Why is science knowledge important?

- Human brain is bad at distinguishing real from illusory correlations
  - We tend to ascribe causality to correlates
- Any question about reality can be approached scientifically or by intuition
  - “Naïve beliefs” to be replaced or augmented: difficult!
- We are 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 many topics or 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 change: Why is it difficult?**
    - Confirmatory bias
    - Failure to reconcile theory with evidence
    - Impoverished knowledge schemas
  - **Conceptual enrichment: may entail basic changes**

- Teach scientific problem-solving
  - Evaluate evidence, decide whether conclusion is certain, revise theory in light of evidence
  - Thinking critically about hypotheses & data
  - Be a smart consumer of scientific information
Challenge to Science Ed: Naïve Concept Frames

- Examples:
  - Shape of Earth*
  - What does it mean to be alive?
  - Density

- What do children believe? (ex: “alive”)
  - Problem of words & meanings
  - Knowing conceptual distinctions; category boundaries
    - Wrong distinctions: “aliveness” ≈ “how much like people?”
    - Wrong boundaries: [fish, whales] vs. [dogs, cows, mice…]
    - Wrong connections: “volition-causes-movement” inference

- The basis of beliefs & belief change
  - Good: Everyday experience & induction (Hatano: fish)
  - Bad: Everyday experience & induction (weight)
  - Experience forms basic concepts to be modified
What initially informs kids “mental model” of the earth?
- Aside: How can we “get at” these models?
- Presuppositions: What are they? Come from where?
- Role of cultural experience?

What is the significance of synthetic models? Of misconceptions?
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
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
  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<br>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)
Do the challenges, all together, keep students from making sense of complex data?

- Kuhn et al. 1995: Explaining educational outcomes
- What did community college students learn?
- What did 4th graders learn?
- What kinds of effects are harder to learn?
  - Interactions
  - Null effects (due to confirmation bias?)
  - Counter-intuitive effects
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 vs. discovery)?
    - Training “included an explanation of the rationale…as well as examples.”
  - 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.