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Where Do Students Go Wrong in Applying the Scientific Method?

Louis J. Rubbo

Coastal Carolina University, lrubbo@coastal.edu

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Where do Students Go Wrong in Applying the Scientific Method?

Louis Rubbo, Katherine Hunt, and Christopher Moore

Department of Chemistry & Physics
Coastal Carolina University
The path to developing scientific reasoning skills may be more complicated than we originally thought. Scientific reasoning needs to be explicit in the classroom.

Implementation strategies for teaching scientific reasoning:

Students show difficulties with scientific reasoning at all stages.
Our liberal arts physics and astronomy courses use SCALE-UP with a number of interactive activities.

Class sizes range from 24 (in physics) to 60 (in astro).
We can attempt to measure scientific reasoning using the Lawson

The LCTSR measures:
- Conservation
- Proportionality
- Control of Variables
- Probability
- Correlation
- Hypothetico-deductive

---

Lawson, JRST 15, 11 (1978)
Multiple choice version (2000)
Content knowledge does not necessarily translate into scientific reasoning abilities

DIRECT
N = 40

TUG-K
N = 38

SPCI
N = 36

Moore & Rubbo, PRST-PER 8, 010106
Content knowledge does not necessarily translate into scientific reasoning abilities

DIRECT
N = 40

TUG-K
N = 38

SPCI
N = 36

LCTSR (Phys)
N = 41

LCTSR (Astro)
N = 21

Moore & Rubbo, PRST-PER 8, 010106
Content knowledge and scientific reasoning abilities appear to be disconnected

Content knowledge and scientific reasoning abilities appear to be disconnected

Scientific reasoning can be made explicit by using “If... and ... then” (IAT) statements

<table>
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<tr>
<th>Causal Question</th>
<th>A question that can be addressed through causal events</th>
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<tbody>
<tr>
<td>If ...</td>
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<tr>
<td>and ...</td>
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<td>And/But ...</td>
<td>the actual observed results from performing the experiment</td>
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<td>the conclusions inferred by comparing the prediction to the observed results</td>
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Adopted from Lawson, The American Biology Teacher 62
Science starts with causal questions that are often derived from observations related to unexplained phenomena.
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What is Earth’s shape?
Science starts with causal questions that are often derived from observations related to unexplained phenomena.

What is Earth’s shape?
Once a causal question is asked an IAT statement guides the scientific reasoning

If
and
then
Once a causal question is asked an IAT statement guides the scientific reasoning

If the Earth is flat and then
Once a causal question is asked an IAT statement guides the scientific reasoning.

If the Earth is flat and we travel in one direction for an extended amount of time then
Once a causal question is asked an IAT statement guides the scientific reasoning

If the Earth is flat

and we travel in one direction for an extended amount of time

then we should eventually fall off the edge of the Earth.
Once a causal question is asked, an IAT statement guides the scientific reasoning.

If the Earth is spherical and then...
Once a causal question is asked an IAT statement guides the scientific reasoning

If the Earth is spherical

and we travel in one direction for an extended amount of time

then
Once a causal question is asked an IAT statement guides the scientific reasoning.

If the Earth is spherical and we travel in one direction for an extended amount of time then we should arrive back at our starting point.
A conclusion is formed by comparing the predicted outcome to the observed results
A conclusion is formed by comparing the predicted outcome to the observed results.
A conclusion is formed by comparing the predicted outcome to the observed results.

Therefore, the experimental evidence does not support the flat-earth model, but is consistent with the round-earth model.
Implementation is carried out through in-class group activities, laboratory exercises, and mini-essays.

Activity 2: Why do we have seasons

In the table below, propose an explanation for why we experience seasons. Also, describe an experiment that follows from your proposal and the expected results from your experiment.

Causal Question

Why do we experience seasons?

Proposed Explanation

If ...

and ...

then ...

therefore ...

Planned Test

Expected Result

Observed Result

Conclusion
Have these changes made a difference?
Have these changes made a difference?

Average LCTSR Gains

IATs were first introduced here
Have these changes made a difference?

Fall 2014

- Conservation of Weight: Pre - 80%, Post - 75%
- Conservation of Volume: Pre - 75%, Post - 70%
- Proportional Thinking: Pre - 60%, Post - 65%
- Advanced Proportional Thinking: Pre - 40%, Post - 45%
- Identification of Control of Variables: Pre - 50%, Post - 55%
- Probabilistic Thinking: Pre - 55%, Post - 60%
- Advanced Probabilistic Thinking: Pre - 45%, Post - 50%
- Correlation Thinking: Pre - 40%, Post - 45%
- Hypothetico-Deductive: Pre - 30%, Post - 35%

N = 46
Have these changes made a difference?
A cursory investigation indicates a wide range of difficulties in applying IAT statements.
A cursory investigation indicates a wide range of difficulties in applying IAT statements.

NAME:

Activity 10: Everyday Example of the Scientific Process

In the table below give an example of how you use evidence based reasoning in an everyday situation. Make sure to include a detailed description of each step in the process. You can make up an observed result for the purpose of this activity.

Causal Question

Do violent video games cause aggression?

Proposed Explanation

If ...

I have 20 subjects play a video game with violence if 20 subjects not play a video game then answer an aggression survey...

and ...

the subjects who played the video game with violence even get significant increases when compared to subjects that didn’t play the video game.

Planned Test

Expected Result

then ...

it can be assumed that playing violent video games causes aggression.

Observed Result

Violent video games cause aggression.

Therefore ...

Playing violent video games will cause aggression levels to increase.
A cursory investigation indicates a wide range of difficulties in applying IAT statements.

Activity 10: The Wow Signal

Some have argued that the Wow signal represents our first contact with an intelligent alien civilization. Outline an experiment that could be conducted in a signal person’s lifetime to test the Wow signal for its authenticity.

Causal Question

Are we alone?

Proposed Explanation

If ...

the Wow signal represents alien civilization

and ...

we observe that same patch of the sky for a period of time

Planned Test

Expected Result

then ...

you would see repeated signals

Conclusion

therefore ...

We CANNOT prove that there is an alien civilization.
Even students within a collaborative peer group demonstrate vastly different reasoning abilities.
A more thorough assessment of IATs employed a scientific reasoning rubric

### Scientific Reasoning Rubric

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A more thorough assessment of IATs employed a scientific reasoning rubric.

**Scientific Reasoning Rubric**

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A more thorough assessment of IATs employed a scientific reasoning rubric

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We expected to see improvement in IAT statements as the semester progressed

**Causal Question**

Can we improve students’ scientific reasoning abilities using IAT activities?

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<td>then ...</td>
<td>students should progressively score higher as more activities are completed</td>
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Students performed the same as the semester progressed

Average Rubric Values by Category

Activity 1 Activity 2 Activity 9 Activity 10

Average Total Scientific Reasoning Score

Activity 1 Activity 2 Activity 9 Activity 10
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</table>
Students may struggle with IAT statements because they lack pre-

Have humans ever stepped foot on the Moon?

**IF . . .**
Humans have been to the Moon

**AND . . .**
We make some kind of measurement

**THEN . . .**
We expect some kind of result
A possible solution to the context issue is to have students extract IAT arguments from published articles.

At the end of the day we want students to use scientific reasoning in everyday situations.

The Upshot
MYTH BUSTING

No, Celebrity Deaths Do Not Come in Threes

AUG. 14, 2014
Alan Flippin

It happens time and time again. Two celebrities — like Robin Williams and Lauren Bacall — die within a couple days of each other, and people start holding their breath. “Celebrities always die in threes,” they say, post and tweet. “Who’s next?”

Probably nobody, if history is any guide. Despite the all-too-human desire to find patterns in life, there really are none here.

The Upshot took a look at celebrity deaths, using data from The New York Times obituary archives. We defined “celebrity” as anyone whose obit ran at least 2,000 words, roughly two-thirds of a printed page when photos are added. (For comparison, Ms. Bacall’s was about 3,000 words. The longest, for Pope John Paul II, ran 13,363 words.)

Since 1990, 449 such people have died. In 75 cases, two of them died within three days of each other. But in only seven cases did three of them die within a five-day period. According to my colleague Boris Chen, a statistician, this is about what

New York Times
Aug 14, 2014
What we’ve found so far:

Results from the LCTSR instrument imply the IAT activities are improving scientific reasoning abilities.

Students struggle at all stages of the hypothetico-deductive argument.

Students don’t show improvement in IAT activities as the semester progresses.