Why is science important?

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

THE 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!**
  - **or their careers will require interpretation of science**
- However, all will be consumers of scientific info.
  - **Can we change our culture by training students: skeptical, critical consumers**
    - who often adopt a "systematically skeptical" stance?
  - **Can novices do critical evaluation of evidence?**

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, make inferences, revise theory**
  - **think critically about theory AND 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
  - distinctions: “aliveness” ≈ “how much like people?”
  - boundaries: [fish,whales] vs. [dogs,cows,mice…]
  - connections: “volition-causes-movement” inference
- everyday-experience and concepts
  - **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…"

  "Most likely all the time you get a cold w/ the mustard. Like there...and there."

2) Ignore evidence or theory, or misconstrue theory

- **10% of 6th- and 9th-graders mention a discrepancy;**
- **only 10% revise theory based on evidence**
- **Why?**

(Intuition Authority Experience Naïve theory)

- 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)**
- H.S. biology textbook analysis:
  - **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 x^{th} 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)

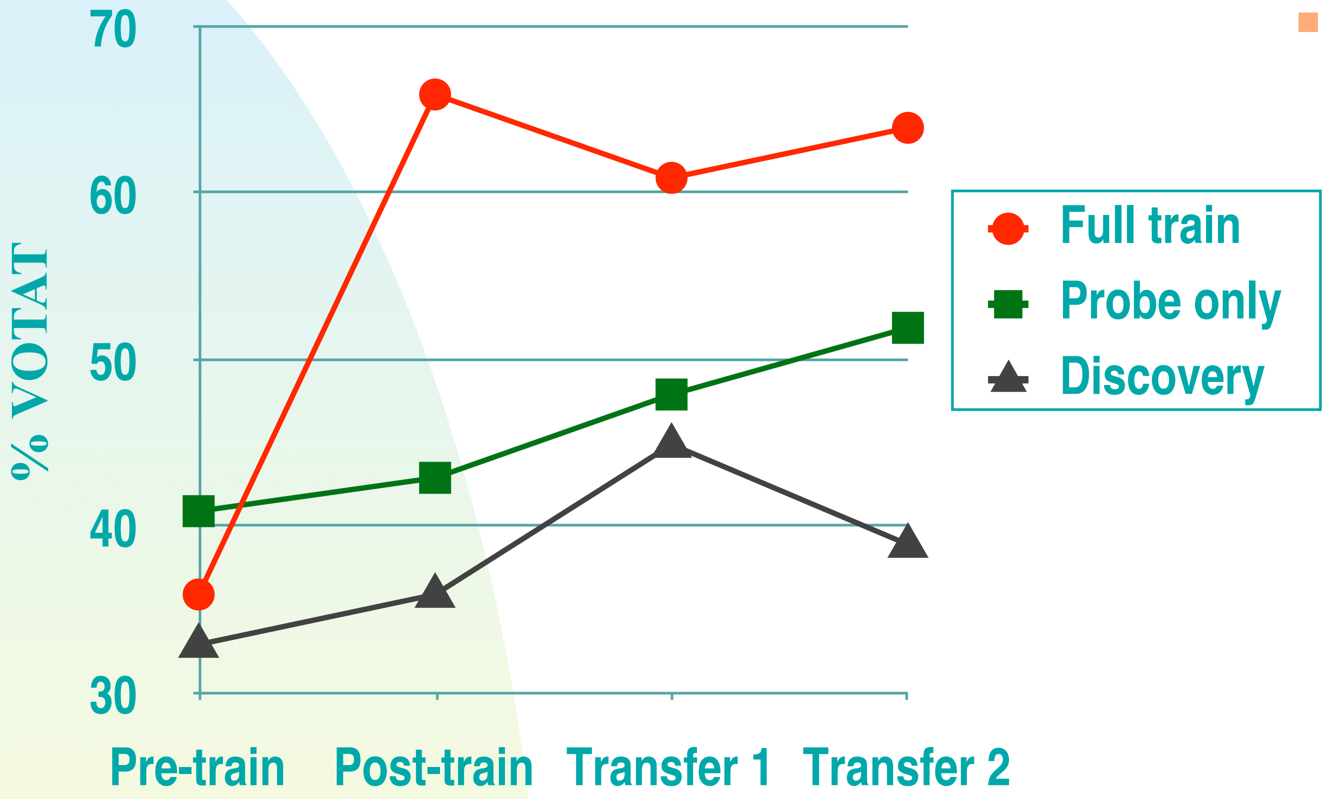
Meeting the challenges: How can we change conceptual schemas?

- Problem: Misconceptions can be resilient
  - **Ex: Concept of force (diSessa)**
- Science education for intelligent novices
  - **Learn students' misconceptions (can be hard!)**
  - **Don't be disparaging: misconceptions make sense**
    - Capitalize on folk-science; biology (wind...)
  - **Design "benchmark lessons" to focus on critical features & to 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; not taught VOTAT
  - **Transfer to new problems in & out of domain?**
- Physics Problems:
  - **Springs: length? coil diameter? wire diameter? weight?**
  - **Slopes: angle? gate length? surface friction? ball type?**
- 2nd- to 4th-graders:
  - **Pre-training assessment**
  - **Training**
  - **2 later transfer problems: out-of-domain (biology)**

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.