Assessing Student Development of Scientific Thinking Skills: Do They Really Understand?

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The Problem

• “People are remarkably bad at making choices that make them happy”.*

• The $10 billion spent on pseudoscience medical products and services each year dwarfs that spent on actual medical research.

• “smart but acting foolishly” - the smart part we name and measure as IQ, the other part....?  

*Keith Stanovich in “What Intelligence Tests Miss”
**Rational Thought**

- Adaptive behavioral acts
- Judicious decision making
- Efficient behavioral regulation
- Sensible goal prioritization
- Reflectivity
- The proper calibration of evidence

**Specific knowledge structures required to think and act rationally**

- These are the rules, knowledge, procedures, and strategies that a person can retrieve from memory in order to aid decision making and problem solving.

**Tools of Rationality**

- Probabilistic thinking
- Logic
- Scientific reasoning

Often mislearned, not completely learned, or not even learned at all (mindware gaps) or we default to autonomous thinking (cognitive miser)
IQ does not correlate with rational thinking

- Difficult to measure rationality
- Easier to measure when it is being violated

Almost all are cognitive misers and have mindware gaps and/or contaminated mindware*

*Keith Stanovich in “What Intelligence Tests Miss”

Is new drug treatment effective?

- 200 people were given the treatment and improved
- 75 people were given the treatment and did not improve
- 50 people were not given the treatment and improved
- 15 people were not given the treatment and did not improve

Fundamental Mindware gaps

- **Scientific thinking** (controls, alternate hypothesis, falsifiability)
- **Probabilistic reasoning** (e.g., square of probabilities rule requires that events be independent)
I have a rule in mind that classifies a set of 3 integers (triplets)
The triplet 2-4-6 conforms to the rule.
- Figure out the rule: propose triplets, I’ll tell you if they fit the rule
- The rule: any set of three increasing numbers
- Most did not generate sequences to falsify their hypothesis

More than half of University students with a greater than average SAT are lacking in these types of mindware
- Explicit training in rational thought spotty and inconsistent.
- Probabilities, causes, what conclusions follow from arguments go unassessed on intelligence tests.
- Tend to accept conclusions that are believable without engaging in logical reasoning at all.

What Does it Mean to Understand the Scientific Method?
- What do students KNOW? (knowledge)
- What are students able to DO? (skills)
- What do students VALUE? (attitude)
Criteria Desired for Scientific Thinking Assessment Instrument

• Not time consuming for students
• Based on a practical challenge from an “everyday life” problem (buy-in)
• Open ended to reveal student’s thinking (not multiple choice)
• Easy to score consistently (inter- and intra-rater reliability)
• Provides quantitative measure

Experimental Design Ability Test (EDAT)
Slunum and Humbug (2011) Bioscene

Pre/Post Test
Advertisements for an herbal product, ginseng, claim that it promotes endurance. To determine if the claim is fraudulent and prior to accepting this claim, what type of evidence would you like to see? Provide details of an investigative design.


EDAT Score Sheet

1. Recognition that an experiment can be done to test the claim (vs. simply reading the product label).
2. Identification of what variable is manipulated (independent variable is ginseng).
3. Identification of what variable is measured (e.g., endurance).
4. Description of how dependent variable is measured (e.g., how far subjects run).
5. Realization that there is one other variable that must be held constant.
6. Understanding of the placebo effect.
7. Understanding that the larger the sample size or number of subjects, the better the data.
8. Realization that there are many variables that must be held constant (vs. only one or no mention).
9. Understanding that the experiment needs to be repeated.
10. Awareness that one can never prove a hypothesis, that one can never be 100% sure, that there might be another experiment that could be done that would disprove the hypothesis, that there are possible sources of error, that there are limits to generalizing the conclusions [credit for any of these].
Pre/Post EDAT scores

Science Reasoning Skills

Quantitative Literacy:
The knowledge and skills required to apply arithmetic operations, either alone or sequentially, using numbers embedded in printed material (National Center for Education Statistics).

Visual Literacy:
The ability to interpret images and to generate images for communicating ideas and concepts (Stokas, 2002).

Science Reasoning:
Experimental Design and Evidence Evaluation skills, including the ability to systematically explore a problem, to formulate and test hypotheses, to manipulate and isolate variables, and to infer causation from the consequences (Stokas et al., 2008).

Specific Science Reasoning Assessments:
- Experimental Design Ability Test (EDAT) (Sinan and Hamborg, 2011), Analysis of Data Ability Test (ADAT) (Sinan et al., in development).

Analysis of Data Ability Test (ADAT)

Part A. Villages 1-3 are similar in size and human population. Which organism is likely to be the cause of the most human deaths? Give your reasoning.

<table>
<thead>
<tr>
<th>Name of organism</th>
<th>Village 1</th>
<th>Village 2</th>
<th>Village 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trees</td>
<td>28</td>
<td>27</td>
<td>27</td>
</tr>
<tr>
<td>Birds</td>
<td>297</td>
<td>301</td>
<td>125</td>
</tr>
<tr>
<td>Spiders</td>
<td>120</td>
<td>80</td>
<td>124</td>
</tr>
<tr>
<td>Locusts</td>
<td>502</td>
<td>498</td>
<td>200</td>
</tr>
<tr>
<td>Wasps</td>
<td>314</td>
<td>621</td>
<td>303</td>
</tr>
<tr>
<td>Bats</td>
<td>203</td>
<td>203</td>
<td>198</td>
</tr>
</tbody>
</table>

Part B. How would you set up a Village 4 to test your answer in Part A above? In other words, which organisms, and how many of each, would you need to see in Village 4 to find out if human deaths are due to the organism you chose in Part A? Explain your answer.

Yearly number of human deaths per 10,000 people in each Village

<table>
<thead>
<tr>
<th>Yearly number of human deaths per 10,000 people in each Village</th>
</tr>
</thead>
<tbody>
<tr>
<td>Village 1</td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td>15</td>
</tr>
</tbody>
</table>
One of the biggest gaps in students’ science thinking skills that we detect is *controlling variables*.

An understanding of this important concept may be critical for student understanding of uncertainty and limits.

### Perry’s Stages of Cognitive Development

1. Dualistic
2. Multiplistic
3. Relativistic
4. Commitment in Relativistic stage

*William G. Perry, Forms of Intellectual and Ethical Development in the College Years: A Scheme (1968).*
Students Entering College AND Graduating as Dualistic Thinkers

Knowledge = Received Truths

BLACK OR WHITE

2. Multiplistic:

All opinions are equally valid

3. Relativistic:

Learn to weigh evidence and distinguish between weak and strong support.
4. Commitment:

Transfer these understandings of complexities and diverse perspectives from academic pursuits to the creation of a personal world view.

Learning environment to challenge dualistic students:

- Provide possibilities for ambiguity, varied interpretations, and multiple perspectives.
- Small group work, students do the talking—diminishes instructor's authoritative role and students contribute to creating knowledge.
- Require opinions, ideas, and hypotheses to be substantiated with evidence.
- High expectations for student understanding.

Student Cognitive Development

- Instruction that develops these science skills may also facilitate cognitive development that helps the student transition from the dualistic thinker, who sees the world as "black or white", to the relativistic thinker, who acknowledges uncertainty (Perry, 1968).

SHADES OF GRAY
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