Causality + Scientific Concepts
What is an *Animal*?

Living thing w/  
Sentience  
Locomotion

Living thing b/c  
Heterobolic metabolism  
Sentience  
Locomotion
Scientific Concepts Refined by Causal Discoveries

- Heat
- Mass
- Organism
- Gene
- &c.
Causality

If a burglar is in the house, then the door will be ajar. The door is ajar. Ergo, a burglar is in the house.
Causality & Bayes’ Theorem

P (the door is ajar | a burglar is in the house) = ?
P (the door is ajar) = ?, P (the door is not ajar) = 1 - ?
P (a burglar is in the house | the door is ajar) = ?
Causality & Bayes’ Theorem

conditional prob. \quad P(\text{the door is ajar} \mid \text{a burglar is in the house}) = ?

prior prob. \quad P(\text{the door is ajar}) = ?, P(\text{the door is not ajar}) = 1 - ?

post prob. \quad P(\text{a burglar is in the house} \mid \text{the door is ajar}) = ?
Causality & Bayes’ Theorem

\[
P(\text{the door is ajar} \mid \text{a burglar is in the house}) \cdot P(\text{the door is ajar}) = P(\text{the door is ajar} \mid \text{a burglar is in the house}) \cdot P(\text{the door is ajar}) + P(\text{the door is ajar} \mid \text{a burglar is NOT in the house}) \cdot P(\text{the door is NOT ajar})
\]
FIGURE 2 | Various reactions from a child interacting with two ‘Blicket Detectors’ (originally used by Gopnik and Sobel\textsuperscript{65}), from the protocol described in Legare.\textsuperscript{66}
concept “Blicket” corresponds to Bayes’ Theorem
What about other concepts?
- **Theory-theory**
  - Depicts children’s thinking as constrained by their prior theories
    - *Theories posit causes that allow children to interpret, predict, and explain covariation*
Theory-theory

- Seeks to characterize children’s theories at discrete ages
• **Theory-theory**
  
  • **Theory of mind** (3 to 4.5 years; Wellman, 1990)
    
    Causes of behavior: desires to beliefs
  
  • **Theory of biology** (4 to 7 years; Carey, 1985)
    
    Causes of illness: misbehavior to germs
  
  • **Theory of physics** (6 to 12 years; Spelke et al., 1992)
    
    Causes of balancing: size to mass
Theory-theory

“The Mystery of the Immaculate Transition”

- How do children generate new theories?
- What does a conceptual change look like?

- Source
- Breadth
- Path
- Rate
- Variability in any combination of these
• The Microgenetic Method

• High density of observations relative to the rate of change

• When the change is catalyzed through input (e.g., feedback), many observations are required
The Microgenetic Method

- Observations are subjected to intensive trial-by-trial analysis
  - For example, tracking variation in rule-use over successive learning trials
Integrating the two trends:

- Microgenetic methods should reveal
  - Sources of conceptual change
  - How prior theories affect children’s responses to these sources
• **Initial State:**

Theory of life ⇒ X is necessary for life

Extension of X ⇒ Only animals have X

*Living things* concept ⇒ Only animals are alive
• **Pattern of Change:**

  Theory of life $\Rightarrow$ X is necessary for life

  Extension of $X$ $\Rightarrow$ Animals *and plants* have $X$

  *Living things* concept $\Rightarrow$ Animals *and plants* are alive
Pattern of Change:

Theory of life ⇒ X is necessary for life

Extension of W ⇒ Animals and plants have W

Living things concept ⇒ Animals are alive
Model Case:
Development of the *Living Thing* Concept
Piagetian interview with a 6-year-old:

Give me the name, tell me some thing that is alive. —*Animals.*

A cat? —*Yes.* ... *We often see some cats.*

An automobile? —*No... It runs.*

The wind? —*No. ... Because it does not run.*

A bird? —*Yes. ... Because it flies in the air.*

An airplane? —*No. ... Because it flies in the air, like birds.*

A fly? —*Yes. ... Because it flies in the air.*

(Laurendeau & Pinard, 1962)
What is Alive?

<table>
<thead>
<tr>
<th></th>
<th>Animals</th>
<th>Plants</th>
<th>Artifacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>4- to 5-y.o.</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>5- to 7-y.o.</td>
<td>✓</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>10-y.o. to Adults</td>
<td>✔</td>
<td>✔</td>
<td></td>
</tr>
</tbody>
</table>

(Carey, 1985; Hatano et al., 1993)
### Biological Features

<table>
<thead>
<tr>
<th>Feature</th>
<th>Animals</th>
<th>Plants</th>
<th>Artifacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grow</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Heal</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Reproduce</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Need Water</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>

4- to 10-y.o.  

(Hickling & Gelman, 1995; Backscheider, Shatz, & Gelman, 1993; Springer & Keil, 1989; Hatano & Inagaki, 1996)
Teleological Action

- self-generated movement
- contingently directed toward an object, state, or location (i.e., its goal)
- for the sake of the benefit the goal provides to the agent.
Teleological Agents
CHANGE for BENEFITS

BENEFIT

NO BENEFIT

YES!

NO!
Non-teleological Agents
DO NOT CHANGE for BENEFITS

BENEFIT

NO!

NO BENEFIT

NO!

NO!
Teleological action is necessary for life

Only teleological agents can be alive.
Children’s Theory of Life:  
*Life is caused by teleological action.*

- **Predictions:**
  1. Attribute life to novel goal-directed agents
Children’s Theory of Life:  
*Life is caused by teleological action.*

- **Predictions:**

  (2) Errors in predicting teleological action should mirror errors in attributing life.

  - *Five-year-olds: everything or only animals act teleologically;*
  - *Ten-year-olds and adults: plants and animals—but not artifacts—act teleologically*
Children’s Theory of Life: 
*Life is caused by teleological action.*

- **Predictions:**

  (3) Upon learning that plants—like animals—act teleologically, 5s should infer that plants—like animals—are living things.
PREDICTION #1:

- Children attribute life to novel goal-directed agents

TEST:

- Showed children novel agents that
  - Moved autonomously and toward a goal, or
  - Moved autonomously but aimlessly
- And asked them whether the agent is alive

(Opfer, 2002)
GOAL VIDEO

4-year-olds (N = 16)
5-year-olds (N = 16)
7-year-olds (N = 16)
10-year-olds (N = 16)
Adults (N = 16)

NO GOAL VIDEO

4-year-olds (N = 16)
5-year-olds (N = 16)
7-year-olds (N = 16)
10-year-olds (N = 16)
Adults (N = 16)

(Opfer, 2002)
Biological Properties

- Is it alive?
- Can it die?
- Can it grow?
- Can it make more little ones just like it?
- Does it need something?
- Does it need food?
- Does it need water?

(Opfer, 2002)
Attributions of LIFE

(Opfer, 2002)
Attributions of BIOLOGICAL PROPERTIES

Yes (of 7 possible)

0% 25% 50% 75% 100%

4 5 7 10 Ad

Goal

No Goal

(Opfer, 2002)
Age-Differences in Attributions:

4-year-olds: No goal effects, nothing > chance

5-year-olds: life

7-year-olds: life, growth

10-year-olds: life, growth, death, reproduction, needing something

Adults: life, growth, death, reproduction, needing food & water

(Opfer, 2002)
What WERE the agents anyway?

- **Animal-type life form:**
  - “an animal”
  - “insect”
  - “frog”

- **Non-animal life form:**
  - “germ”
  - “jelly monster”
  - “a heart”
  - “something that lives and can die”

- **Non-life form:**
  - “shooting star”
  - “rocksteroid”
  - “volcano guts”
  - “magnet”

(Opfer, 2002)
Life Form Identifications

No Goal (Opfer, 2002)
Life Form IDs—Goal Condition

% Life Form Identities

- All Life Forms
- Non-Animals
- Animals

(Opfer, 2002)
Children’s Theory of Life: Life is caused by teleological action.

- **Predictions:**
  1. Attribute life to novel goal-directed agents

(Opfer, 2002)
**Finding:**

(1) DO attribute life to novel goal-directed agents

- 5-year-olds through adults associated life with goal-directed movement
- Around age 10, children began to interpret goal-directed agents as non-animal life forms.
Children’s Theory of Life:  
Life is caused by teleological action.

- **Predictions:**

  (2) Errors in predicting teleological action should mirror errors in attributing life.

  - *Five-year-olds*: everything or only animals act teleologically;

  - *Ten-year-olds and adults*: plants and animals—but not artifacts—act teleologically
Option A. Option B.

Option A. Option B.

Option A. Option B.

Opfer & Gelman, 2001
ANIMALS

BENEFIT CONDITION

NO BENEFIT CONDITION

Option A.
Option B.
Option A.
Option B.

(From Opfer & Gelman, 2001)
MACHINES

BENEFIT CONDITION

NO BENEFIT CONDITION

Option A.
Option B.
Option A.
Option B.

Option A.
Option B.
Option A.
Option B.

(Opfer & Gelman, 2001)
ARTIFACTS

**BENEFIT CONDITION**

Option A.

Option B.

**NO BENEFIT CONDITION**

Option A.

Option B.

(Opfer & Gelman, 2001)
<table>
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<tr>
<th>Entities Predicted to Act Teleologically</th>
<th>Animals</th>
<th>Plants</th>
<th>Machines</th>
<th>Artifacts</th>
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<tbody>
<tr>
<td>Everything</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Complex Things</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Living Things</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Animals</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Opfer & Gelman, 2001)
Rule Use
No Benefit Condition

Subjects Following Rule

Animals

Living Things
Complex Things
Everything

(Ropfer & Gelman, 2001)
Rule Use

Benefit Condition

Subjects Following Rule

50%

40%

30%

20%

10%

0%

5 10 Ad

Living Things

Complex Things

Animals

Everything

(Opfer & Gelman, 2001)
### Rule Use

**Entities Predicted to Act Teleologically**

<table>
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*(Opfer & Gelman, 2001)*
Children’s Theory of Life:  
*Life is caused by teleological action.*

- **Predictions:**

  (2) Errors in predicting teleological action should mirror errors in attributing life.
Children’s Theory of Life:  
Life is caused by teleological action.

- **Finding:**

  (2) Errors in predicting teleological action DID mirror errors in attributing life.

  - *Five-year-olds: everything or only animals act teleologically;*
  
  - *Ten-year-olds and adults: plants and animals—but not artifacts—act teleologically*
Children’s Theory of Life:  
*Life is caused by teleological action.*

- **Predictions:**
  
  (3) Upon learning that plants—like animals—act teleologically, 5s should infer that plants—like animals—are living things.
TEST–A Microgenetic Study

- **Source of change in life judgments**
  - Information that plants and animals are
    - *Teleological agents*
    - *Growing things*
    - *Things that need water*
    - *Living things*

*(Opfer & Siegler, 2004)*
TEST–A Microgenetic Study

- Effects of information on
  - Breadth of change
  - Path of change
  - Rate of change
- Variability in categorization by different properties

(Opfer & Siegler, 2004)
TEST: A Microgenetic Study

- **Participants**
  - 106 Kindergartners (M = 5.7 years)

- **Pretest:**
  - Is X alive?

- **Training:**
  - Feedback as Ss categorized items based on
    - Teleological agency
    - Life Status
    - Growth
    - Need for water

- **Posttest:**
  - Is X alive?

(Opfer & Siegler, 2004)
Task: Categorize items as living things.

“Alive Box” and “Not Alive Box”

“This plant is a flower.”

(Opfer & Siegler, 2004)
Task: Categorize items as living things.

"This plant is a clover."

(Popfer & Siegler, 2004)
Task: Categorize items as living things.

“This thing is a glass.”

(Opfer & Siegler, 2004)
Task: Categorize items as living things.

“Pretest” (Opfer & Siegler, 2004)
**Task:** Categorize items as living things.

“This animal is a cat.”

*(Opfer & Siegler, 2004)*
Task: Categorize items as living things.

“This animal is a caterpillar.”

(Opfer & Siegler, 2004)
The pretest continued for 3 more trial blocks.
Each trial block comprised 2 animals, 2 plants, & 2 artifacts.

Task: Categorize items as living things.

(Opfer & Siegler, 2004)
<table>
<thead>
<tr>
<th>RULES</th>
<th>Animals</th>
<th>Plants</th>
<th>Artifacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animal-Rule</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Living Thing-Rule</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Everything-Rule</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Plant-Rule</td>
<td></td>
<td>X</td>
<td>X</td>
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</table>

(Opfer & Siegler, 2004)
## Training Phase

<table>
<thead>
<tr>
<th>TRIAL BLOCK 0</th>
<th>TRIAL BLOCKS 1-3</th>
<th>TRIAL BLOCK 4</th>
</tr>
</thead>
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<tr>
<td>LIFE STATUS training group</td>
<td>Categorize items; no feedback until finished with all items for that trial block; explain corrections</td>
<td>Continue categorizing the items; receive feedback after every item for 3 new sets; explains corrections</td>
</tr>
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<td>TELEOLOGY training group</td>
<td></td>
<td></td>
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<tr>
<td>GROWTH training group</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NEED WATER training group</td>
<td></td>
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(Opfer & Siegler, 2004)
## Training Phase

<table>
<thead>
<tr>
<th>Training Group</th>
<th>Trial Block 0</th>
<th>Trial Blocks 1, 2, 3</th>
<th>Trial Block 4</th>
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<tr>
<td>LIFE STATUS training group</td>
<td>Categorize items; no feedback until finished with all items for that trial block; explain corrections</td>
<td>Continue categorizing the items; receive feedback after each item; explain corrections</td>
<td>Feedback is terminated; continue categorizing</td>
</tr>
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<td></td>
<td></td>
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*(Opfer & Siegler, 2004)*
## Training Phase

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<tr>
<td>NEED WATER training Group</td>
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(Opfer & Siegler, 2004)
Task: Categorize items as teleological agents.

(Opfer & Siegler, 2004)
TRAINING

Teleological Box

Not Teleological Box

Task: Categorize items as teleological agents.

(Opfer & Siegler, 2004)
Each trial block comprised 2 animals, 2 plants, & 2 artifacts.
Feedback-rule was identical in all conditions

Task: Categorize items as teleological agents.

(Opfer & Siegler, 2004)
During Training: Teleology Group—First Trial

First Answer to a Plant Problem

(Opfer & Siegler, 2004)
During Training:
Teleology Group—Last Trial

Child: Because it wanted to get sunlight to live and to .... If the sun was over on the other side and someone moved it [the plant], it would have to go back to the other side to live ... to live.

(Opfer & Siegler, 2004)
POSTTEST

Alive Box

Not Alive Box

“This plant is a houseplant.”

Task: Categorize items as living things.

(Opfer & Siegler, 2004)
Task: Categorize items as living things.

Alive Box

Not Alive Box

“This plant is a pine tree.”

(Opfer & Siegler, 2004)
The posttest continued for 3 more trial blocks. Each block comprised 2 animals, 2 plants, & 2 artifacts.

**Task:** Categorize items as living things.

*(Opfer & Siegler, 2004)*
Source of Change in Life Judgments

% L-Rule on Life Task

- Water
- Growth
- Life
- Teleology

Learned L-Rule for Property

Did Not Learn L-Rule for Property
Breadth of Change in Life Judgments

“This plant is a fern.”

“This plant is a pine tree.”

(Opfer & Siegler, 2004)
Breadth of Change in Life Judgments

% L-Rule on Life Task

Old New

Life Teleology Growth Water

(Opfer & Siegler, 2004)
PRETEST vs. POSTTEST performance confirmed...
Children’s Theory of Life: Life is caused by teleological action.

- **Predictions:**

  (3) Upon learning that plants—like animals—act teleologically, 5s should infer that plants—like animals—are living things

(Opfer & Siegler, 2004)
Children’s Theory of Life: 
Life is caused by teleological action.

- **Finding:**
  
  (3) Upon learning that plants—like animals—act teleologically, 5s DID infer that plants—like animals—are living things

(Opfer & Siegler, 2004)
PRETEST vs. POSTTEST performance also raises new questions... 

(Opfer & Siegler, 2004)
PRETEST vs. POSTTEST performance also raises new questions...

(1) Why doesn’t learning about growth and needing water produce more change?

(Opfer & Siegler, 2004)
Path of Change in Categorization

% of Children Using Rule

0 20 40 60 80 100
-1 0 +1 +2 +3

Animals
Living Things
Everything
Plants

Trial Block

Trial Block
Path of Change in Categorization

Life Status

Teleological Agency

% of Children Using Rule

Trial Block

Animals

Living Things

Everything

Plants

n=15  n=19  n=19  n=18  n=16

n=15  n=17  n=15  n=13  n=7
Path of Change in Categorization

**Growth**

**Need for Water**

% of Children Using Rule

Trial Block

Animals

Living Things

Everything

Plants
PRETEST vs. POSTTEST PERFORMANCE also raises new questions...

(2) If it’s so easy to train children that plants are alive, why do children normally take so long to learn that plants are alive?

(Opfer & Siegler, 2004)
Rate of Change in Categorization

After feedback on one trial block,
• 67% error-free;
• 46% error-free;
• 9% error-free.

(Opfer & Siegler, 2004)
Some children resist idea that plants are teleological.

(Opfer & Siegler, 2004)
Main Findings

- Children attribute life to novel and familiar teleological agents.

(Opfer & Siegler, 2004)
Main Findings

- Children re-classify plants as living things upon learning that plants are teleological agents

(Opfer & Siegler, 2004)
Main Findings

- Children may resist the idea that plants are alive
  - NOT because their concept “life” must be changed
  - BUT because they resist the idea that plants are teleological agents

(Opfer & Siegler, 2004)
General Conclusions

- There’s nothing magical about age
  - “Before [age 6], children lack the biological concept of life, and thus cannot unite animals and plants under a single category, ‘living thing’....” (Slaughter et al., 1999, p. 76)

(Opfer & Siegler, 2004)
General Conclusions

- Theories constrain conceptual development by governing the effect of different sources of change.

(Opfer & Siegler, 2004)
General Conclusions

- For concepts that develop slowly, information that produces conceptual change may be the most difficult to learn.

(Source: Opfer & Siegler, 2004)
Current Directions

- **Goal-Directed Movement & Animacy**
  - Centrality of goal-directed movement
    - Psychological versus biological inferences
    - Effect of shape versus natural kind information