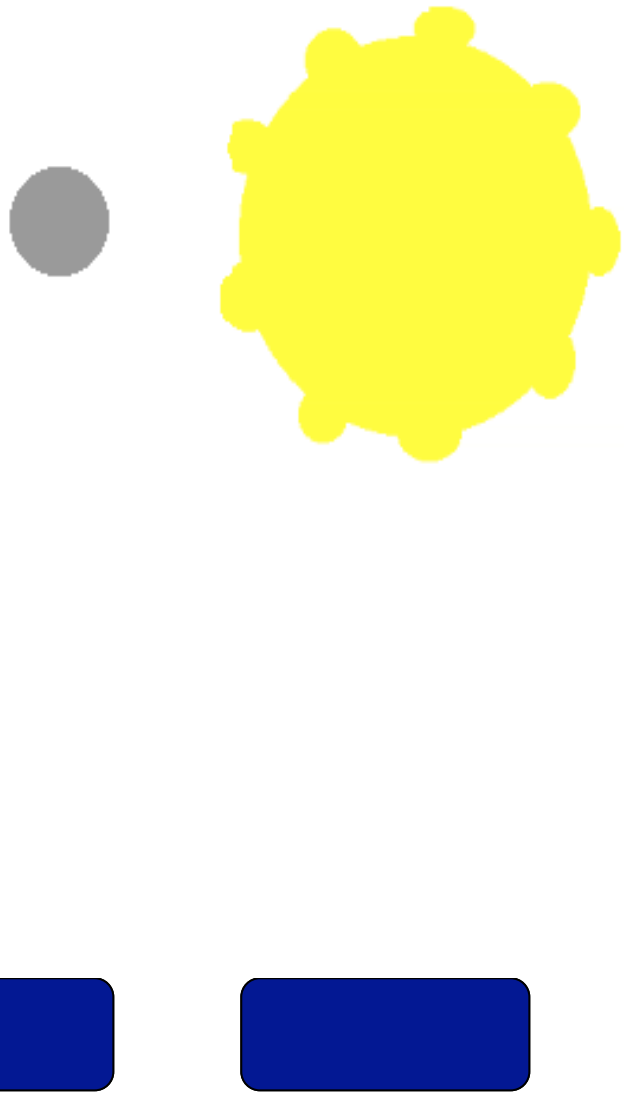


The Causal Mystery

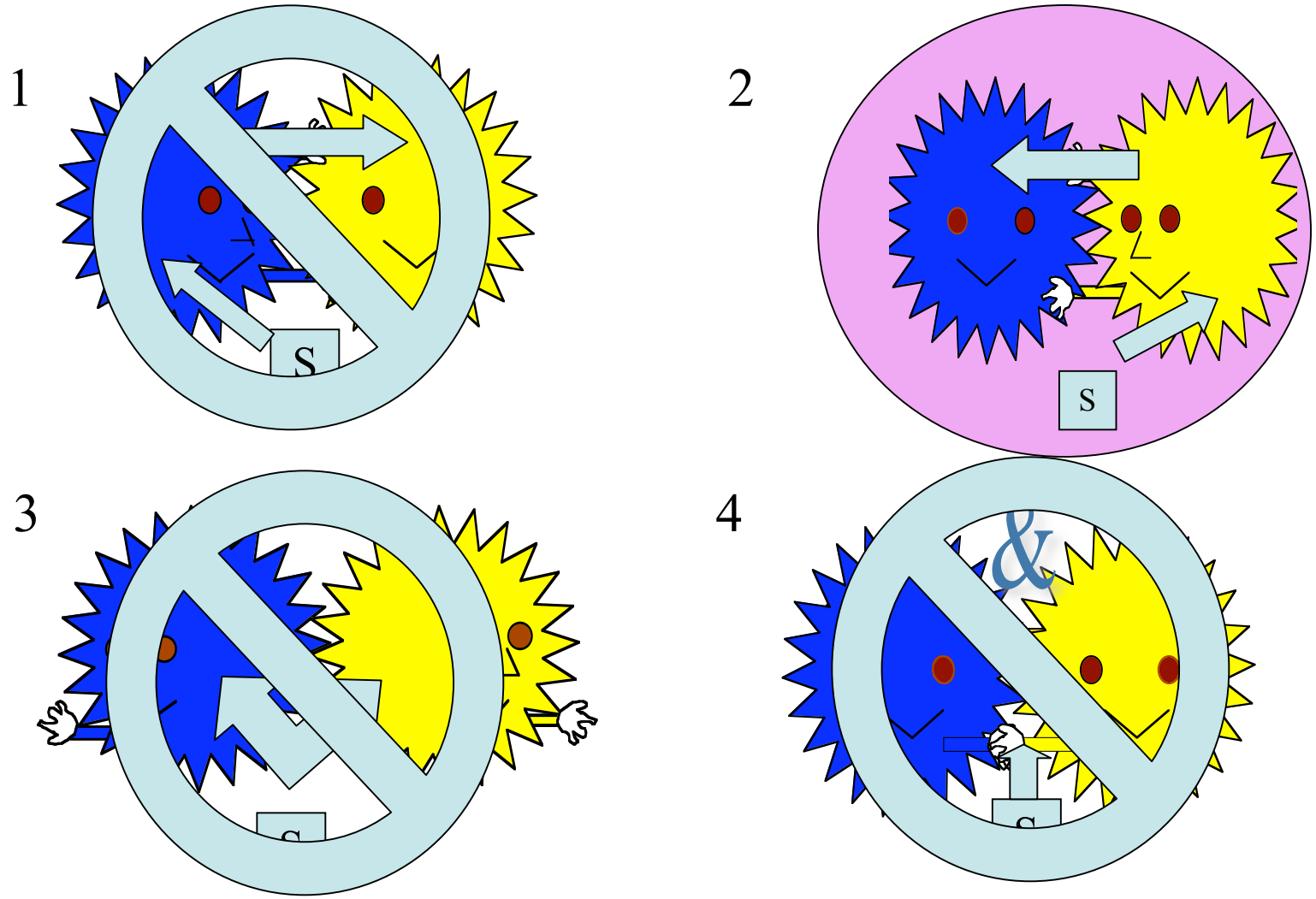
- These causal structures cannot be distinguished by:
  - Spatiotemporal cues
  - Associative strength
  - Direct interventions
  - Causal mechanisms

- In the world at large, cues to causal structure might be either redundant or absent.



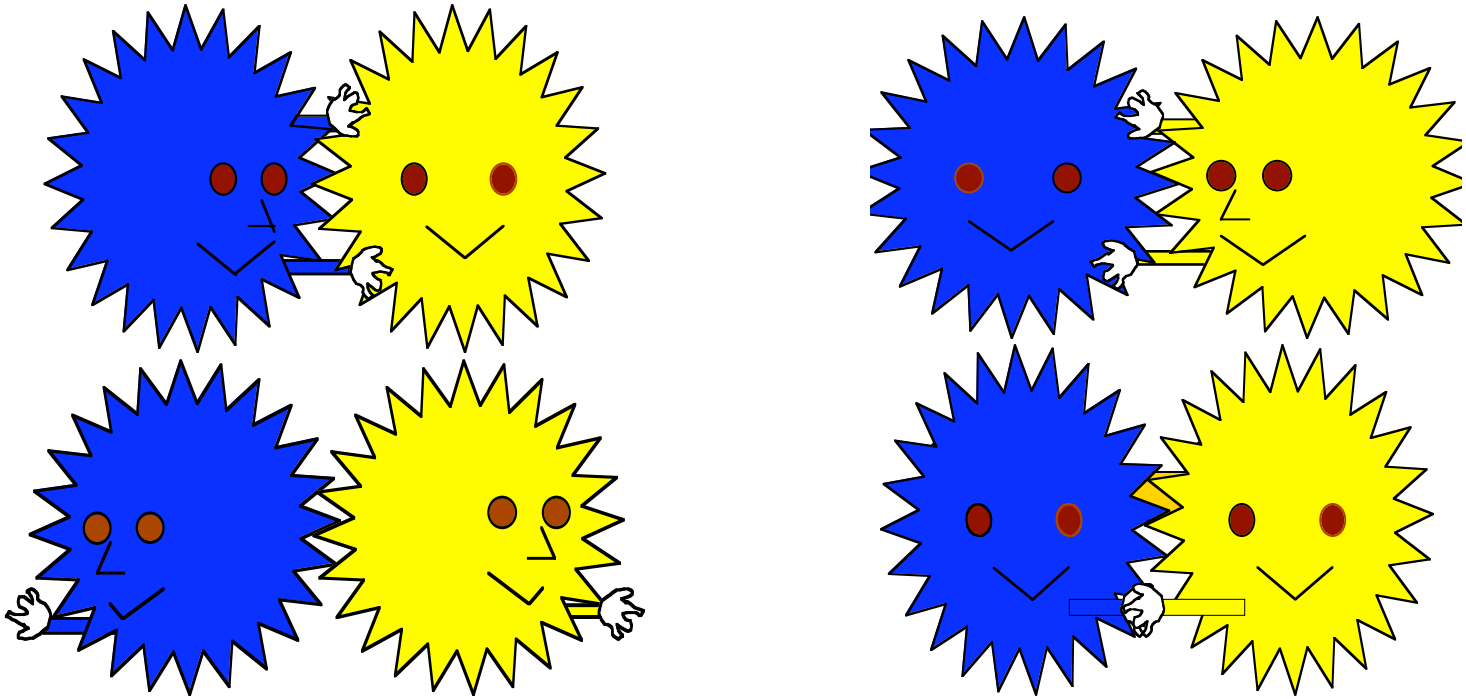


Interventions on each causal structure will produce different patterns of evidence.



Conditional interventions . . .

Knowing each gears' relationship to the switch let you determine the gears' relationship to one another . . .

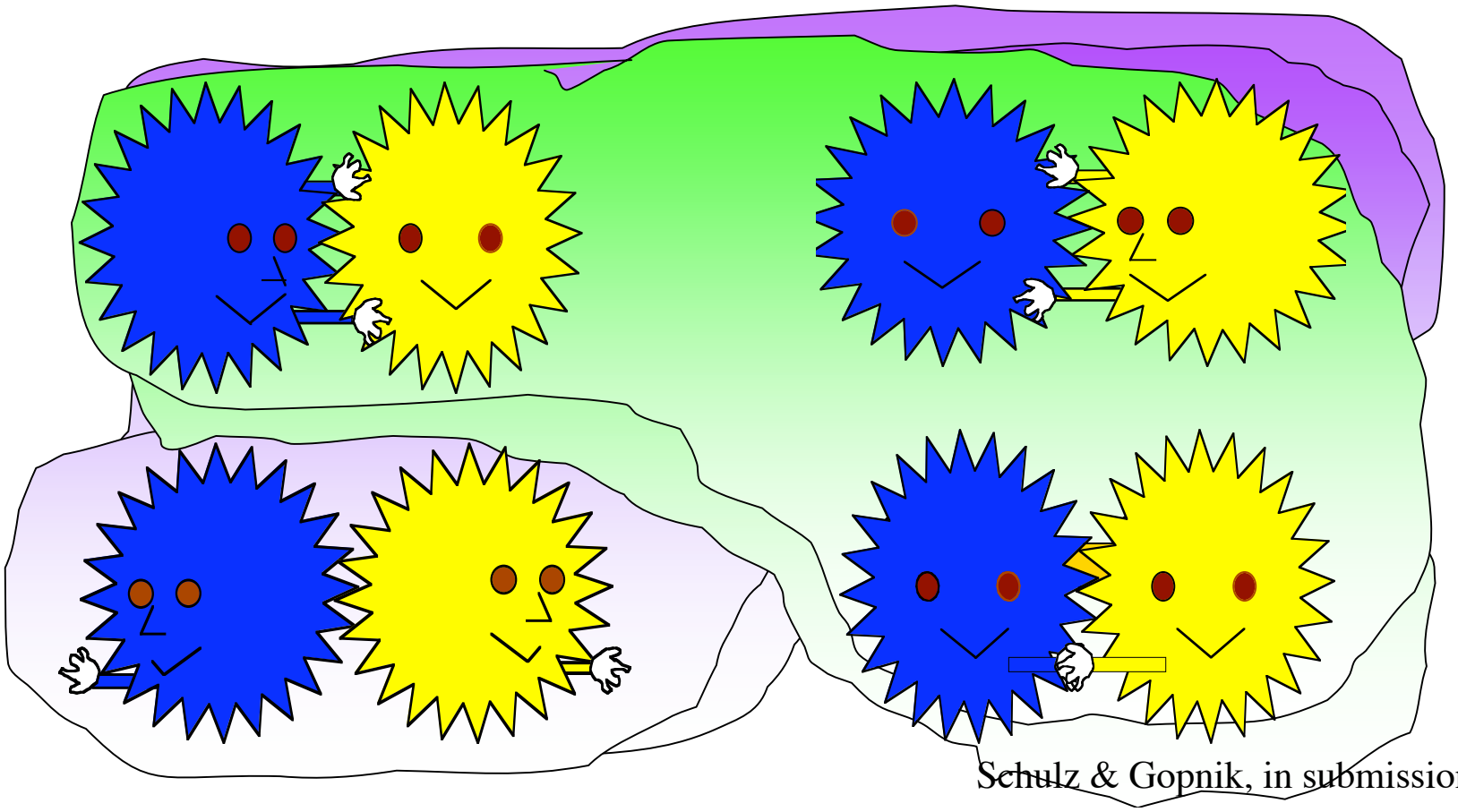


Question

- Do formal assumptions about how patterns of conditional dependence and independence indicate causal relations, allow children to distinguish causes from effects and learn the structure of causal events?

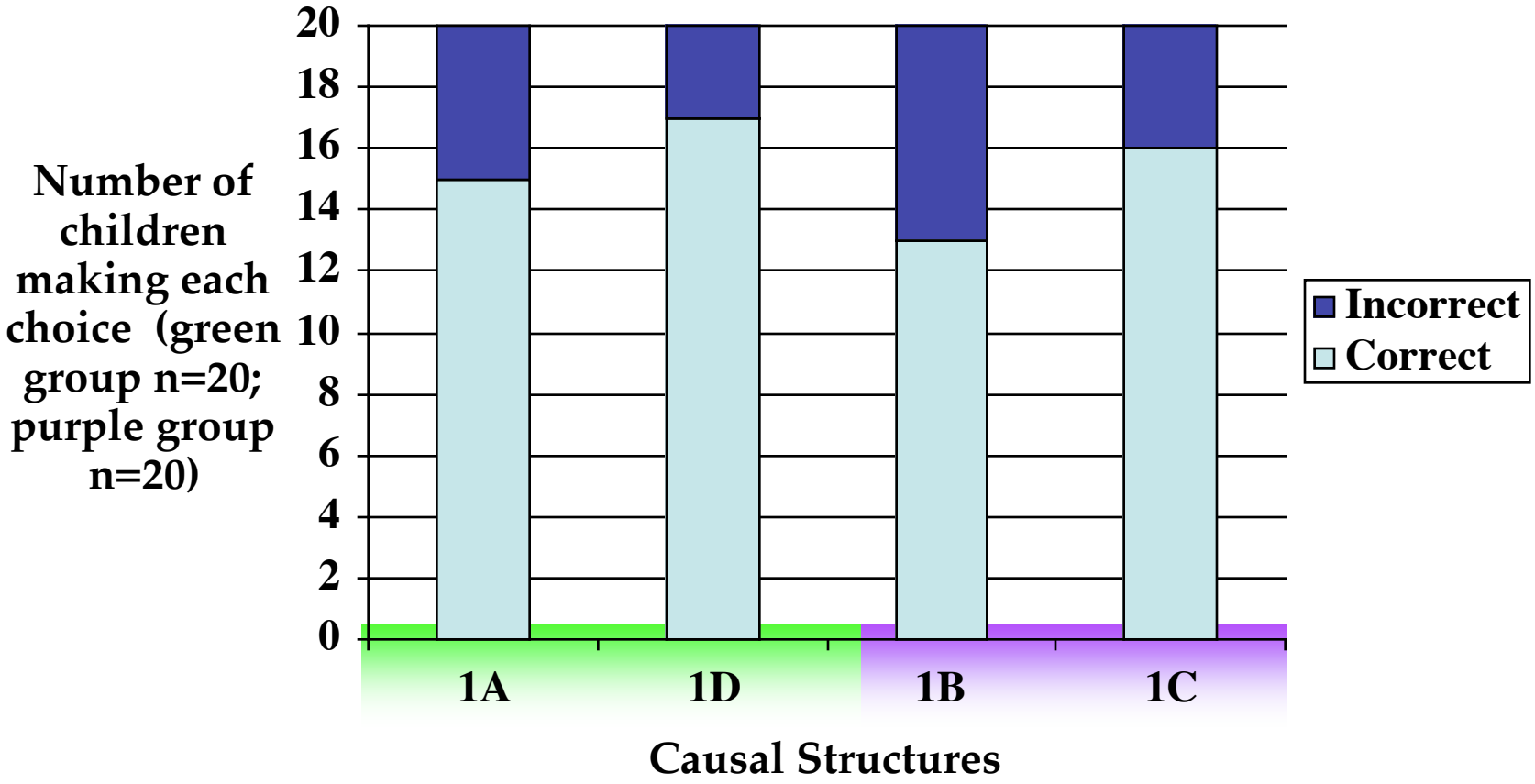
Experiment 2

- 40 preschool children (mean age: 4;8) were randomly assigned to one of two groups.



Schulz & Gopnik, in submission

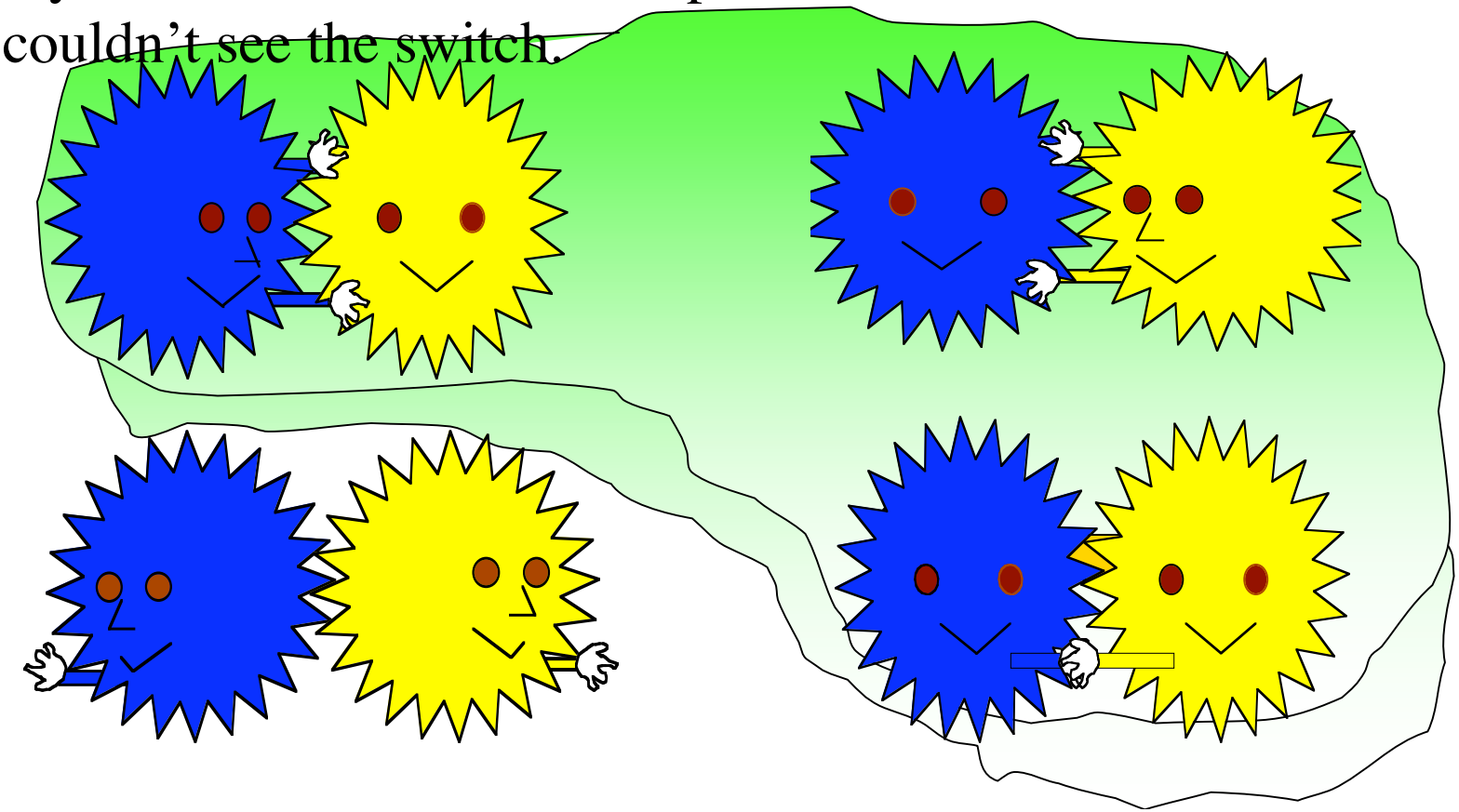
Predicting the structure from patterns of evidence



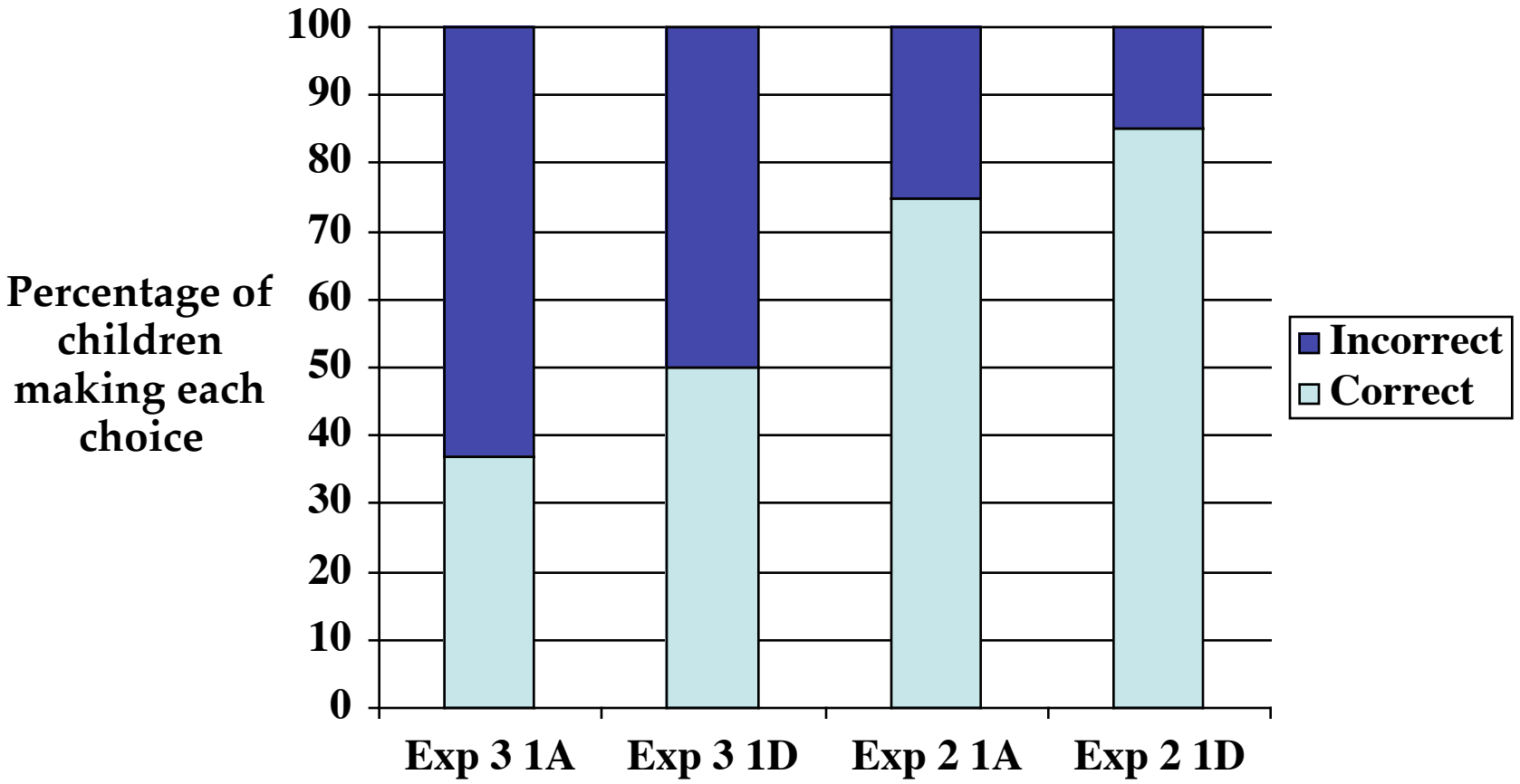
Schulz & Gopnik, in submission

Experiment 3

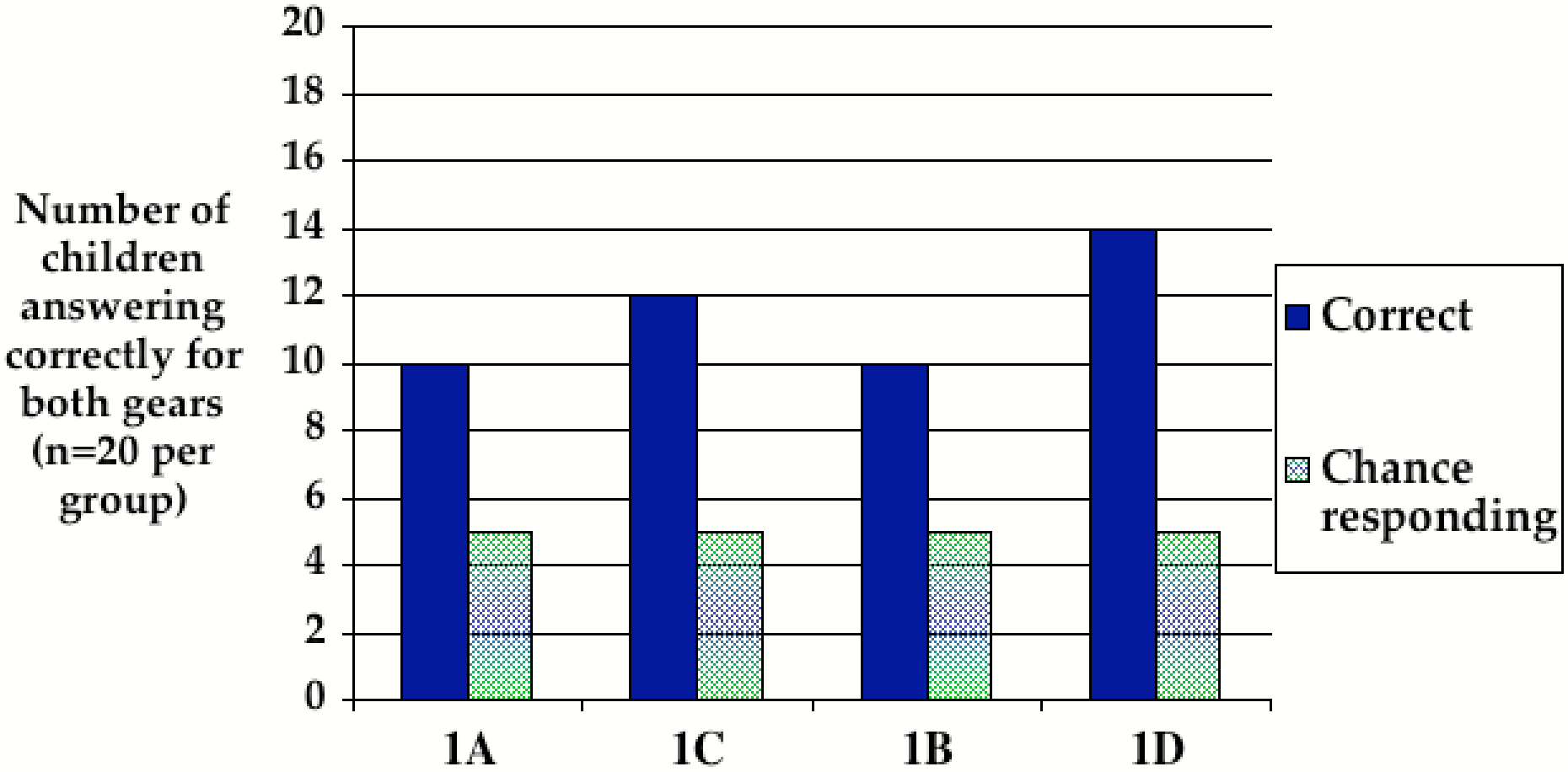
- Sixteen children were tested as in Experiment 2 -- but the toy was turned to face the experimenter. Children couldn't see the switch.



Experiment 3 v. Experiment 2



Predicting patterns of evidence from the structure



Schulz & Gopnik, in submission

Results

- Preschool children can use interventions and the resulting patterns of conditional dependence and independence to learn causal structure.
- Preschool children can use knowledge of causal structure to predict the patterns of evidence that will result from interventions.

Schulz & Gopnik, in submission

Pilot work:

- In Experiments 1 and 2, the children were given the relevant patterns of independence and dependence. Would children be able to discover this evidence on their own?

- Advantages of immaturity?
  - Impulsivity
  - Perseveration

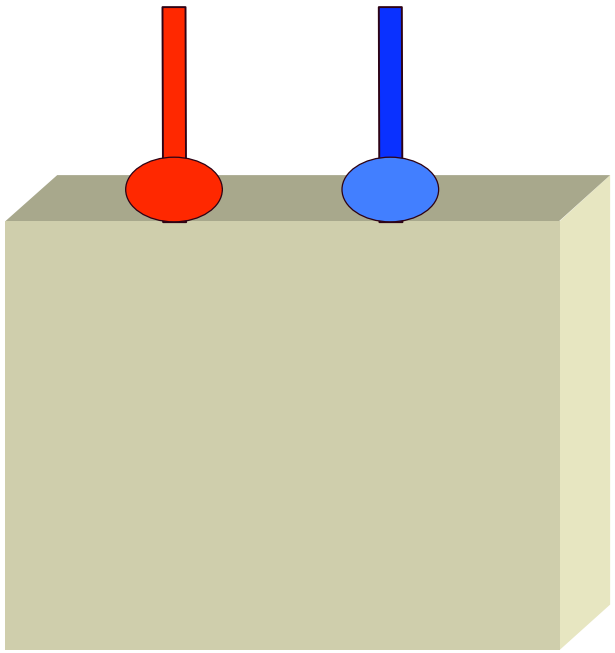
Results

- 9 dyads have been tested so far.
- 8 of the 9 dyads spontaneously generated the pattern of independence and dependence
- 7 of the 8 dyads correctly identified the causal gear.

Inferring Unobserved Causal Structure

- Intervene on insomnia and no anxious thoughts
- Intervene on anxious thoughts and no insomnia
- Insomnia ←?→Anxious Thoughts

Hidden Common Cause



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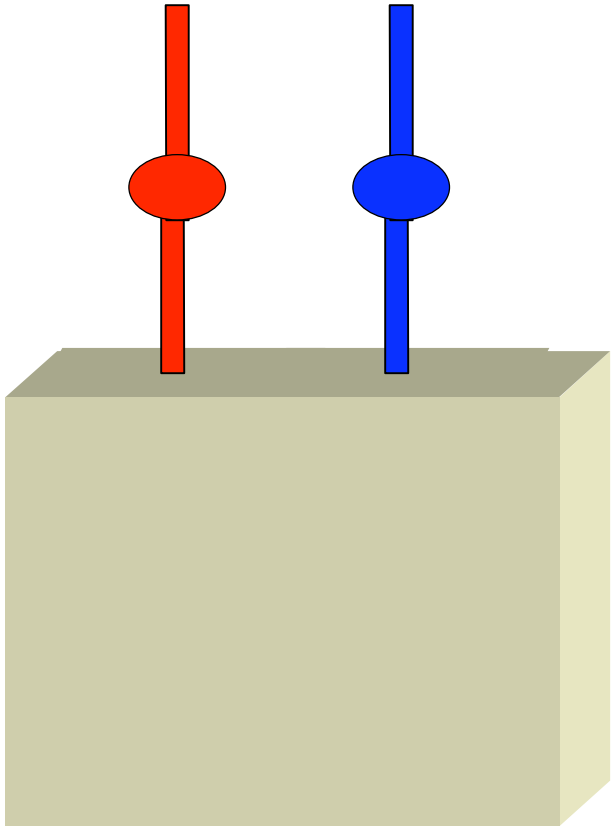

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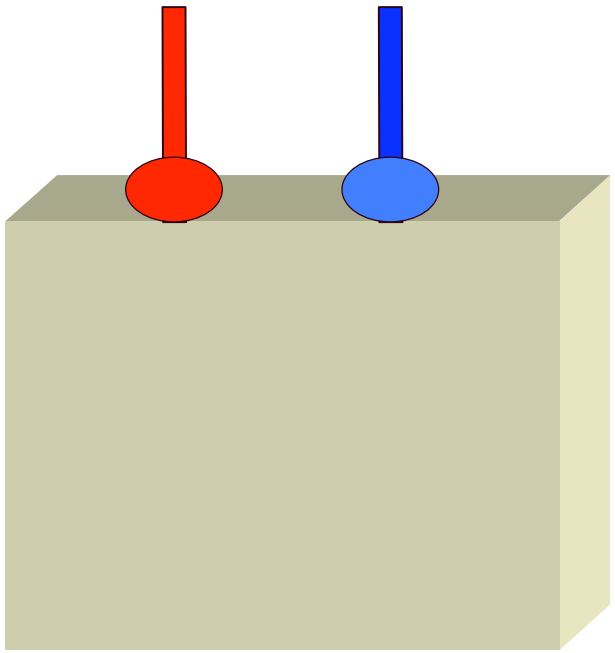

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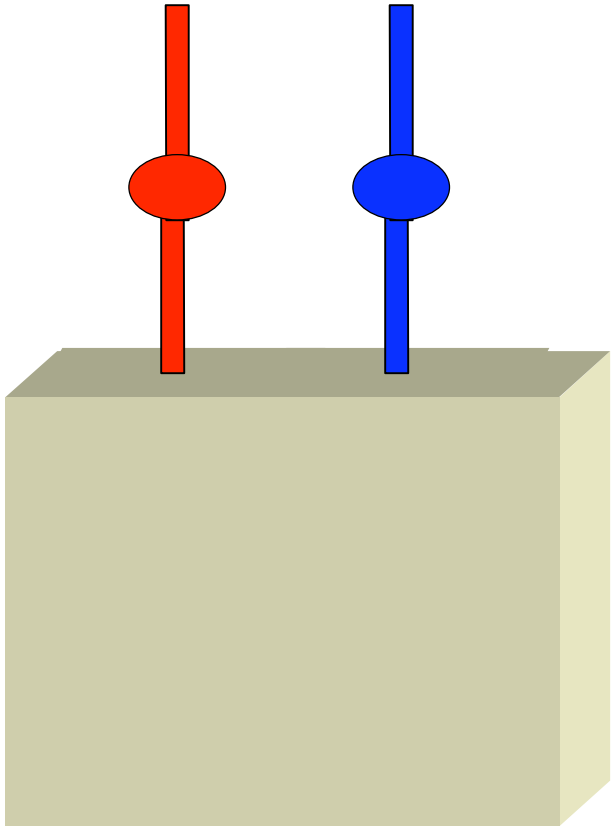

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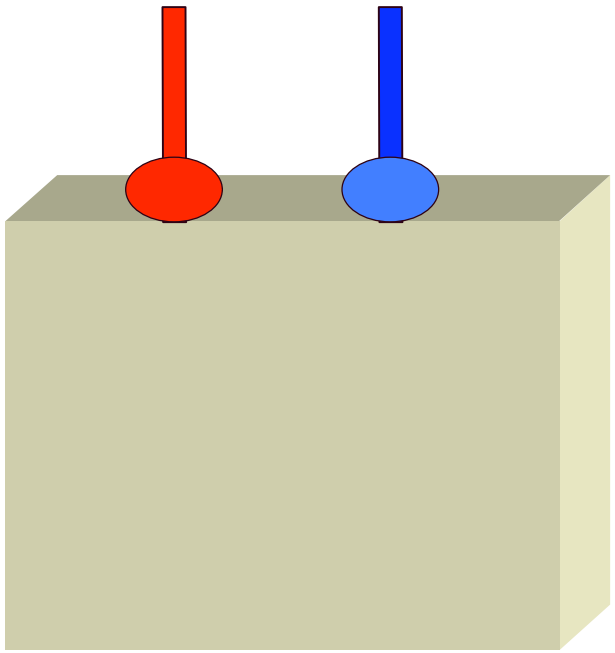

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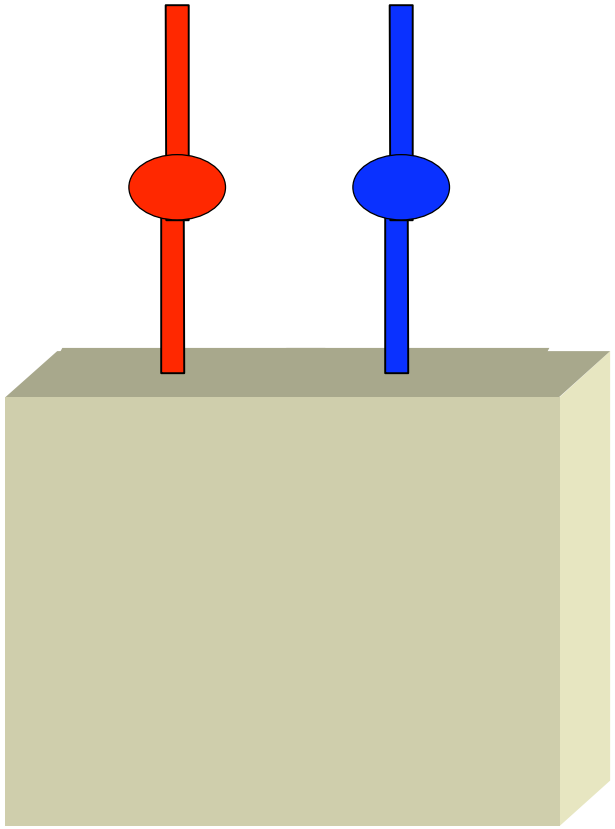

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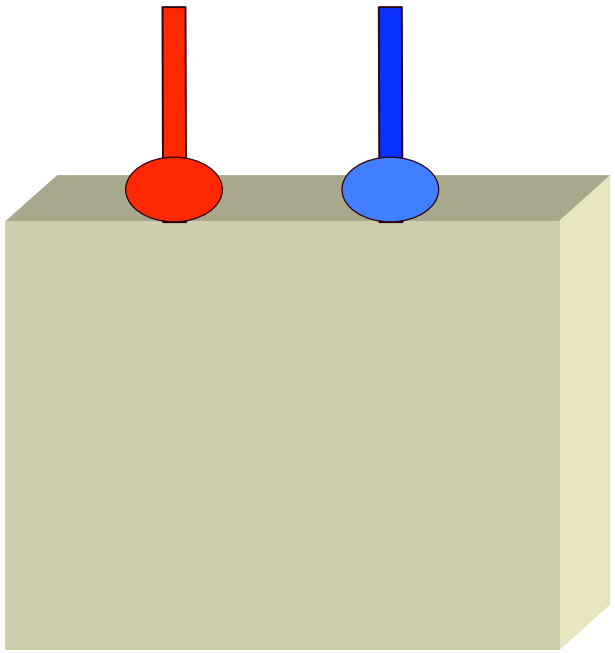

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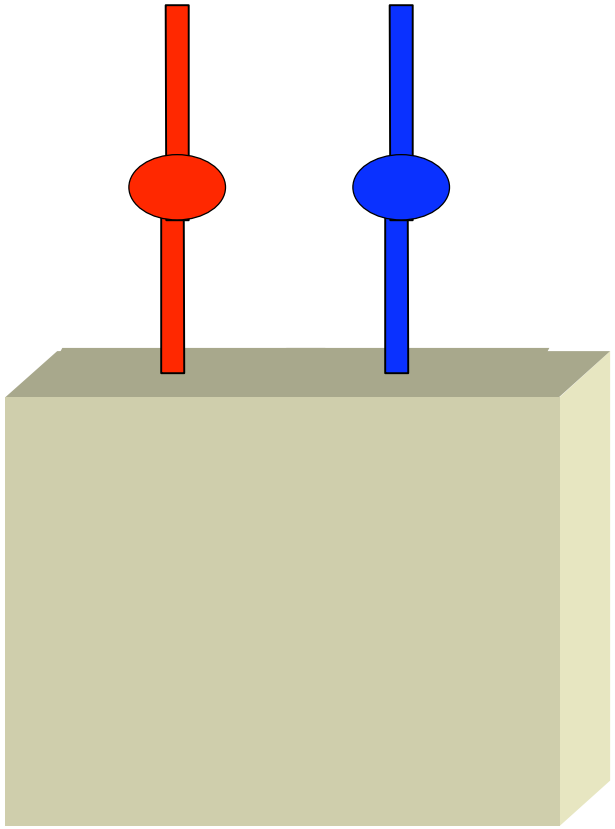

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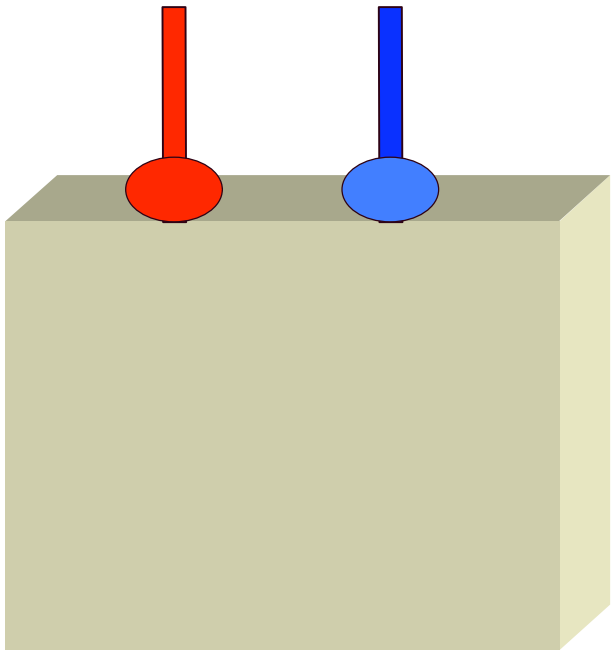

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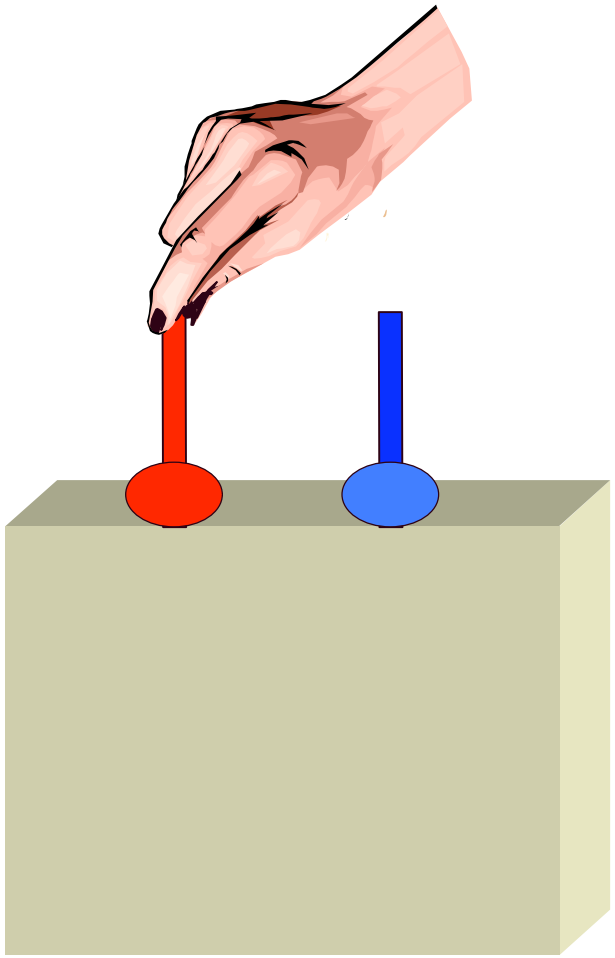

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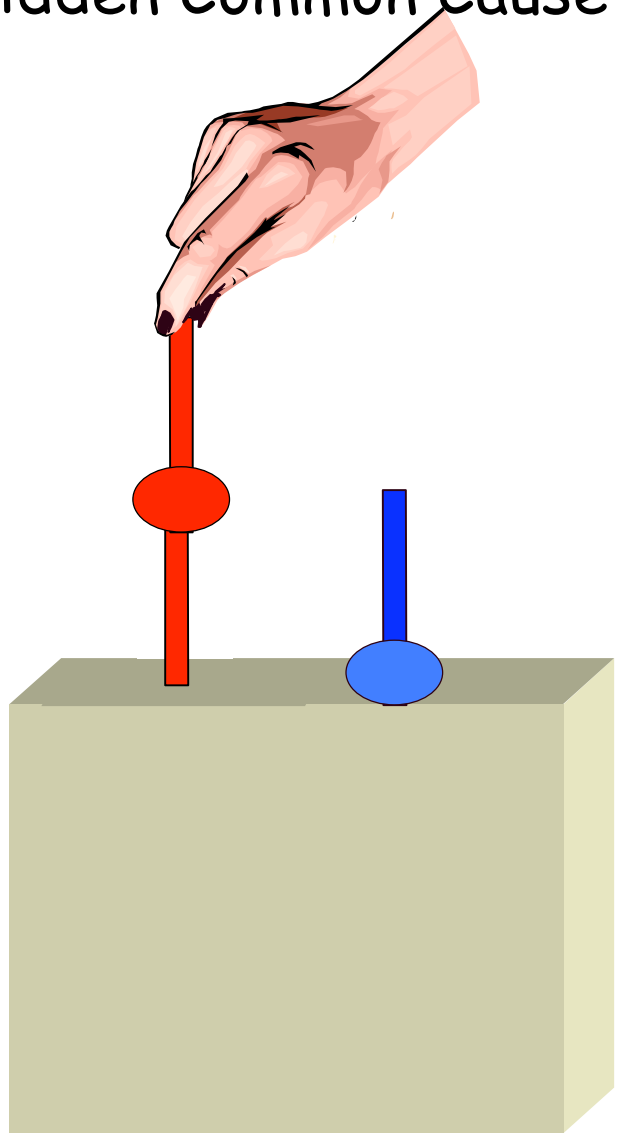

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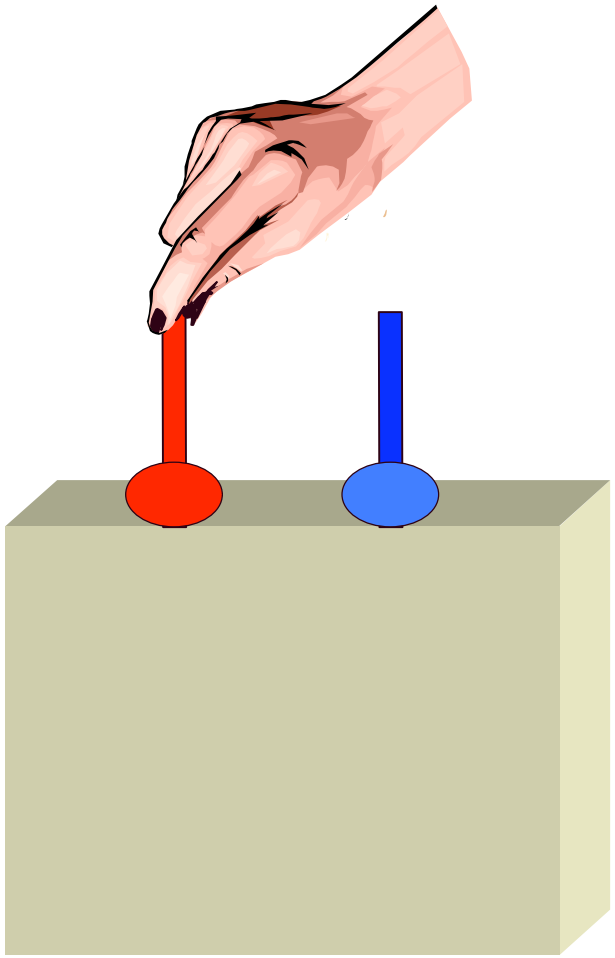

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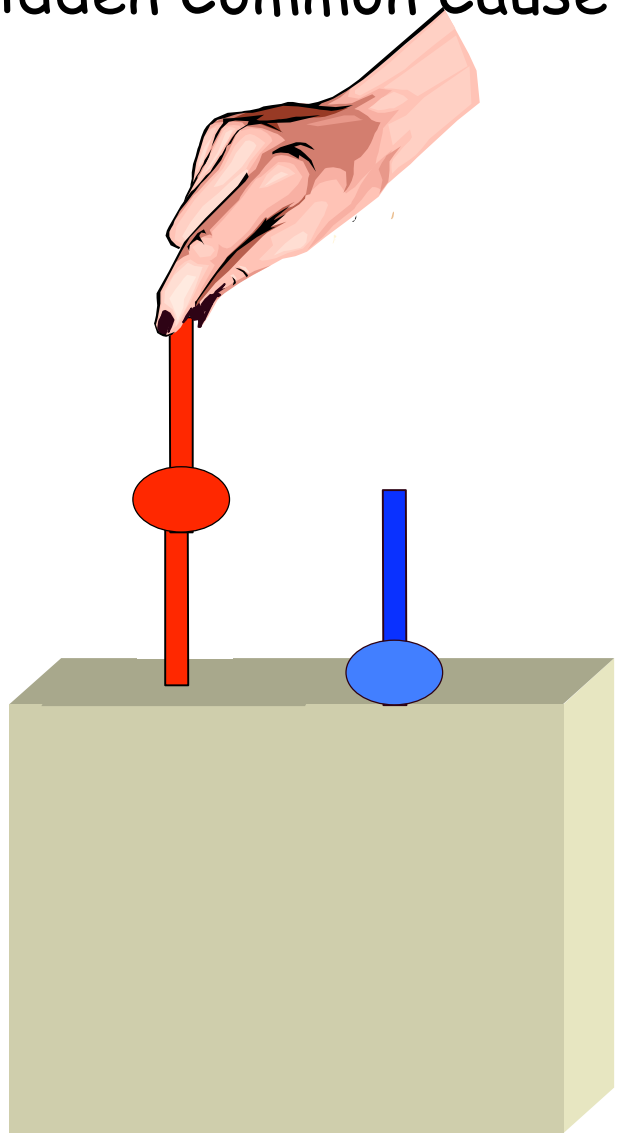

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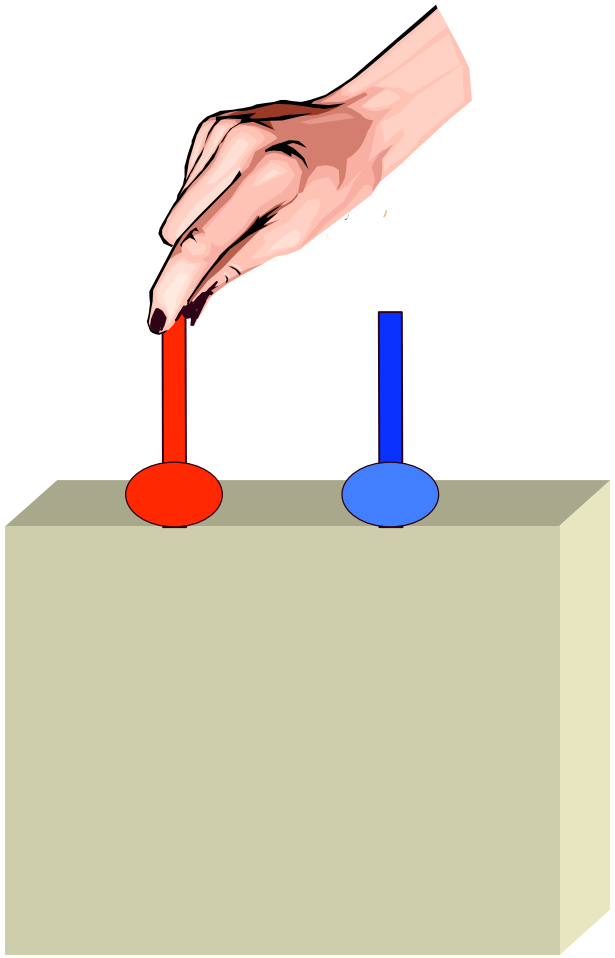

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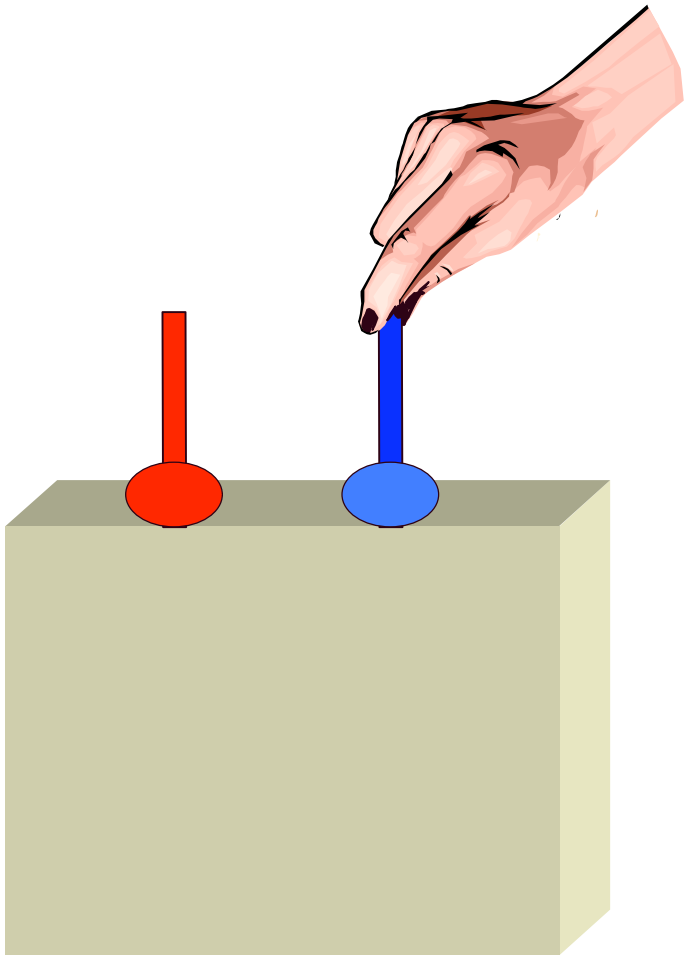

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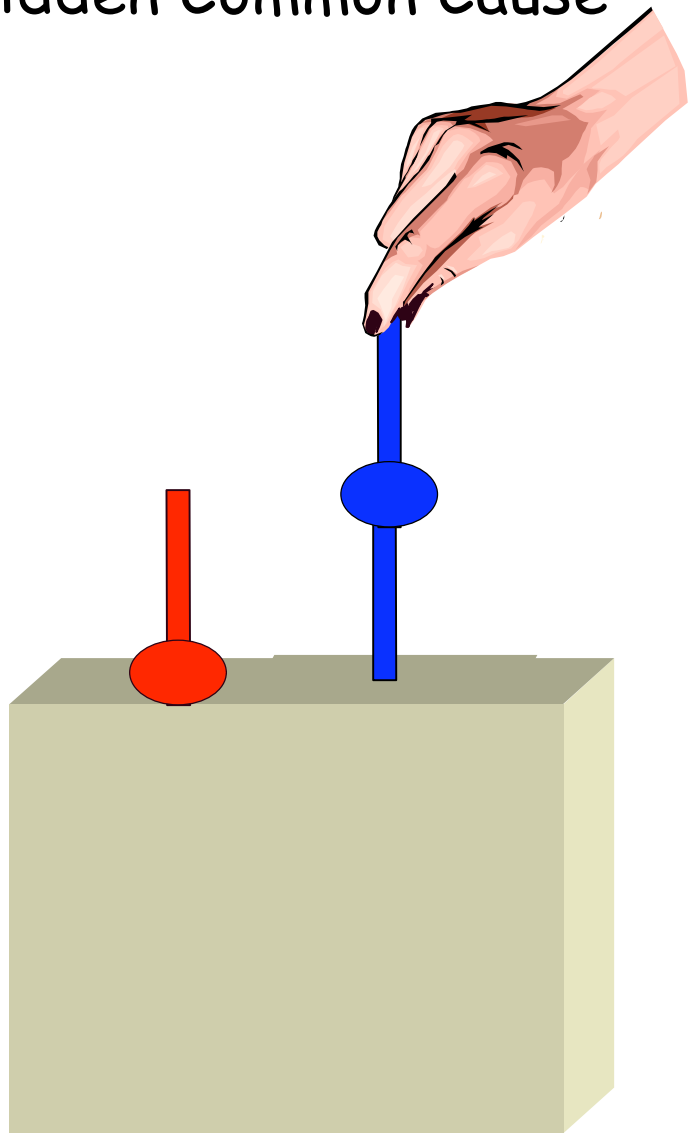

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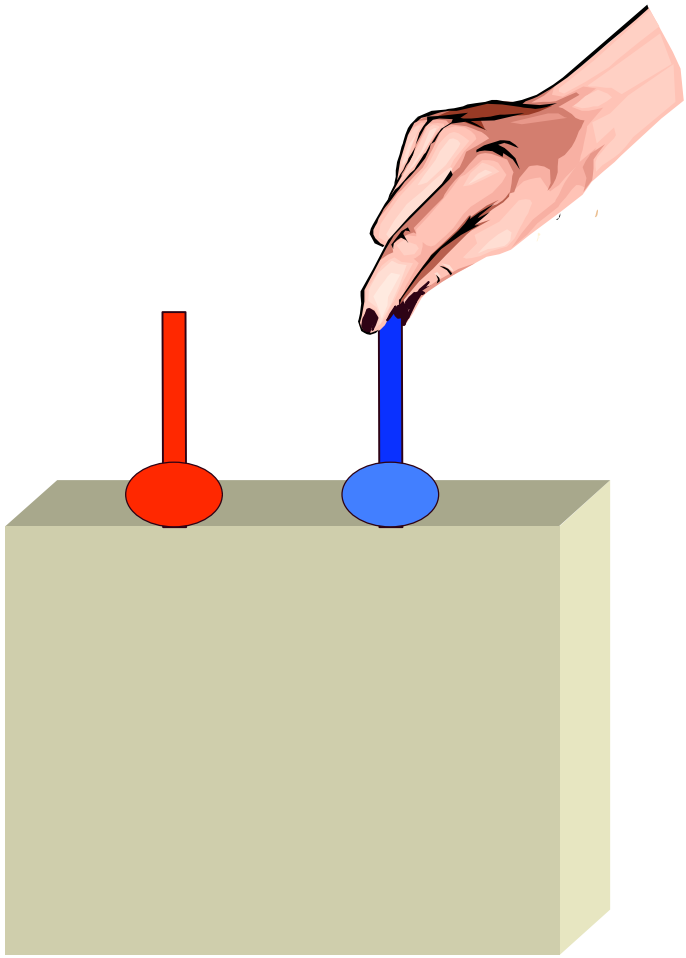

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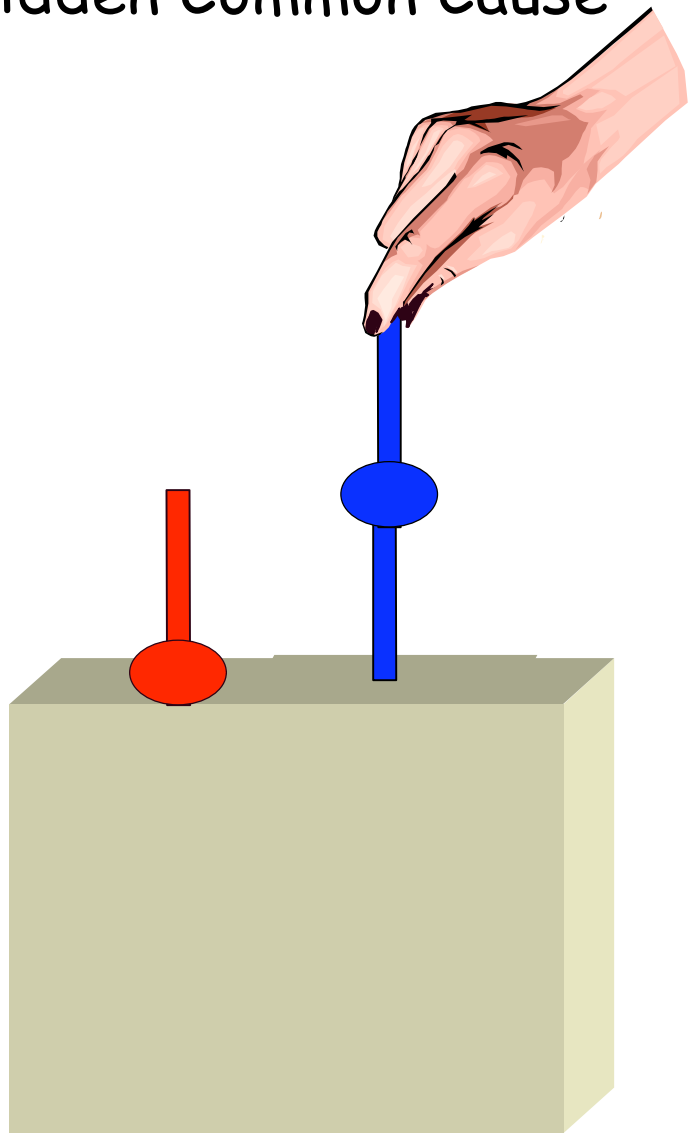

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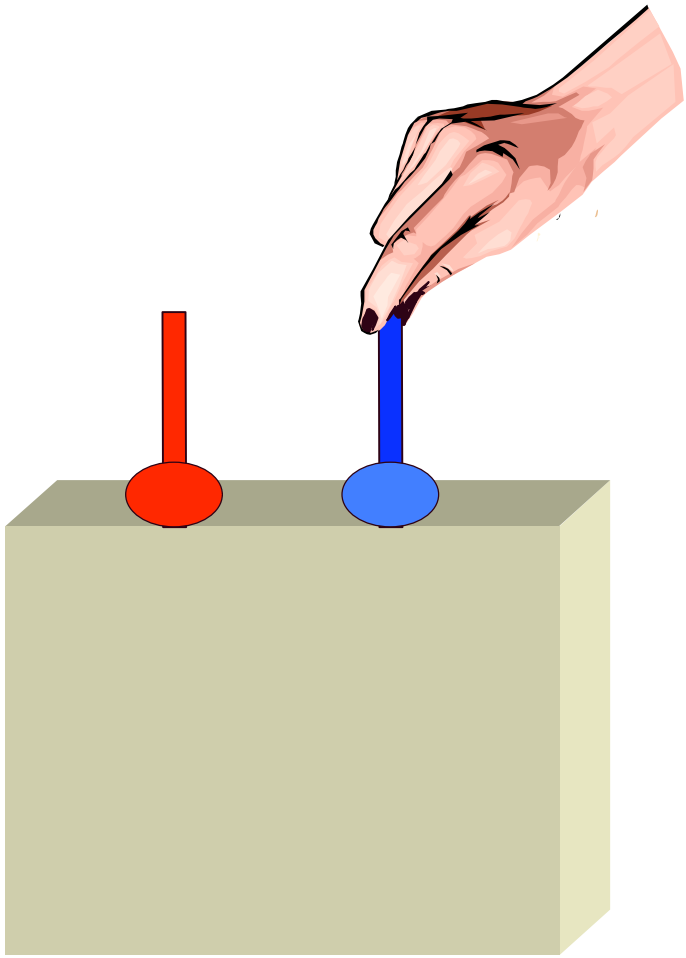

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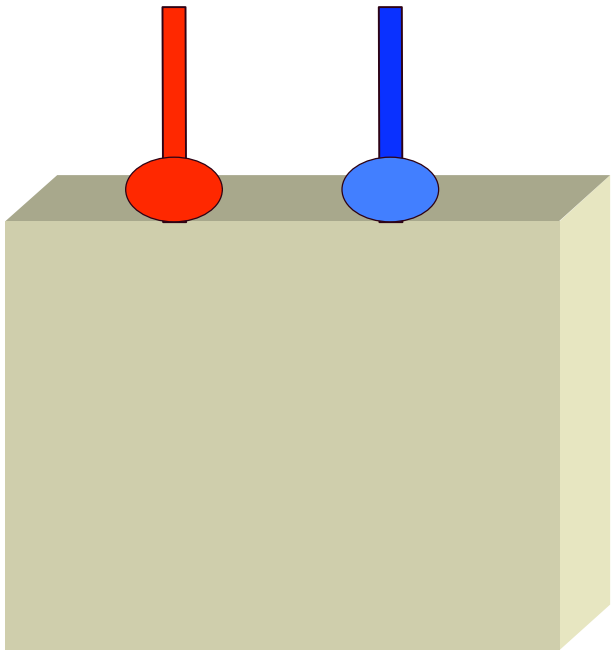

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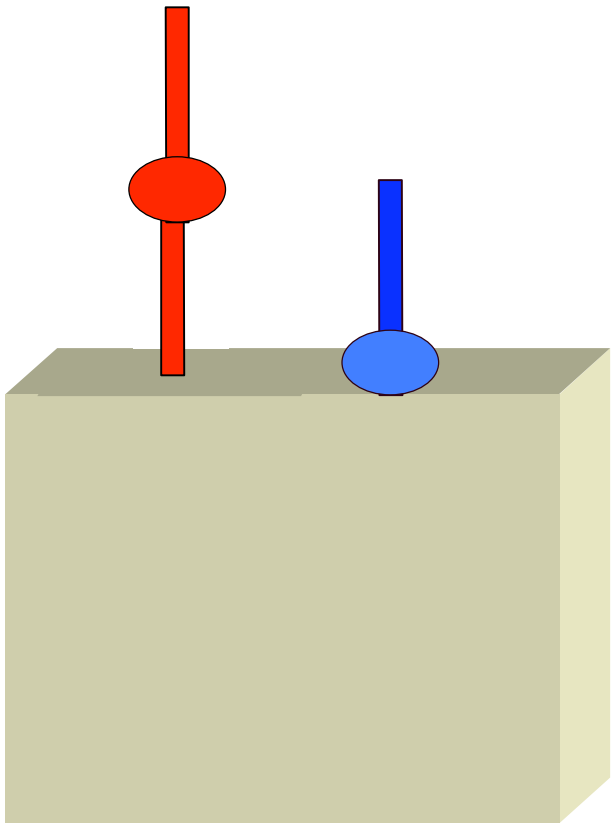

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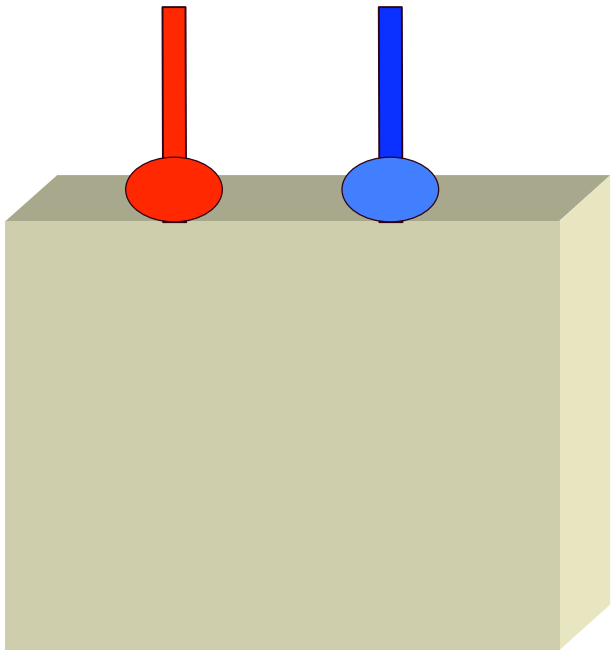
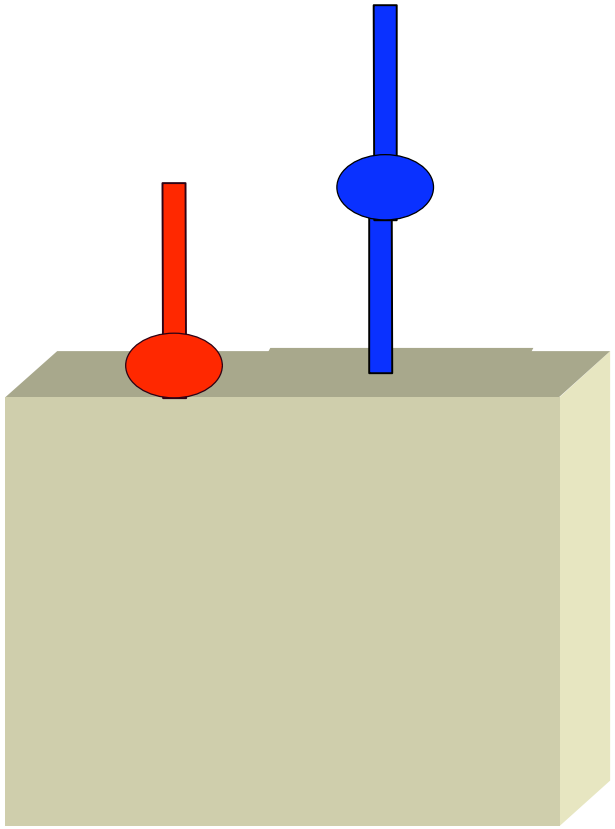
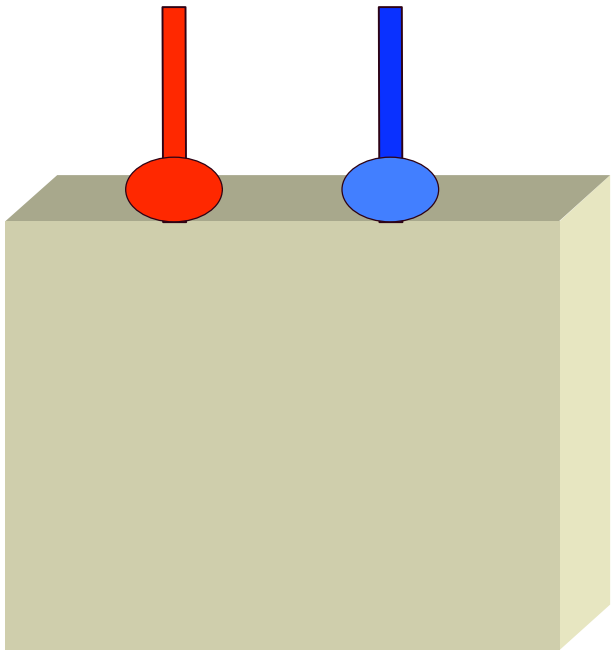


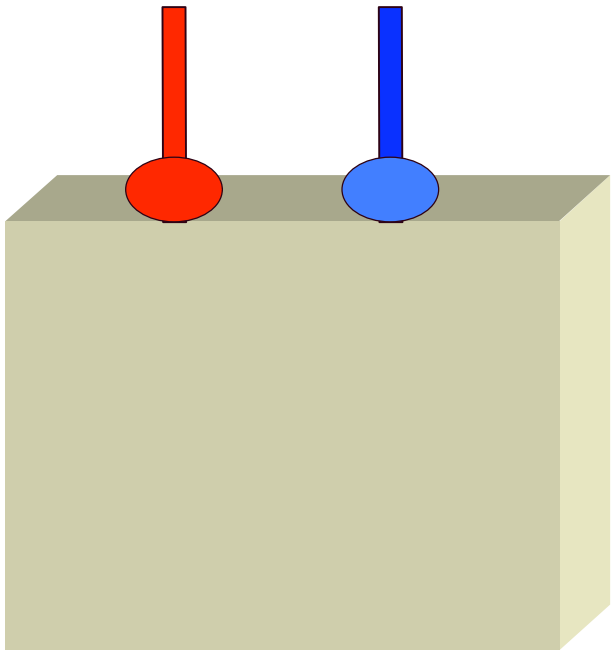
Hidden Independent Causes



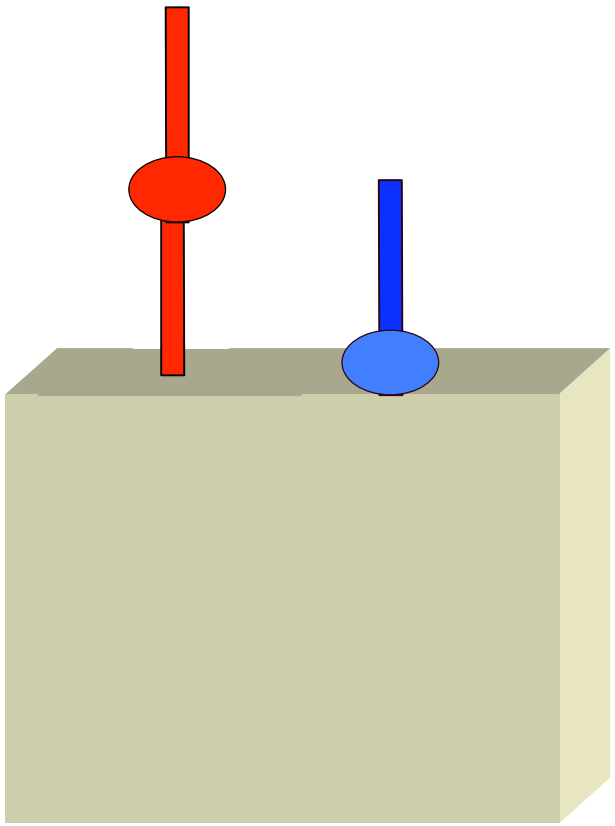
Hidden Independent Causes



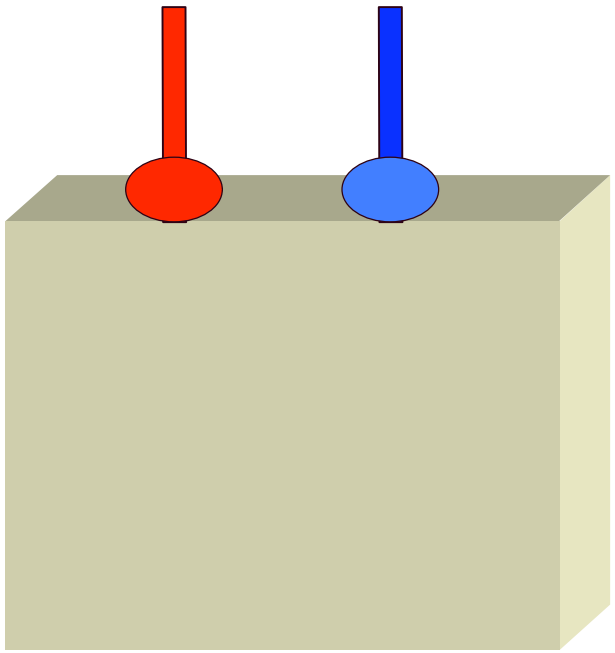
Hidden Independent Causes



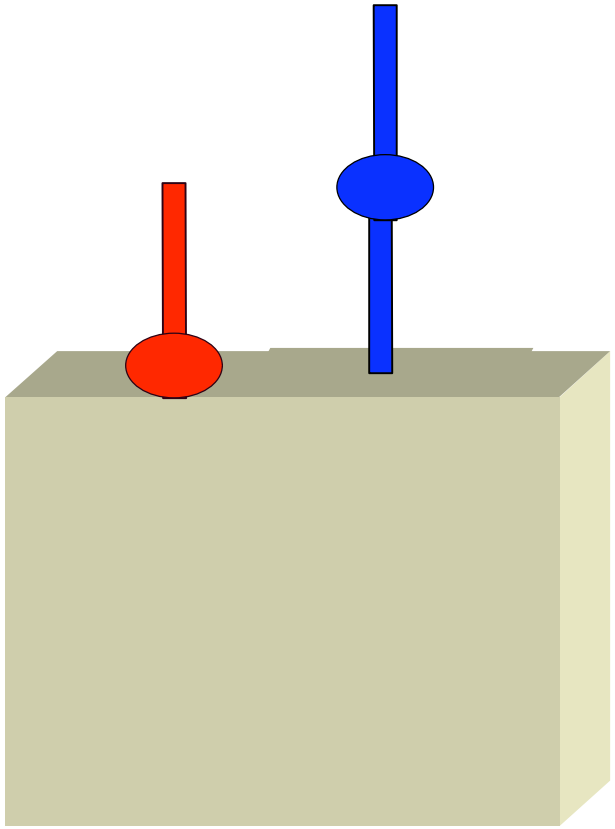
Hidden Independent Causes



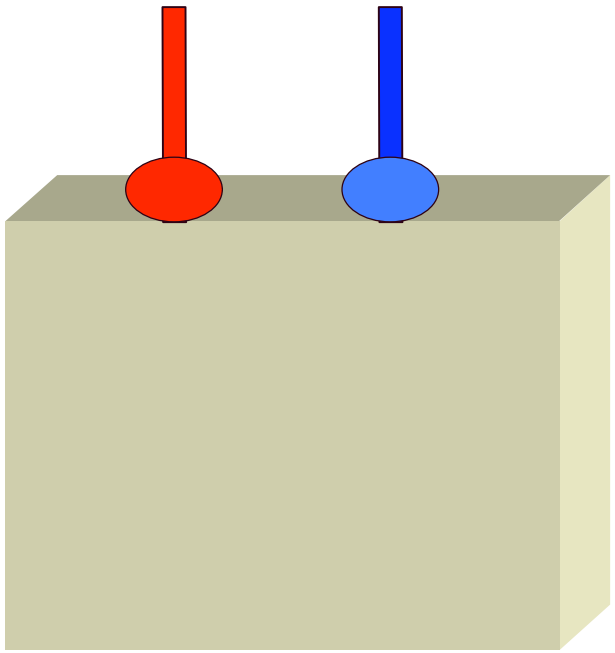
Hidden Independent Causes



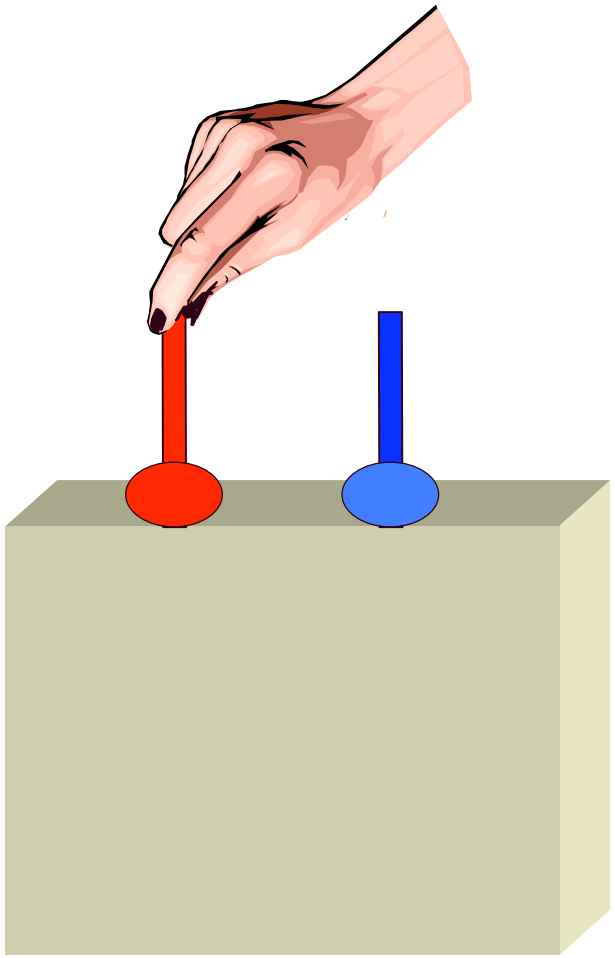
Hidden Independent Causes



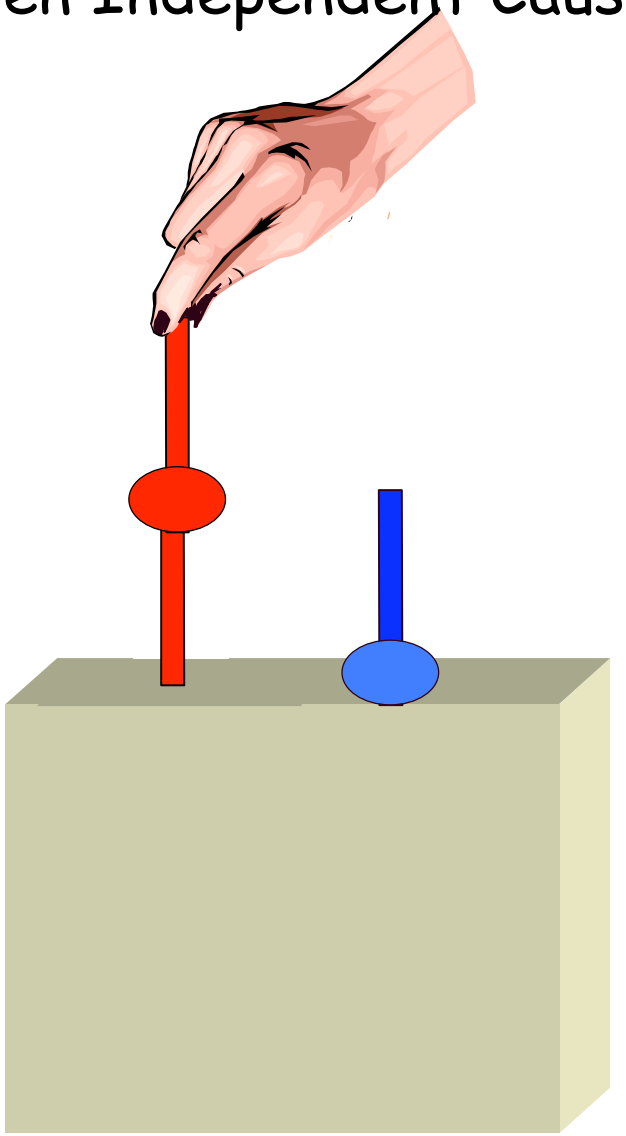
Hidden Independent Causes



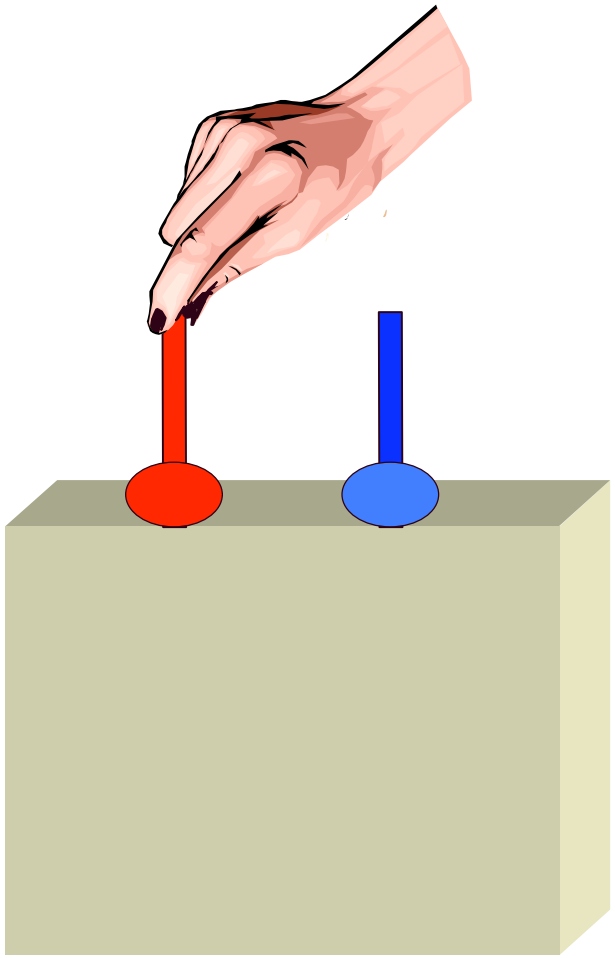
Hidden Independent Causes



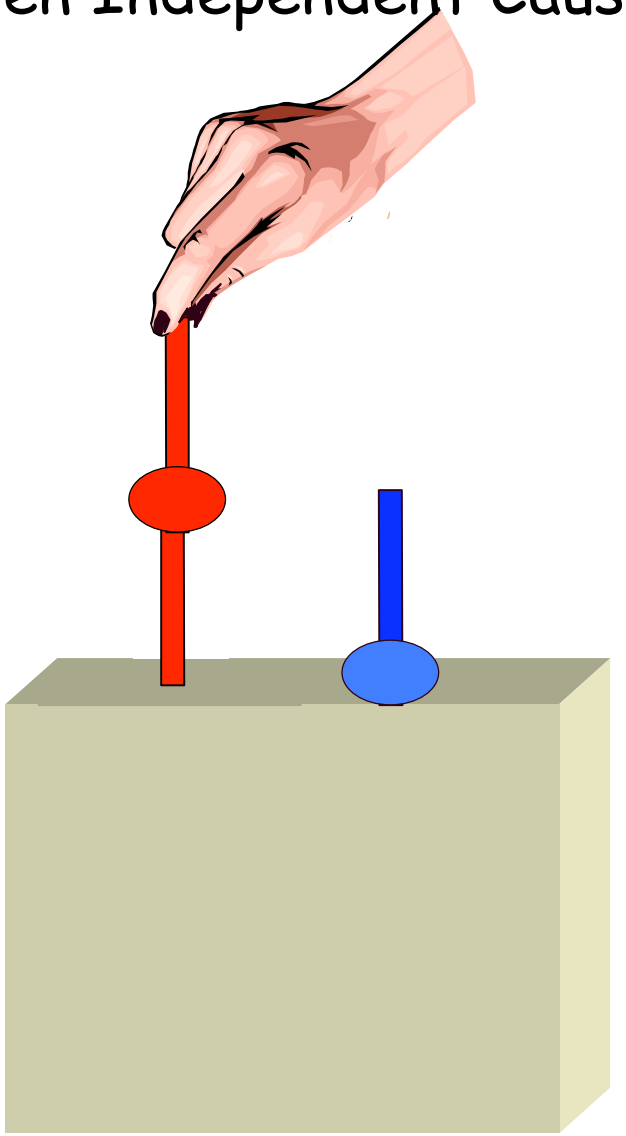
Hidden Independent Causes



Hidden Independent Causes



Hidden Independent Causes



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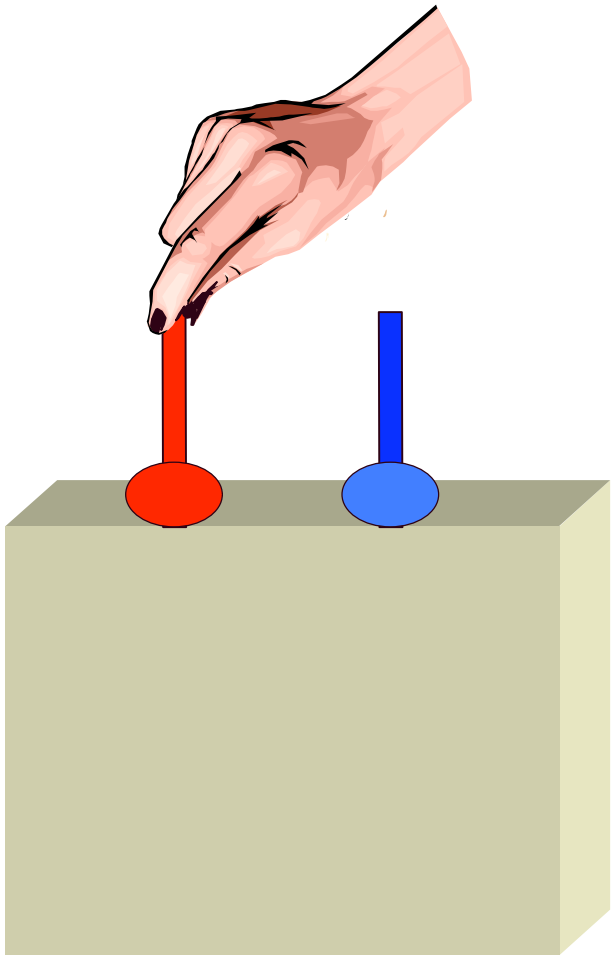
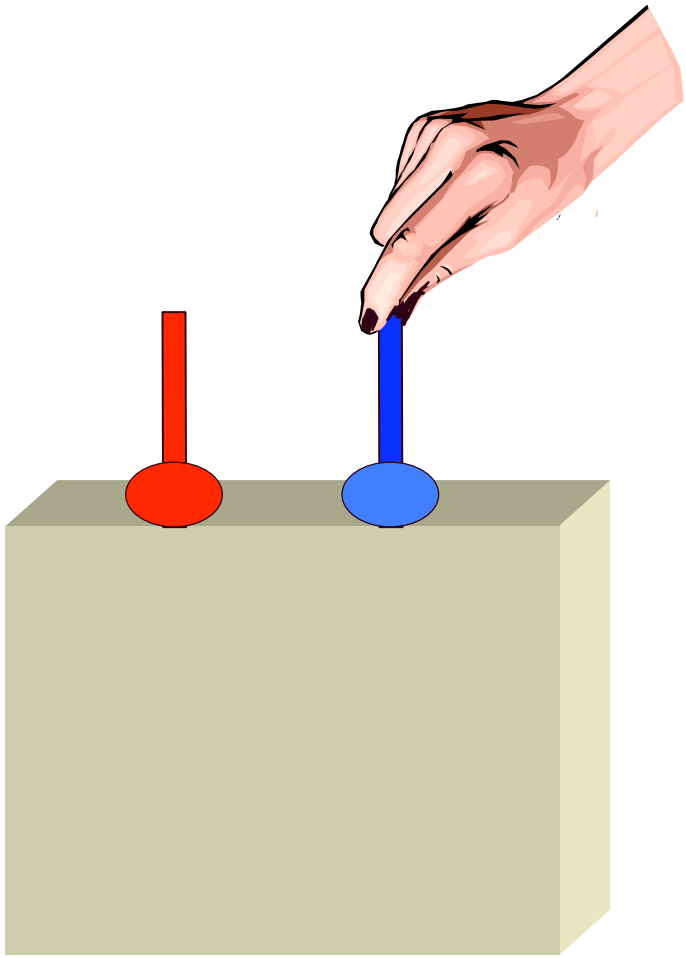
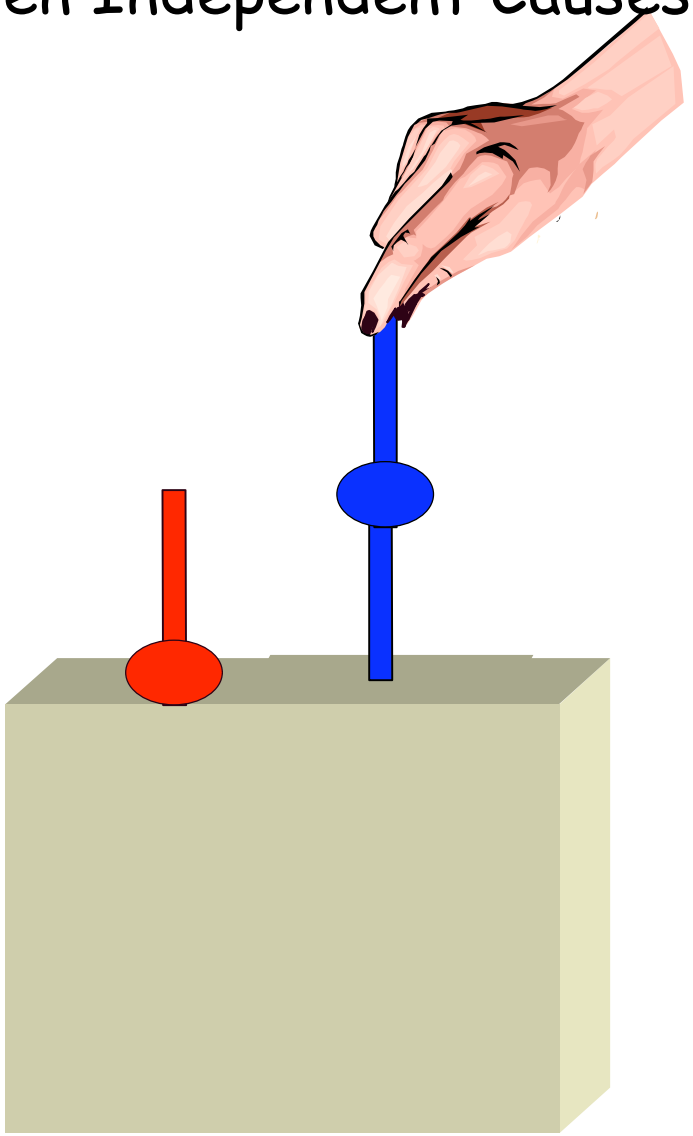


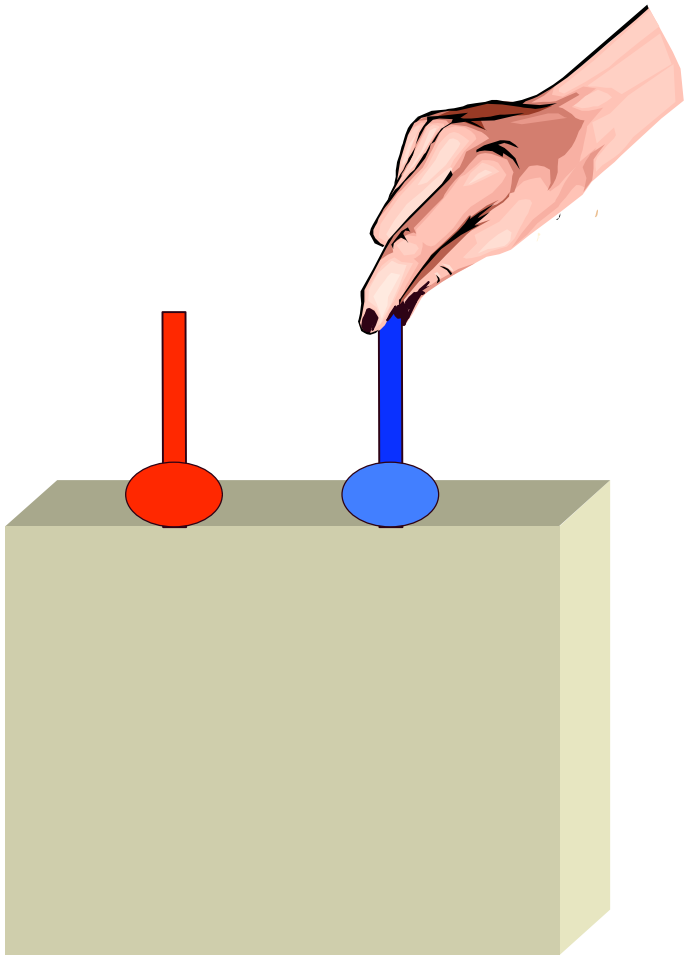
Hidden Independent Causes



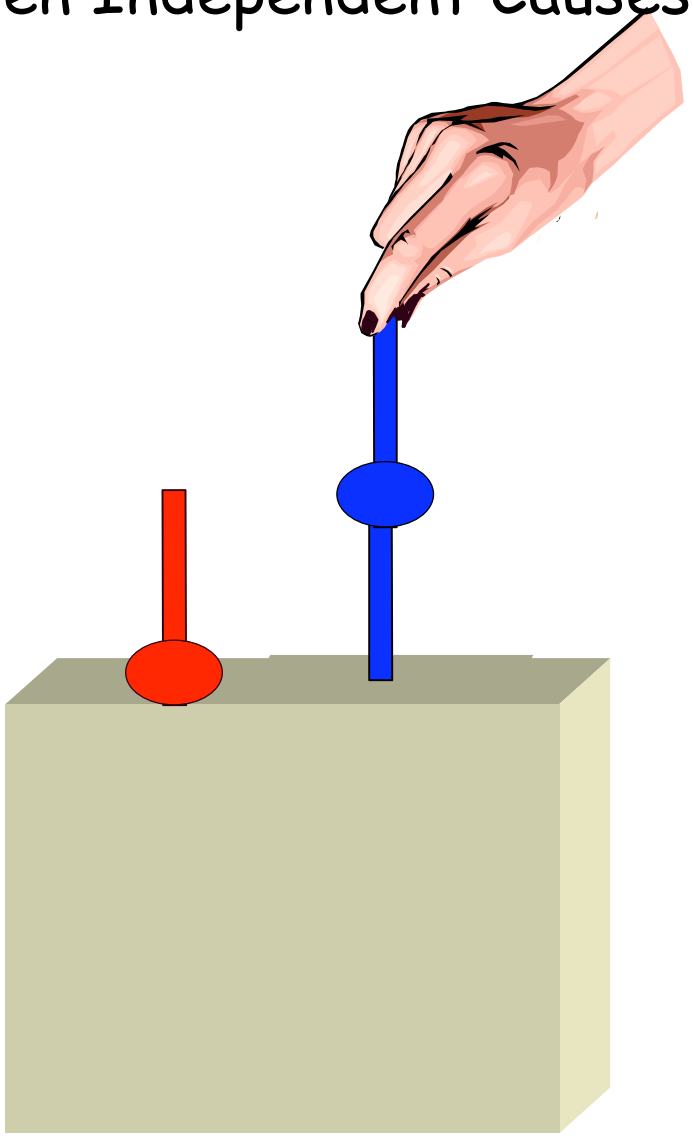
Hidden Independent Causes



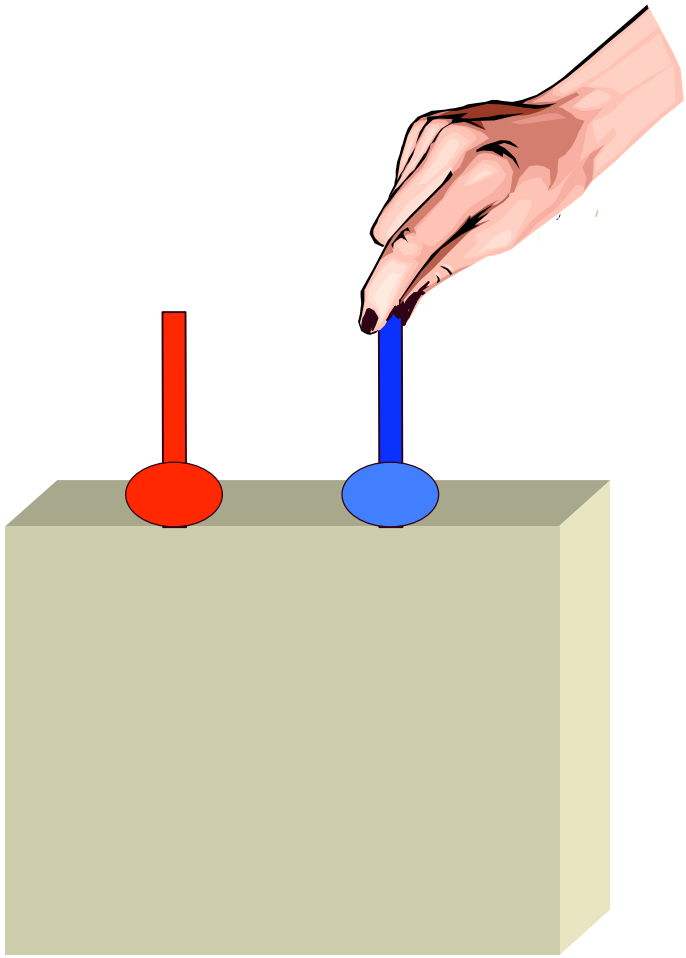
Hidden Independent Causes



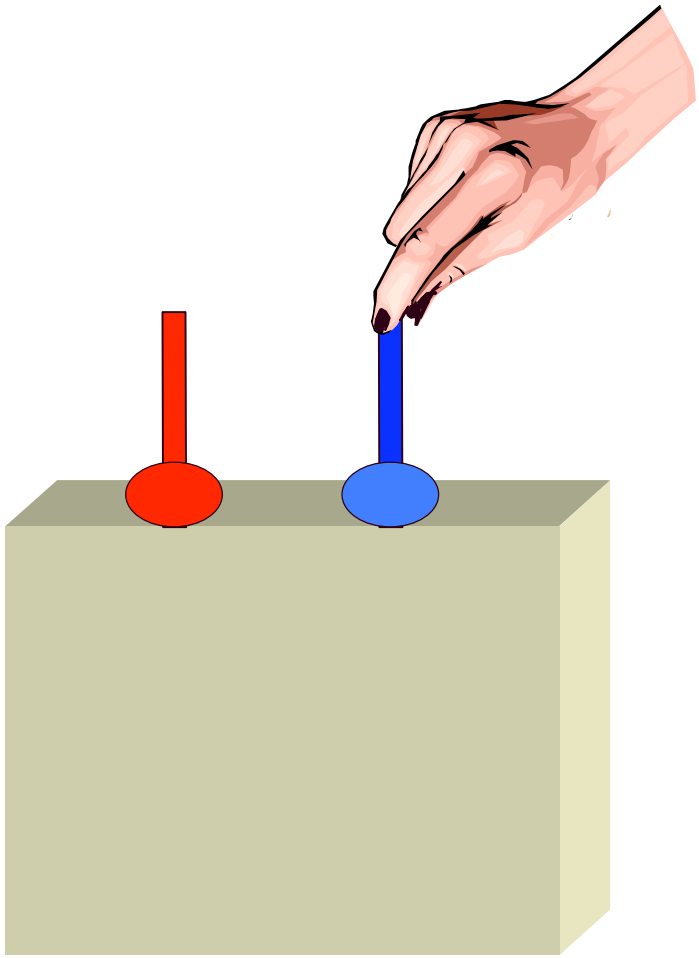
Hidden Independent Causes



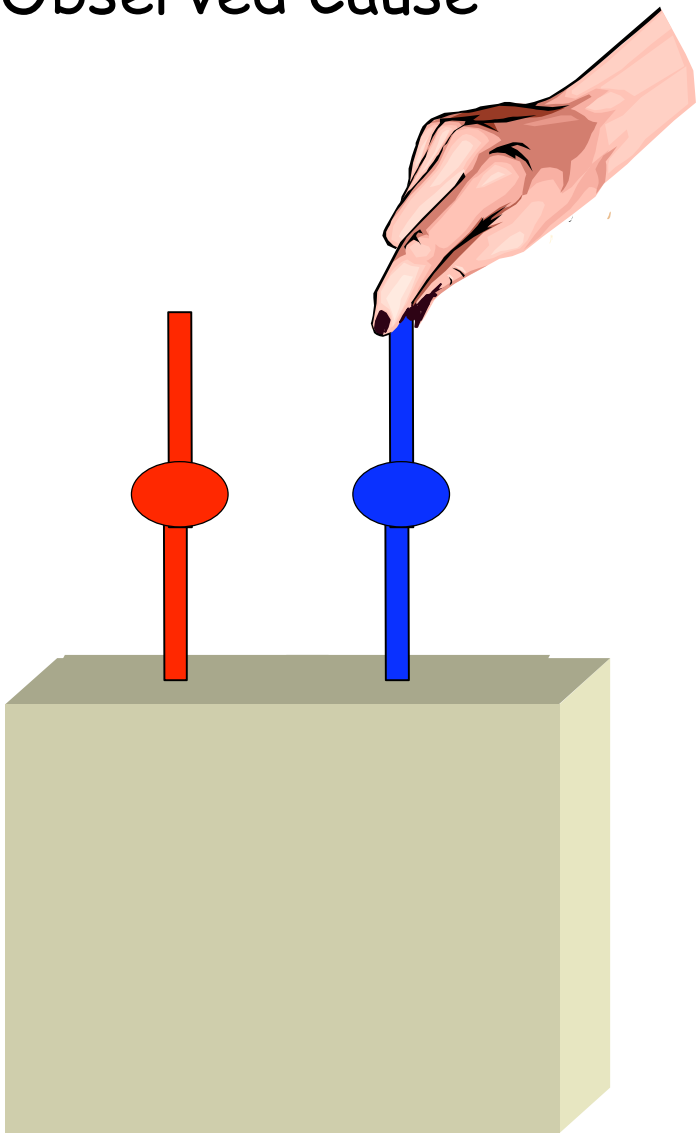
Hidden Independent Causes



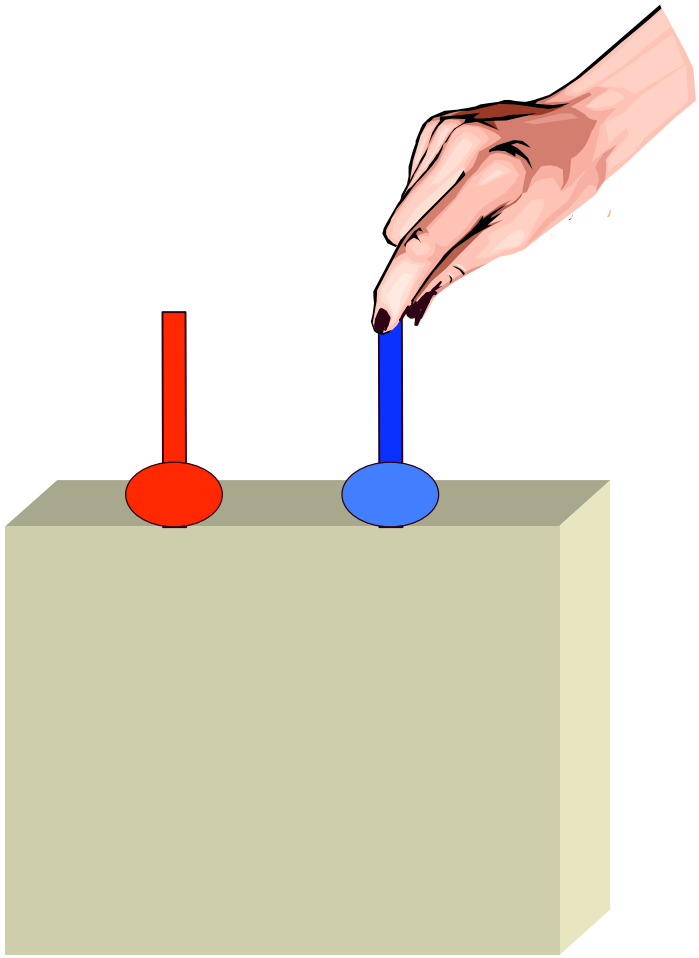
One Observed Cause



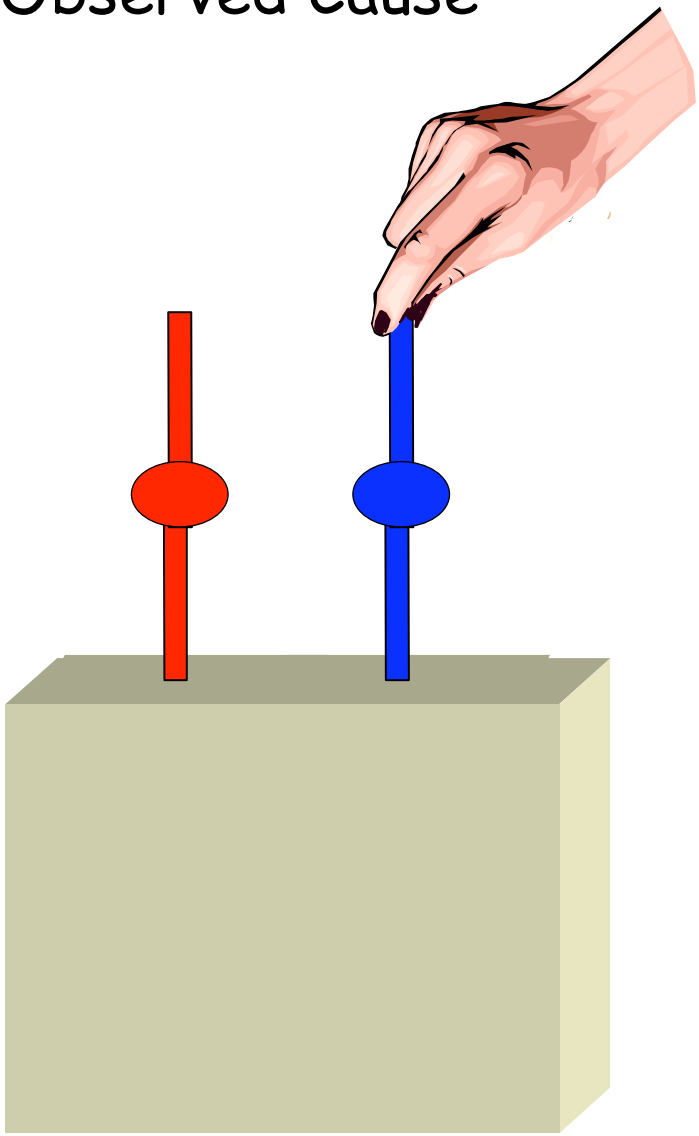
One Observed Cause



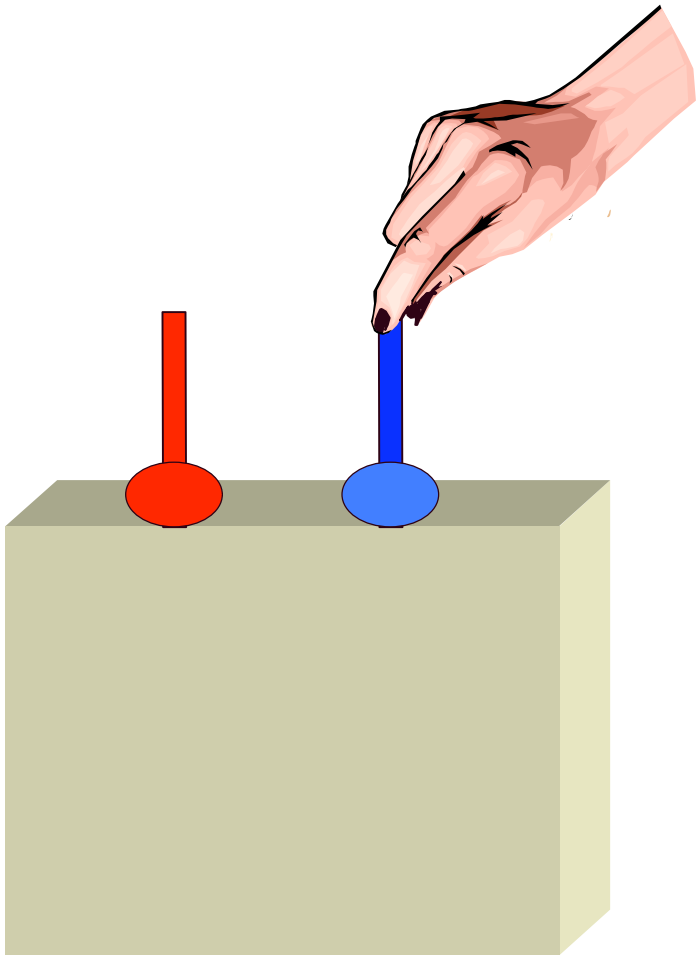
One Observed Cause



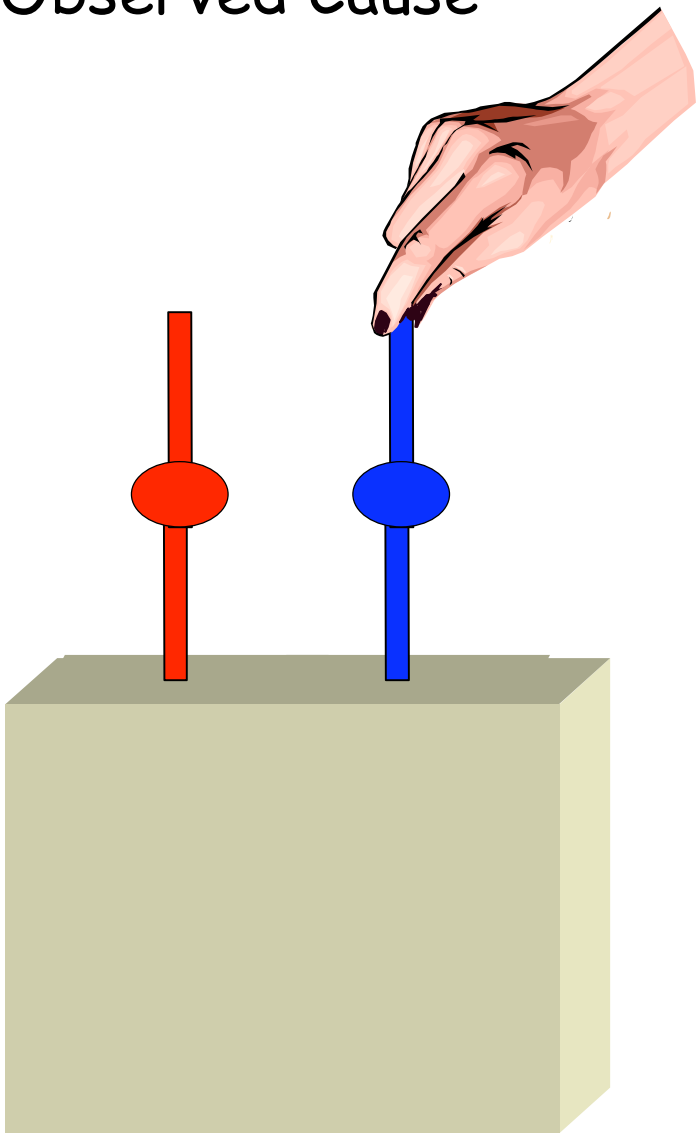
One Observed Cause



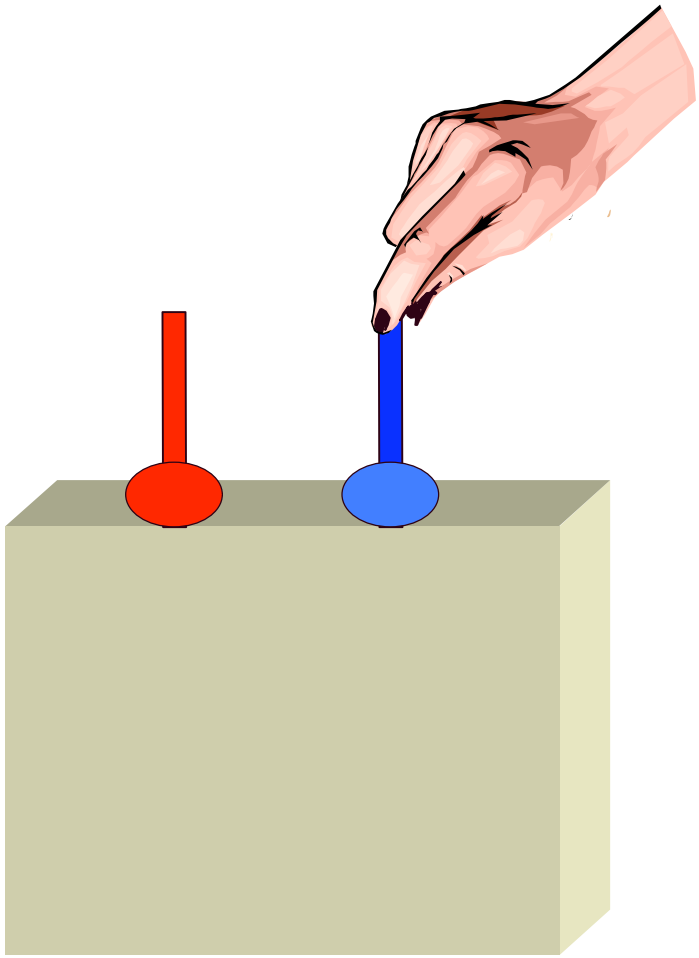
One Observed Cause



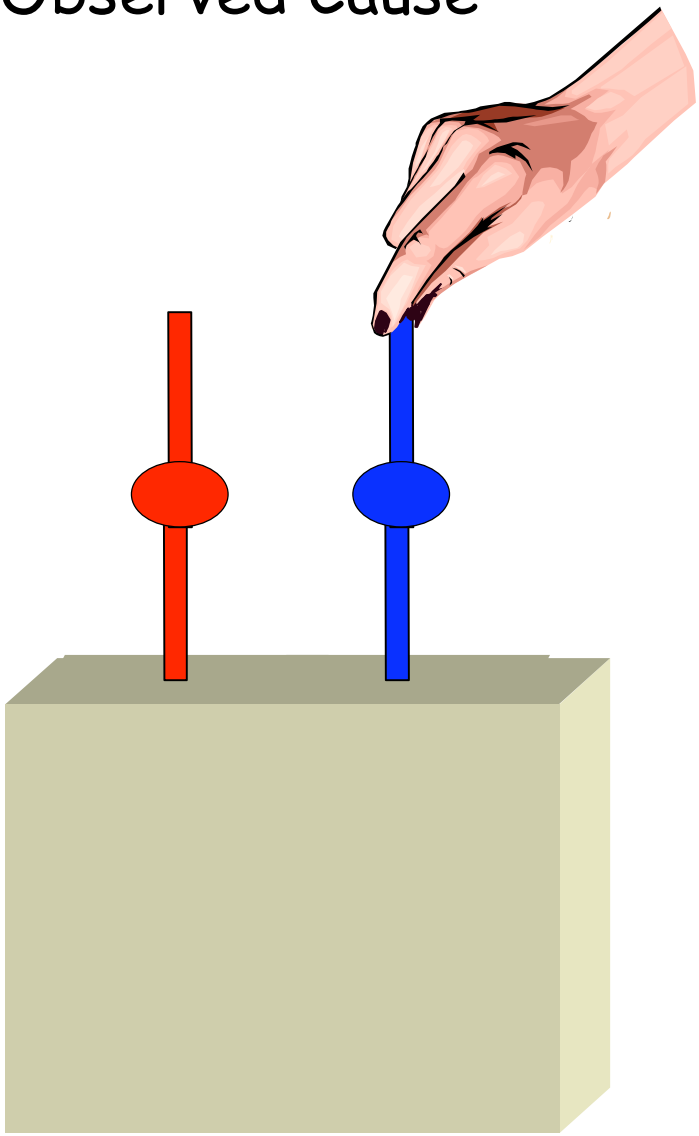
One Observed Cause



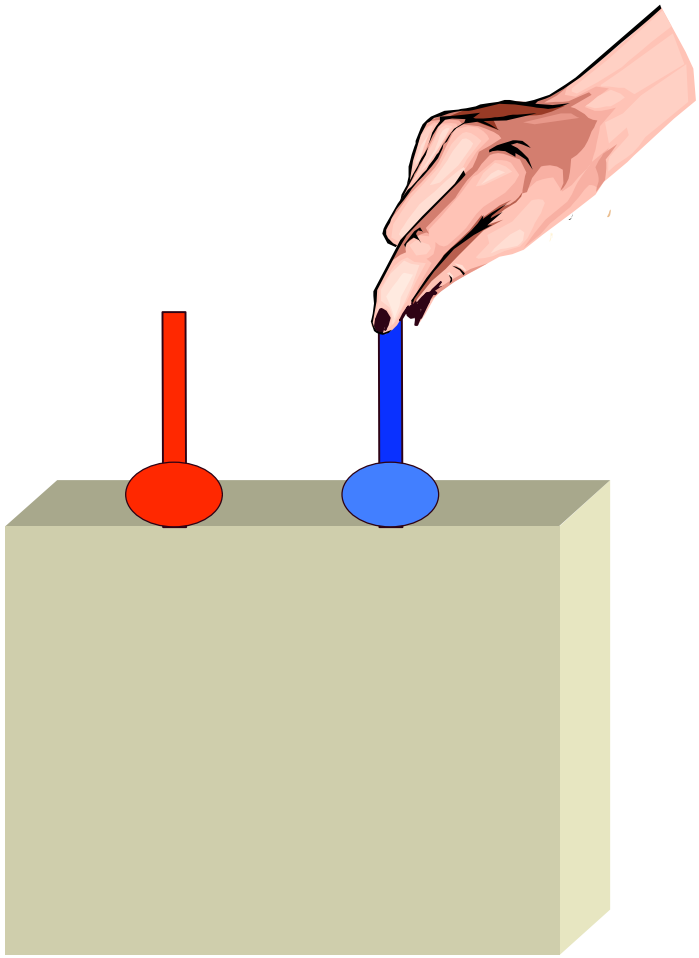
One Observed Cause



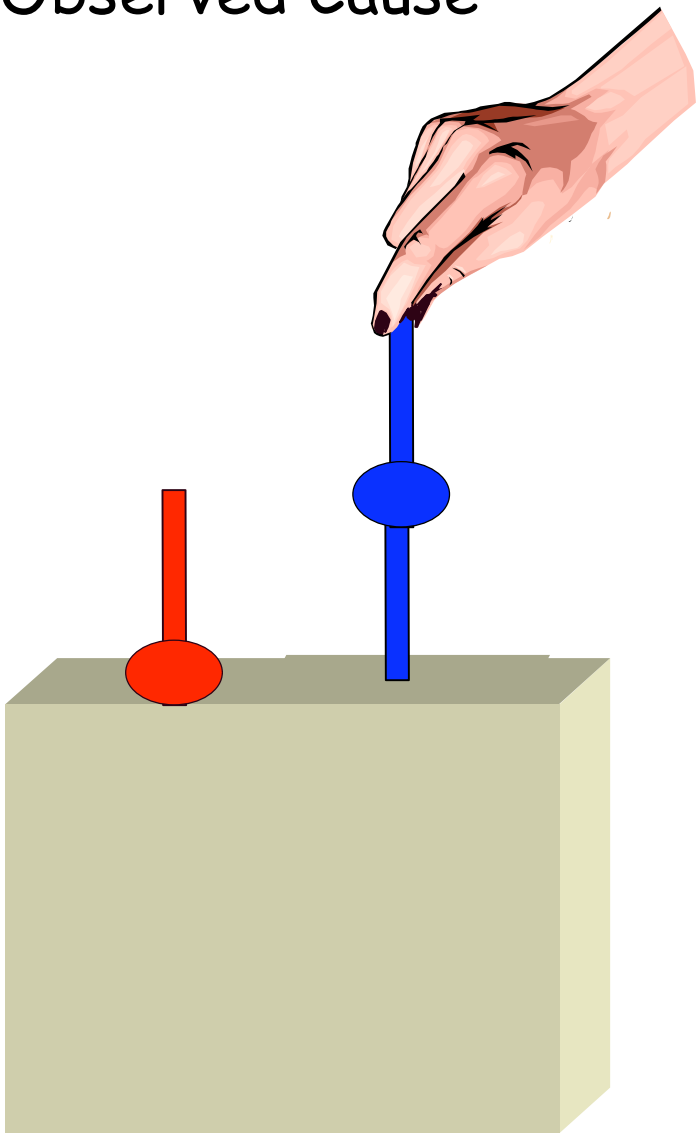
One Observed Cause



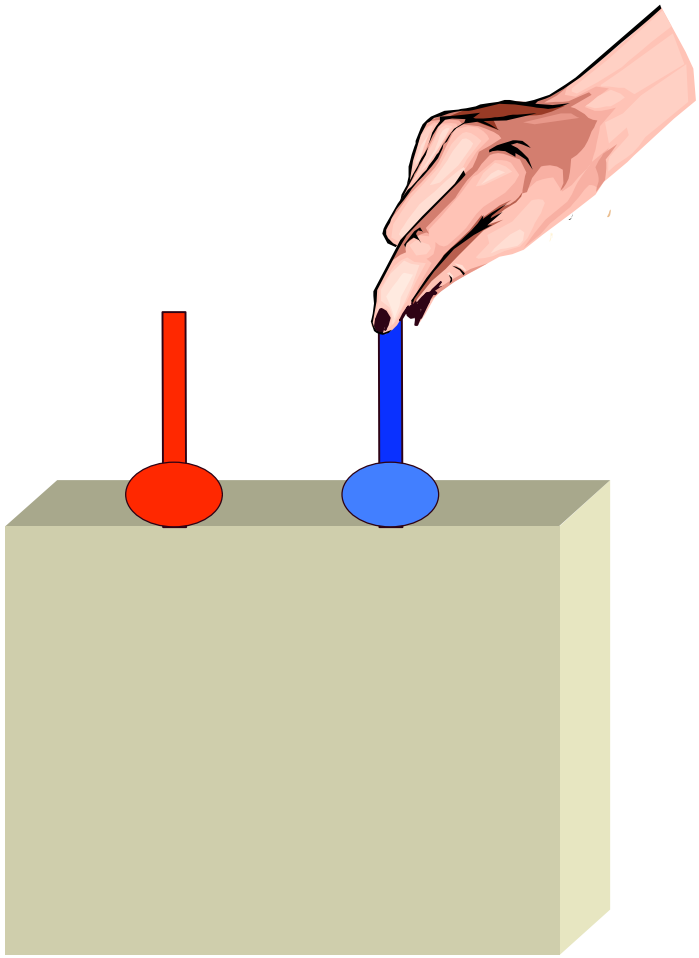
One Observed Cause



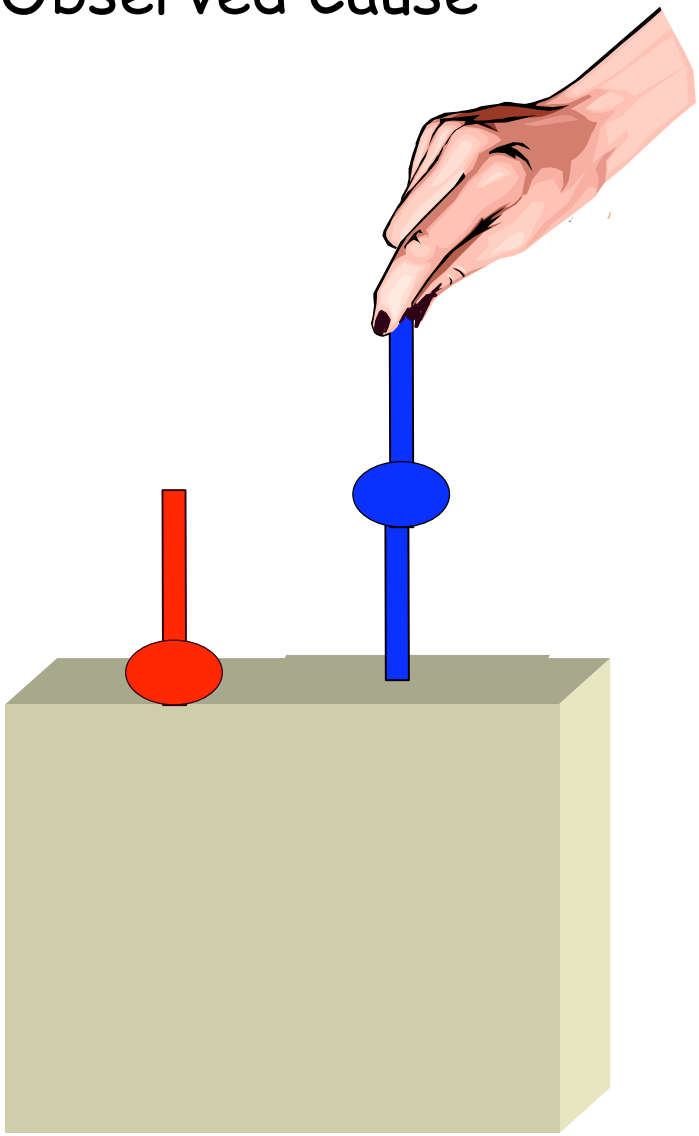
One Observed Cause



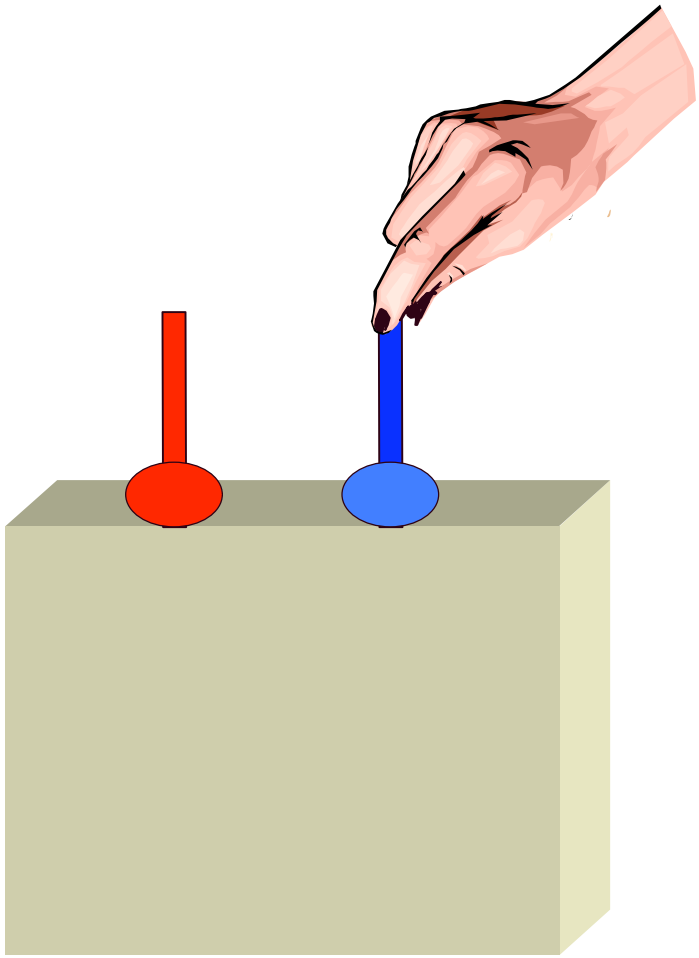
One Observed Cause



One Observed Cause

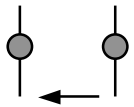
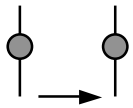
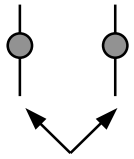
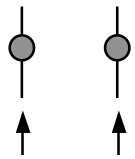


One Observed Cause



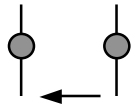
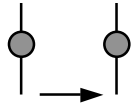
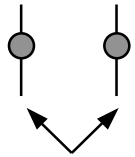
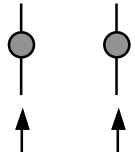
Multiple Choice - Adults

What is making the stick-balls move?

Bluey makes Reddy move	Reddy makes Bluey move
	
Something makes them both move together	Two things make each of them move separately
	

Results

Percentage of Responses in Each of the Test Trials (N = 48)

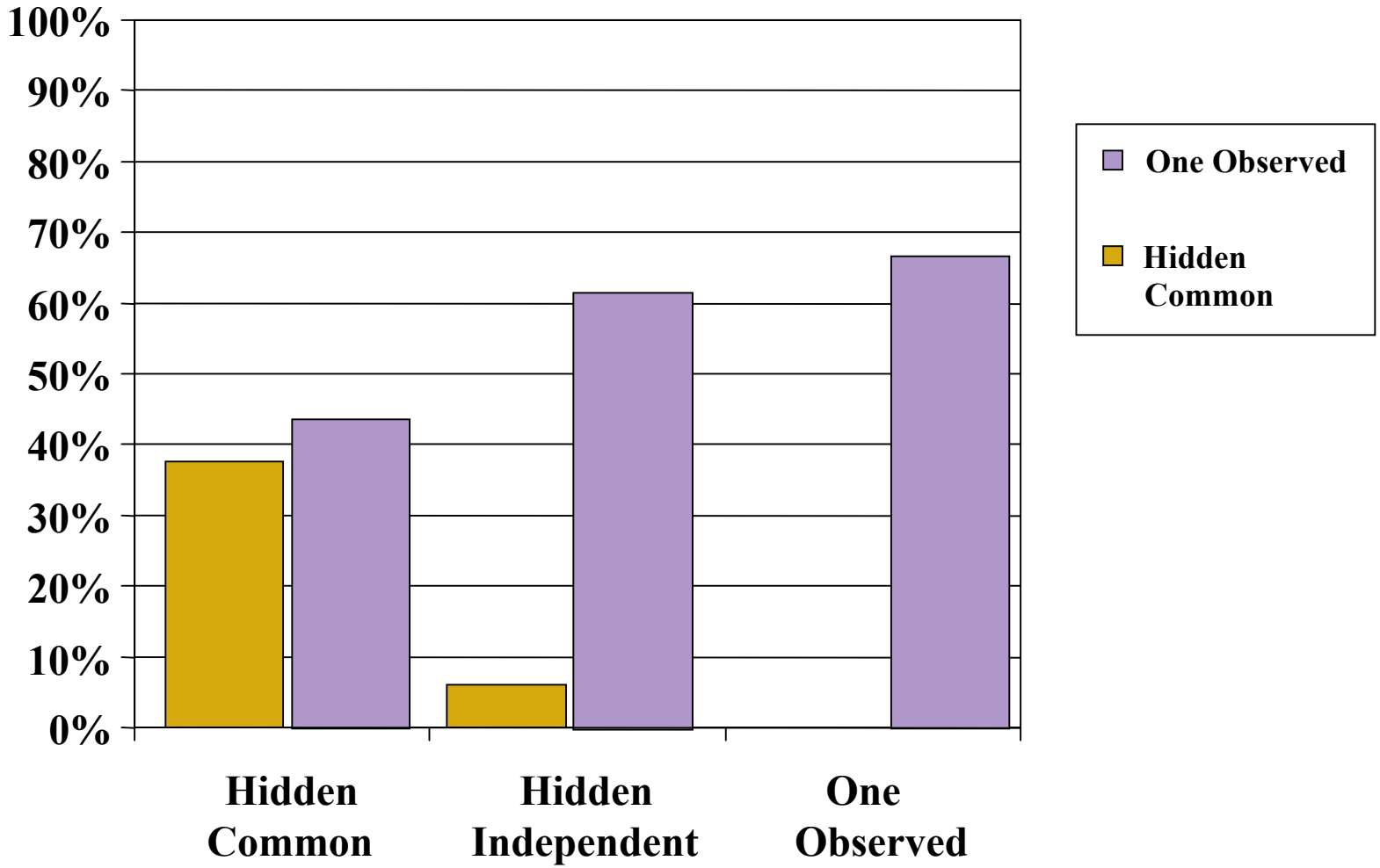
	Trial Type		
Answer Choice	Hidden Common	Hidden Independent	One Observed
	0	0	**65**
	2	0	6
	**63**	4	8
	35	**96**	21

5-year-olds

- Do young children also infer a hidden cause given the same pattern of data?

- Method
  - Multiple Choice
  - Three conditions: Hidden common cause, hidden independent causes, one observed cause

Results

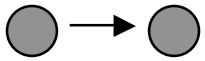
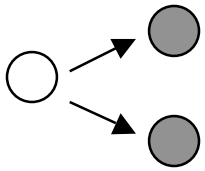
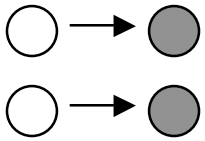

100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Hidden Common
Hidden Independent
One Observed
One Observed
Hidden Common

Free-response

- Multiple choice: Participants can choose by elimination rather than learning causal structure.
- Can people infer hidden causal structure without being given explicit choices?
- Method:
  - Train participants to draw causal graphs.
  - Identical procedure to multiple choice

Results

Percentage of Responses in Each of the Test Trials (N = 48)

Answer Choice	Trial Type		
	Hidden Common	Hidden Independent	One Observed
	4.3	0	**71.7**[a]
	**58.7**	28.3	6.5
	17.4	**52.2**	8.7
Other	19.6	19.6	13

[a] This was the correct one-cause answer only, no one was incorrect

Free-response

- Multiple choice: Participants can choose by elimination rather than learning causal structure.
- Can people infer hidden causal structure without being given explicit choices?
- Method:
  - Train participants to draw causal graphs.
  - Identical procedure to multiple choice

Common Effects vs. Unobserved

Common Effects

Y and X move together (3times)

E. Moves Y and X doesn't move

Y and X move together (2 times)

Why are they moving together?

Unobserved Variables

Y and X move together (3times)

E. Moves Y and X doesn't move

E. Moves X and Y doesn't move

Y and X move together (2 times)

Why are they moving together?

One Puppet Explanations

	Common Effects	Unobserved
No	0	11
Yes	16	5

Something Else Explanations

	Common Effects	Unobserved
No	16	7
Yes	0	9

The Story So Far

- From patterns of intervention, dependence, independence and probability children (and adults) can normatively infer
- Which cause led to an effect
- Causal strength
- Causal direction
- Complex causal structure
- Unobserved causal structure