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Going Beyond the Content: Teaching Scientific Reasoning in the Classroom

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Going Beyond the Content: Teaching Scientific Reasoning in the Classroom

Louis Rubbo
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The path to developing scientific reasoning skills may be more complicated than we thought.

What do we want out of our science classes?

What is the current state of scientific reasoning abilities in our students?

Methods for improving scientific reasoning skills
Typical learning outcomes for courses aimed at liberal arts majors fall into one of three categories
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Typical learning outcomes for courses aimed at liberal arts majors fall into one of three categories:

- **Science Appreciation**
- **Content**
Typical learning outcomes for courses aimed at liberal arts majors fall into one of three categories:

- **Science Appreciation**
- **Scientific Reasoning**
- **Content**
Typical learning outcomes for courses aimed at liberal arts majors fall into one of three categories:

- **Science Appreciation**
- **Scientific Reasoning**
- **Content**
Typical learning outcomes for courses aimed at liberal arts majors fall into one of three categories:

- **Science Appreciation**
  - It's most likely the terminal science course
  - Limited number of dedicated hours
  - Students have 12+ years of formal education
We can attempt to measure scientific reasoning using the Classroom Test of Scientific Reasoning (CTSR).

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

**Problem 11.** Twenty fruit flies are placed in each of four glass tubes. The tubes are sealed. Tubes I and II are partially covered with black paper. Tubes III and IV are not covered. The tubes are placed as shown. Then they are exposed to red light for five minutes. The number of flies in the uncovered part of each tube is shown in the drawing.

![Diagram of experiment](image)

*This experiment shows that flies respond to* (respond means move to or away from):

a. red light but not gravity
b. gravity but not red light
c. both red light and gravity
d. neither red light nor gravity

**Problem 12.** *because*

a. most flies are in the upper end of Tube III but spread about evenly in Tube II.
b. most flies did not go to the bottom of Tubes I and III.
c. the flies need light to see and must fly against gravity.
d. the majority of flies are in the upper ends and in the lighted ends of the tubes.
e. some flies are in both ends of each tube.

**Lawson,** JRST 15, 11 (1978)
Multiple choice version (2000)
Content knowledge assessments are done through nationally normed instruments

- Force Concept Inventory
- Brief Electricity and Magnetism Assessment
- Test of Understanding Graphs in Kinematics
- Determining and Interpreting Resistive Electric Circuit Concepts Test
- Star Properties Concept Inventory
Content knowledge and scientific reasoning abilities appear to be disconnected.

Content knowledge and scientific reasoning abilities appear to be disconnected.

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).
Content knowledge does not necessarily translate into scientific reasoning abilities

Data from Longwood and Coastal Carolina Universities
Content knowledge does not necessarily translate into scientific reasoning abilities

Data from Longwood and Coastal Carolina Universities
Students struggle with proportional reasoning, control of variables, and hypothetico-deductive reasoning.
Scientific reasoning abilities do correlate with content learning gains

DIRECT
\[ m = 0.45 \quad r = 0.50 \]

TUG-K
\[ m = 0.64 \quad r = 0.59 \]

Moore & Rubbo, PRST-PER 8, 010106 (2012)
Scientific reasoning abilities do correlate with content learning gains

\[ m = 0.0069 \quad r = 0.51 \]

Coletta & Phillips, AJP 73, 1172 (2005)
How do we incorporate explicit instruction on scientific reasoning into the classroom?

Examples of Mellinarks

Examples of Not Mellinarks

Which of these are Mellinarks?
How do we incorporate explicit instruction on scientific reasoning into the classroom?

Examples of Mellinarks

Examples of Not Mellinarks

Which of these are Mellinarks?

**IF . . .**

Mellinarks have an interior dot
How do we incorporate explicit instruction on scientific reasoning into the classroom?

Examples of Mellinarks

Examples of Not Mellinarks

Which of these are Mellinarks?

**IF . . .**
Mellinarks have an interior dot

**AND . . .**
We look at non-Mellinarks
How do we incorporate explicit instruction on scientific reasoning into the classroom?

Examples of Mellinarks

Examples of Not Mellinarks

Which of these are Mellinarks?

IF . . .
Mellinarks have an interior dot

AND . . .
We look at non-Mellinarks

THEN . . .
None of the non-Mellinarks should have an interior dot
How do we incorporate explicit instruction on scientific reasoning into the classroom?

Examples of Mellinarks

IF . . .
Mellinarks have an interior dot

AND . . .
We look at non-Mellinarks

THEN . . .
None of the non-Mellinarks should have an interior dot

Therefore . . .
Mellinarks are not solely defined by an interior dot. Need to modify hypothesis!
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?

If ...

Proposed Explanation

and ...

Planned Test

then ...

Expected Result

then ...

Observed Result

therefore ...

Conclusion
Causal Question

Why do we experience seasons?

If

and

then

therefore
Why do we experience seasons?

If the seasons are caused by Earth’s varying distance from the Sun

and then

therefore
Causal Question

Why do we experience seasons?

If the seasons are caused by Earth's varying distance from the Sun

and we record when the seasons occur throughout the world

then therefore
Causal Question  Why do we experience seasons?

If  the seasons are caused by Earth’s varying distance from the Sun

and  we record when the seasons occur throughout the world

then  we should find that all parts of the world experience the same season at the same time

therefore
Causal Question

Why do we experience seasons?

If

the seasons are caused by Earth's varying distance from the Sun

and

we record when the seasons occur throughout the world

then

we should find that all parts of the world experience the same season at the same time

therefore

Not all parts of the world experience the same seasons at the same time
If the seasons are caused by Earth’s varying distance from the Sun

and we record when the seasons occur throughout the world

then we should find that all parts of the world experience the same season at the same time

therefore Not all parts of the world experience the same seasons at the same time

Causal Question Why do we experience seasons?
The seasons are not caused by Earth’s varying distance to the Sun!
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 ...

the Earth orbits the Sun

and ...

the distance to the Sun changes

Expected Result

As the Earth's distance changes, so will the seasons.

Observed Result

Winter will occur when the Sun is further away. Summer will occur when the Sun is closer.

Conclusion

Therefore ...

We experience seasons.
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 ...
The tilt of the earth and orbit dictate seasons

and ...
and Earth is tilted towards the Sun.

Planned Test

Expected Result
then ...
it is Summer in the Northern Hemisphere

Observed Result
In the Summer, the earth is tilted towards the Sun

Conclusion

therefore ...
Tilt & orbit dictate seasons.
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...

the seasons are caused by Earth's varying distance from the sun

and...

we measure the distances of the sun and the earth and the temperature

Expected Result

then...

the seasons should change as the distance change

Observed Result

January is when we are closest to the sun.

Conclusion

therefore...

The distance has nothing to do with the seasons, it's the earth's rotation about its axis.
In general, students struggle with IF...AND...THEN questions at different stages

IF . . .
Proposed explanation

AND . . .
Planned test

THEN . . .
Expected results

THEREFORE . . .
Conclusion
In general, students struggle with IF...AND...THEN questions at different stages

**IF . . .**
Proposed explanation

**AND . . .**
Planned test

**THEN . . .**
Expected results

**THEREFORE . . .**
Conclusion

Formulating a testable hypothesis
In general, students struggle with IF...AND...THEN questions at different stages.

**IF** . . .
Proposed explanation

**AND** . . .
Planned test

**THEN** . . .
Expected results

**THEREFORE** . . .
Conclusion
In general, students struggle with IF...AND...THEN questions at different stages

**IF . . .**
Proposed explanation

**AND . . .**
Planned test

**THEN . . .**
Expected results

**THEREFORE . . .**
Conclusion

Outlining an experiment that uniquely tests the hypothesis
In general, students struggle with IF...AND...THEN questions at different stages

**IF . . .**
Proposed explanation

**AND . . .**
Planned test

**THEN . . .**
Expected results

**THEREFORE . . .**
Conclusion

Distinguishing experiment from prediction
In general, students struggle with IF...AND...THEN questions at different stages

**IF . . .**
- Proposed explanation

**AND . . .**
- Planned test

**THEN . . .**
- Expected results

**THEREFORE . . .**
- Conclusion

Identifying an expected outcome that follows from the hypothesis and experiment
In general, students struggle with IF...AND...THEN questions at different stages

- **IF . . .**
  - Proposed explanation

- **AND . . .**
  - Planned test

- **THEN . . .**
  - Expected results

- **THEREFORE . . .**

  Science isn’t in the business of proving theories
Students may struggle with IAT statements because they lack prerequisite knowledge

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
Students may also struggle with IAT statements because they lack prior expected development.

Based on Lawson et al. JRST 37, 81 (2000)
Have these changes made a difference?
Have these changes made a difference?
Have these changes made a difference?

N = 47
Have these changes made a difference?
What we’ve found so far:
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Reformed pedagogy focused on content alone is not necessarily sufficient to achieve gains in scientific reasoning.
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Reformed pedagogy focused on content alone is not necessarily sufficient to achieve gains in scientific reasoning.

Scientific reasoning is correlated to gains in content knowledge.
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Reformed pedagogy focused on content alone is not necessarily sufficient to achieve gains in scientific reasoning.

Scientific reasoning is correlated to gains in content knowledge.

Students demonstrate poor preparation in some scientific reasoning patterns but explicit intervention leads to improvements in as little as one semester.