Developing scaffolds to promote geoscience thinking: the rigor and promise of systemic classroom-based research

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Scaffolding is a metaphor related to the idea that people construct knowledge both cognitively & socially.

In education and educational research, scaffolding consists of instructional materials and strategies that facilitate students’ knowledge construction.
Scientific literacy involves knowing both (1) *what* scientists know & (2) *how* scientists know.

Evaluation as argument, critique, and analysis is central to scientific thinking and knowledge construction (NRC, 2012).
Relatedly, students may find scientific explanations to be implausible.

Epistemic judgments (e.g., plausibility) are often formed through automatic cognitive evaluations with little purposeful thinking (Lombardi et al., 2016a).
With explicit reappraisal, plausibility—a tentative epistemic judgment about explanations—may facilitate change.

**Model of plausibility judgments in conceptual change (PJCC; Lombardi et al., 2016a)**

- **Source Validity Pre-processing**
  1. Corroborative & coherent alignment
  2. Information complexity
  3. Perceived conjecture
  4. Source credibility perceptions
  5. Heuristic rules & biases

- **Plausibility Judgment**
  - High/explicit: Degree of evaluation, depending on:
    1. Epistemic dispositions & motives
    2. Motivation
    3. Topic emotions
  - Low/implicit

- **Plausibility Reappraisal Feedback Loop**
  - If yes: Reappraisal Prompt? (e.g., exposure to new information)
  - If no:
    - Strong potential for conceptual change:
      1. If plausibility of novel explanation > plausibility of background …and…
      2. If other factors (e.g., commitment, personal relevance) do not override plausibility
    - Weak potential for conceptual change:
      1. If plausibility of novel explanation = plausibility of background …or…
      2. If other factors (e.g., commitment, personal relevance) do override plausibility
    - No potential for conceptual change if plausibility of novel explanation < plausibility of background
Classroom instructional scaffolds can help make students’ evaluations explicit, thoughtful, & scientific.

Chinn & colleagues (2012, 2014)

Example of student completed Model-Evidence Link (MEL) diagram

Scientific evaluations may also promote students’ reappraisal of their initial plausibility judgments & knowledge reconstruction (Lombardi et al., 2016a)
My projects investigate students’ evaluations, plausibility, & knowledge about Earth science topics.

Research question: How does instruction promoting evaluation result in plausibility reappraisal and knowledge changes about Earth and space science topics?
This first project involved three school districts from very different parts of the US:

- One in a large urban district; low SES
- Two in small suburban districts; high SES

8 master teachers & hundreds of their secondary (grades 9-12) Earth science students participated in this project.
Secondary students experienced instruction about four topics during the course of a school year.

**Causes of current climate change**

- **Temperature vs. Solar Irradiance**

  - **Solar Irradiance (11 year average)**
  - **Temperature (11 year average)**

  ![Graph showing temperature vs. solar irradiance over time](image)

  - Year: 1860 to 2000
  - Temperature change: -0.5 to 0.5
  - Solar irradiance change: 1355 to 1367

**Formation of the Earth’s Moon**

- Moon’s orbit is tilted 5° from the ecliptic.
- Ecliptic: the plane on which most planets orbit around the Sun.

![Diagram of the Earth's Moon formation](image)

**Hydraulic fracturing & earthquakes**

- Trench: Old crust destroyed here
- Mid-Ocean Ridge: New crust formed here

**Value of wetlands**

- Sediment settles out of water
- Water is filtered
- Water is now clean

![Diagram of wetlands](image)
In the project’s third year, we conducted a quasi-experiment comparing three different tasks.

The Model-Evidence Link (MEL) diagram, 4 lines of evidence, 2 alternatives

The Mono-MEL diagram, 4 lines of evidence, only 1 alternative
All students completed a written explanation task after completing their diagram or table.

Provide a reason for three of the arrows you have drawn. Write your reasons for the three most interesting or important arrows.

A. Write the number of the evidence you are writing about.
B. Circle the appropriate word (strongly supports | supports | contradicts | has nothing to do with).
C. Write which model you are writing about.
D. Then write your reason.

1. Evidence # 1 strongly supports | supports | contradicts | has nothing to do with Model A because:
   Evidence 1 says that human activities have lead to greater releases of greenhouse gases, which have been rising for the past 50 years. This strongly supports Model A because it is explaining that our climate change is being caused by human activities.

2. Evidence # 2 strongly supports | supports | contradicts | has nothing to do with Model B because:
   Evidence 2 contradicts Model B because evidence one says that human activities have lead to greater releases of greenhouse gases, while model B says that increasing amounts of energy from the sun is what is causing climate change.

3. Evidence # 2 strongly supports | supports | contradicts | has nothing to do with Model B because:
   Evidence 2 contradicts Model B because evidence 2 says that Earth has received less of the sun's energy, and model B says the opposite, that climate change has been caused by increasing amounts of energy from the sun.
Qualitative analyses revealed 4 levels of students evaluations reflected in the explanation task

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Erroneous Evaluation</strong></td>
<td>Explanation contains an incorrect model-to-evidence link and/or is mostly inconsistent with scientific understanding.</td>
<td>1</td>
</tr>
<tr>
<td><strong>Descriptive Evaluation</strong></td>
<td>Explanation is correct, but the evidence-to-model link weight states that the evidence has nothing to do with the model. Explanation does not clearly distinguish between lines of evidence and explanatory models.</td>
<td>2</td>
</tr>
<tr>
<td><strong>Relational Evaluation</strong></td>
<td>Explanation is correct, with an evidence-to-model link weight of strongly supports, supports, or contradicts as appropriate. Explanation distinguishes between lines of evidence and explanatory models, but does so in a merely associative or correlation manner based on text similarity.</td>
<td>3</td>
</tr>
<tr>
<td><strong>Critical Evaluation</strong></td>
<td>Explanation is correct, with an evidence-to-model link weight of strongly supports, supports, or contradicts as appropriate. The explanation reflects deeper cognitive processing that elaborates on an evaluation of evidence and model. Explanation distinguishes between lines of evidence and explanatory models, allows for more sophisticated connections, and concurrently examines alternative models.</td>
<td>4</td>
</tr>
</tbody>
</table>

Lombardi et al. (2016b, 2017)
Students rate the plausibility of two alternative explanatory models that explain a phenomena

### Case 1: Probabilistic Reasoning

<table>
<thead>
<tr>
<th>Model</th>
<th>Greatly implausible (or even impossible)</th>
<th>Highly Plausible</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model A</td>
<td>1 2 3 4 5 6 7 8 9 10</td>
<td></td>
</tr>
<tr>
<td>Model B</td>
<td>1 2 3 4 5 6 7 8 9 10</td>
<td></td>
</tr>
</tbody>
</table>

### Case 2: Plausibilistic Reasoning (common)

<table>
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<td>Model B</td>
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<td></td>
</tr>
</tbody>
</table>

### Case 3: Plausibilistic Reasoning (uncommon)

<table>
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</tr>
</thead>
<tbody>
<tr>
<td>Model A</td>
<td>1 2 3 4 5 6 7 8 9 10</td>
<td></td>
</tr>
<tr>
<td>Model B</td>
<td>1 2 3 4 5 6 7 8 9 10</td>
<td></td>
</tr>
</tbody>
</table>
Short knowledge surveys probe students’ understanding for each topic

Below are statements about climate change. Rate the degree to which you think that *climate scientists* agree with these statements.

<table>
<thead>
<tr>
<th></th>
<th>Strongly disagree</th>
<th>Disagree</th>
<th>Neither agree nor disagree</th>
<th>Agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The Sun is the main source of energy for Earth’s climate.</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>E</td>
</tr>
<tr>
<td>2. <em>We cannot know about ancient climate change.</em></td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>E</td>
</tr>
<tr>
<td>4. Greenhouse gases absorb some of the energy emitted by Earth’s surface.</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>E</td>
</tr>
<tr>
<td>5. Earth’s climate is currently changing.</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>E</td>
</tr>
</tbody>
</table>

Although short, we have calibrated these with longer forms and classroom testing reveals instrument validity for research purposes.
Participants scores showed meaningful plausibility shifts and knowledge increases toward the scientific...

...but only when students simultaneously evaluated lines of evidence and two alternative explanations (Lombardi et al., 2018a)

Wilks’ $\lambda = .843$, $F(2,61) = 5.67$, $p = .006$, medium effect size ($\eta^2 = .157$)

Wilks’ $\lambda = .893$, $F(2,61) = 3.67$, $p = .03$, medium effect size ($\eta^2 = .107$)
Deeper evaluations facilitated participants’ plausibility reappraisals and greater knowledge.

GoF = .437 (large explanatory power); APC = .265, $p < .001$; ARS = .330, $p < .001$; AVIF = 1.12; AFVIF = 1.46; and NLBCDR = 1.0; Lombardi et al. (2018a)
These results are aligned with and complementary to several empirical studies and recent theory...

...(e.g., Lombardi et al., 2013; Lombardi et al., 2016a,b,c; Lombardi et al., 2018b)

But we are unsatisfied, because unpublished results suggest that students are not transferring their evaluative thinking outside of the classroom context
Our current project examines scaffolds that increase students’ “conceptual agency” (Pickering, 1995)

Students who exercise conceptual agency are authors of their own contributions, accountable to the classroom learning community, and have the authority to think about and solve problems (Nussbaum & Asterhan, 2016)
Initial pilot testing reveals that the baMEL may increase evaluations above the pre-constructed MEL

GoF = .434 (large explanatory power), ARS = .248
Researchers teachers need to help students scientifically evaluate & reappraise their epistemic judgments...

...and development of scientific thinking practices are essential for all so that we can equitably address current and future global challenges
Acknowledgements and thank you!

This line of research resulted from many collaborators, including researchers, teachers, & funders who have been supportive in working with me & my team.

Please visit our current project site at https://serc.carleton.edu/mel/

...and our research team site at http://sciencelearning.net