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.
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\textsuperscript{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.