

Why is science important?

- we're bad at distinguishing real from illusory correlations
 - ◆ **tend to ascribe causality to correlates**
- any question about reality can be approached by (1) intuition; (2) religion; (3) science
 - 1) **“naïve beliefs” hard to replace or re-organize**
 - 2) **religion is unfalsifiable and irrespective of evidence**
 - 3) **science assumes uncertainty which can be reduced by data**
- bombarded with scientific, quasi-scientific, and unscientific information:
 - ◆ **Is there an autism epidemic?**
 - ◆ **Are cell phones dangerous?**
 - ◆ **Is class size an important factor in learning?**

SCIENTIFIC METHOD IS THE BEST AVAILABLE MEANS FOR ANSWERING SUCH QUESTIONS

What are reasonable *general* goals for science education?

- Most students won't become scientists,
 - ◆ **but some will, and they must be prepared!**
- However, all will be consumers of scientific info.
 - ◆ **Can we change our culture by training students to be skeptical, critical consumers, who approach new information in a “systematically questioning” way?**
 - ◆ **Critical evaluation of evidence: Can novices do this?**

Two specific goals of science education

- Help students revise conceptual frameworks
 - ◆ **conceptual enrichment**
 - ◆ **conceptual change: why is it hard?**
 - ✦ confirmatory bias
 - ✦ failure to reconcile theory with evidence
 - ✦ impoverished knowledge schemas
- Teach scientific problem-solving
 - ◆ **evaluate evidence, decide if conclusion is certain, revise theory using evidence**
 - ◆ **think critically about hypotheses & data**
 - ◆ **be smart consumer of scientific information**

Challenge to Science Ed: naïve concepts

- examples:
 - ◆ **shape of Earth***
 - ◆ **what does it mean to be alive?**
 - ◆ **density**
- knowing concepts & category boundaries
 - ◆ distinctions: “aliveness” ≈ “how much like people?”
 - ◆ boundaries: [fish,whales] vs. [dogs,cows,mice...]
 - ◆ connections: “volition-causes-movement” inference
- everyday-experience basis of beliefs & belief change
 - ◆ **can be good (Hatano: fish)**
 - ◆ **can be not-so-good (weight & matter)**

Challenge to Science Ed: refining causal inference


- What “cues” make kids infer cause-effect relations?
 - ✦ contiguity (infancy)
 - ✦ precedence (infancy to 5 yrs, depending on context)
 - ✦ covariation (late [8 yrs] if no contiguity cue)
 - ✦ similarity of cause/effect (resemblance, size)
 - ✦ mechanism theories: depends on domain knowledge
- Importance of *mechanism* for scientific reasoning?
 - ◆ **Historical role of unobservable/hypothetical causes**
 - ◆ **When do we have to understand/teach the “whys?”**
- False causality: Example of autism & vaccination
 - ◆ **Concept of “confounding factor”**: when is it taught?

Challenge to Science Ed: Relating theory to evidence

- Kuhn: Theory-based vs. evidence-based responses:
 - ◆ **Asked to describe evidence, 6th and 9th-graders tend to state their theory**
 - Q: “Do the findings of the scientists show...a difference?”
 - A: “Yes, because [choc cake] has a lot of sugar...[but] not carrot cake”
- Can children say how evidence speaks to a theory?
 - ◆ **“Mouse house” study: Can children pick a good test of competing theories?**
 - ✦ 55% of 1st-graders; 86% of 2nd-graders said the small-door test was better & could explain why.

theories-to-evidence continued...

- 1) Confirmation bias: People (all ages) search for evidence that fits their theories; ignore facts that don't.
 - ◆ **Laura (9th grade) believes mustard, not candy, causes colds:**
“With the Mars bar you get a cold on and off...here’s one that got a cold and over here they didn’t...”
[Given the same pattern of covariation w/ mustard] “Yes [it matters]. Most likely all the time you get a cold w/ the mustard. Like there you did, and there you did.”
- 2) Ignore evidence or theory, or misconstrue theory
 - ◆ **10% of 6th- and 9th-graders will acknowledge a discrepancy; only 10% revise theory based on evidence**
 - ◆ **What do they cite?**
 - ✦ Intuition Authority Personal experience Naïve theory

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- Do science classes teach kids how to relate theories to evidence (Ohlsson)?
 - ◆ **Example: *knowing* theory of evolution, vs. *able to use* it to explain a phenomenon (e.g., robust hybrids)**
 - Analysis of H.S. biology texts: They include:
 - 1) **Facts**
 - 2) **How to collect & classify evidence**
 - 3) ***NOT* how to relate theories to evidence**

Challenge to Science Ed: Designing tests of theories

- Klahr et al: Deducing “Big Trak” commands:
CLR ↑ 5 ← 7 ↑ 3 → 15 HOLD 50 FIRE 2 ↓ 8 RPT 4
 - ◆ **Task: Deduce what “RPT” command does**
 - ✦ repeat last x moves? repeat x times? repeat xth move only?
 - ◆ **Success: adults 83%, 5th-7th-grade 50%, 3rd-grade 33%**
- How do adults succeed?
 - ◆ **VOTAT**
 - ◆ **Set up programs w/ distinctive markers commands**
 - ✦ Use short distances; brief programs
 - ◆ **Set up disconfirming experiments (sometimes)**
 - ✦ Generate alternative hypotheses
 - ◆ **Write down programs and results**
 - ✦ Encode results accurately (half of children mis-encoded trials)

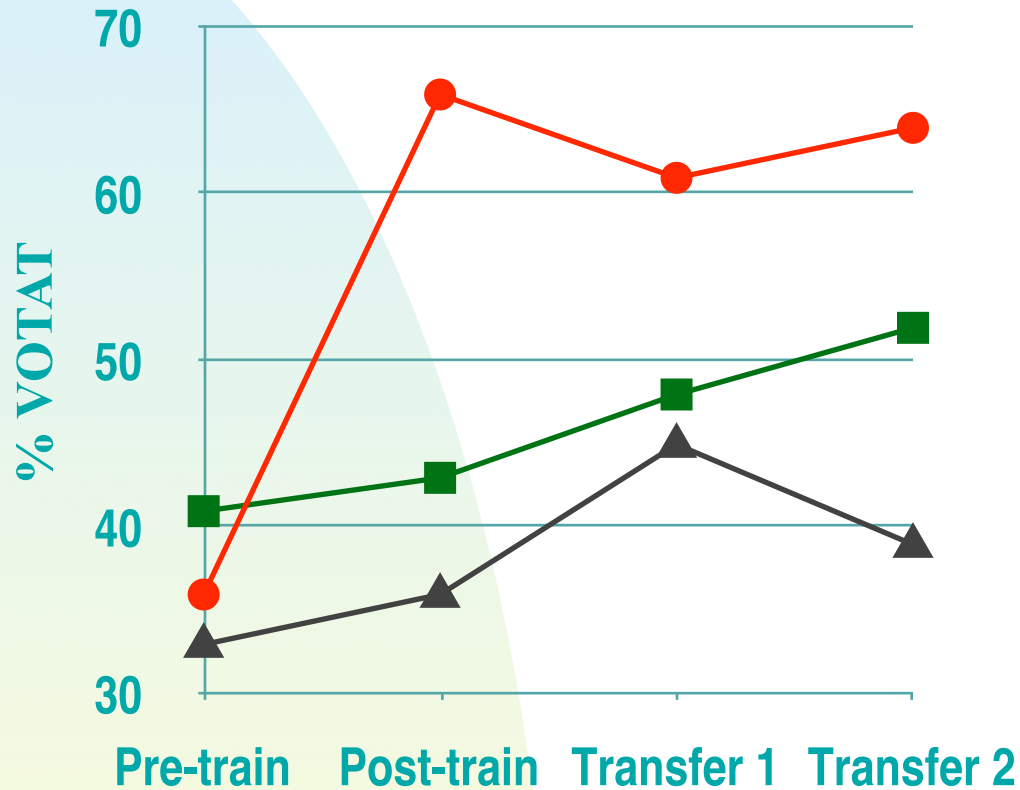
Meeting the challenges: How can we change conceptual schemas?

- Problem: Misconceptions can be resilient
 - ◆ **Ex: Concept of force (diSessa)**
- Science Ed for training intelligent novices
 - ◆ **Learn students' misconceptions (can be hard!)**
 - ◆ **Don't be disparaging: misconceptions are reasonable**
 - ✦ Capitalize on folk scientific ideas (*p*-prims)
 - ◆ **Design “benchmark lessons” that focus on critical features & highlight misconceptions**

Meeting the challenges: Teaching good theory testing

- Chen & Klahr: Attempt to teach VOTAT strategy
 - ◆ **Best way to teach?**
 - ✦ Direct Instruction “included an explanation of the rationale...as well as examples.”
 - ✦ Discovery: Children could explore; make own experiments, but were not instructed on using VOTAT
 - ◆ **Transfer to new problems in & out of domain?**
- Problems: Physics (e.g....)
 - ◆ **Springs: length? coil diameter? wire diameter? weight?**
 - ◆ **Slopes: angle? gate length? surface friction? ball type?**
- 2nd- to 4th-graders:
 - ◆ **Pre-training assessment**
 - ◆ **Training**
 - ◆ **2 physics transfer problems; later: out-of-domain transfer**

How often do kids use VOTAT?



- Distant transfer: Biology problem 7 months later:
 - ◆ 3rd graders: no difference from control
 - ◆ 4th graders: better than controls (90% vs. 60%)

Conclusions:

- Elementary students can understand the logic of VOTAT, they just don't use it spontaneously
- Children don't discover VOTAT themselves. Rather, VOTAT must be explicitly taught.
 - ◆ **Supports Piagetian constructivism?**
- 4th graders generalized VOTAT to later, different problems; 2nd graders didn't even generalize to similar problems.