Students’ Plausibility Shifts and Knowledge Gains When Evaluating Competing Explanatory Models about Freshwater Resource Availability

Timothy G. Klavon¹, Janelle Bailey¹, Doug Lombardi², & Archana Dobaria¹

¹Temple University ²University of Maryland

Digital Presentation of Stand-Alone Paper accepted to NARST Annual International Conference canceled in March of 2020*

*Elaboration text will be footnoted in the presentation and shown in the note section.
Background

1. Constructivism theorizes that learning is an active process with intention, enacting student agency (Roth, 2007).

2. Critique and evaluation are considered essential to process of learning both scientific practices and disciplinary core ideas (NRC, 2012), though they are often under emphasized in the context of science education (Ford, 2015).

3. Plausibility can be defined as the potential truthfulness of explanations and is held to a lesser standard than truth judgements (Lombardi et al., 2013, 2016). Plausibility is a tentative epistemic judgement about explanations and plausibility reappraisal “may be influential on the conceptual change process in situations of competing explanations” (Lombardi et al., 2013, p. 51). Critical evaluation about the connections between evidence and explanations may activate reappraisal of these tentative judgements, which in turn could shift plausibility toward a more scientific stance and facilitate scientifically-accurate knowledge construction (Lombardi et al., 2016). This reappraisal has correlated significantly with meaningful pre- to post knowledge gains when using either the MEL or the baMEL (Lombardi et al., 2018, 2019).
4. An investigation of how students use evidence to evaluate the plausibility of competing explanatory models in Earth science and environmental science classes using our scaffolds. In addition to investigating their shifts in plausibility, we also investigated their knowledge gains regarding the specific topic of the activity. In order to investigate these phenomena, we have implemented a mixed-methods, designed-based research project using instructional scaffolds to assist students in evaluating the plausibility of explanatory models and the use of evidence in the re-appraisal of said plausibility.
Background

The MEL-Diagram
Chinn & Buckland, 2012; Lombardi et al., 2018

The Build-a-MEL Diagram (baMEL)

1. In order to investigate these phenomena, we have implemented a mixed-methods, designed-based research project using instructional scaffolds to assist students in evaluating the plausibility of explanatory models and the use of evidence in the re-appraisal of said plausibility. The MEL Diagrams are designed to scaffold students’ evaluations of the relationship between explanatory models (both scientifically accepted and alternative models) and lines of evidence related to those models.

2. We believe that the baMEL, where students chose from three explanatory models and eight lines of evidence, will allow students to appropriate and modify the conceptual resources available to enact their own agency (Pickering, 1995).
Background

The MEL-Diagram\(^1\)
Chinn & Buckland, 2012; Lombardi et al., 2018

The Build-a-MEL Diagram (baMEL)\(^2\)
Chose 2 of 3 models
Chose 4 of 8 lines of evidence
Have access to more detailed information about the evidence

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2. We hypothesized that the baMEL, where students chose from three explanatory models and eight lines of evidence, will allow students to appropriate and modify the conceptual resources available to enact their own agency (Pickering, 1995).
Research Question

We have added another model into the process, now we ask...

... because evaluating multiple models increases in difficulty (Lee, 2018), how are the plausibility shifts and knowledge gains of students impacted by the evaluation of multiple explanatory models for the future availability of freshwater resources?”

1. Unlike the previous MEL project (Lombardi et al., 2018), which asked students to rate the plausibility of two explanatory models, this investigation asked students to consider three competing models. The evaluation of multiple models for one phenomenon is more sophisticated (Lee, 2018). This leads us to ask, “How are the plausibility shifts and knowledge gains of students impacted by the evaluation of multiple explanatory models for the future availability of freshwater resources?” Considering our pilot data (Klavon et al., 2019; Lombardi et al., 2019), we expect to find pre- to post knowledge gains for the students, as well as positive plausibility shifts towards the scientific model.
Our study

Participants

<table>
<thead>
<tr>
<th>School 1 (MA)</th>
<th>School 2 (SE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N = 76</td>
<td>n = 19</td>
</tr>
<tr>
<td>Mid-Atlantic State</td>
<td>Southeastern State</td>
</tr>
<tr>
<td>Middle level</td>
<td>High school level</td>
</tr>
</tbody>
</table>

Methods

- Up to 4 MEL activities in the school year
- Student undertakings
  - Pre-knowledge survey
  - Rated plausibility
  - Completed the MEL activity
  - Reappraised plausibility
  - Explanation task
  - Post-knowledge survey

This project looks specifically at the results of the “Availability of Freshwater Resources” baMEL

1. The participants also completed pre- and post-knowledge surveys related to the freshwater resource topic. We measured knowledge using a twelve item Likert scale asking students how strongly a hydrologist would agree (1- strongly disagree, 5- strongly agree) with statement about freshwater resources availability. We removed item 12 due to a printing error at the SE school. Six items were negatively worded in order to prevent students from automatically choosing agreement on all responses. These items were reversed coded upon recording the data.

2. Students rated the plausibility of three models in their baMEL diagram, one scientifically accepted model and two alternative models, before and after completing the diagram. Participants rated the plausibility of each model on a scale of 1 = very implausible to 10 = greatly plausible (Lombardi et al., 2013). Final plausibility scores were the scientific model score minus the average of the two alternative models’ scores. Plausibility shifts were post-plausibility scores minus pre-plausibility scores.

3. Once the participants completed the initial plausibility rating for each model, they worked in groups to choose two of the three models to compare and four of eight lines of evidence for the freshwater baMEL used to evaluate the
models. BaMEL models and lines of evidence teachers provided to the participants. Students received additional material about each line of evidence in the form of one-page texts, including data tables or figures as appropriate. The participants then determined the relationship between each of their selected lines of evidence and each chosen model. Potential relationships were that the evidence supports, strongly supports, contradicts, or has no relationship with the models.

4. The participants individually reappraised their plausibility ratings once the diagram was complete and wrote explanations about two of the previous relationships.
# Knowledge Survey

**Likert scale responses**

Given pre and post instruction

**Prompt:** Below are statements about freshwater resources. Rate the degree to which you think that hydrologists agree with these statements.

(1- strongly disagree, 5- strongly agree)

<table>
<thead>
<tr>
<th>Item</th>
<th>Prompt</th>
<th>Likert Scale</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item 1</td>
<td>Water reclamation reduces contaminated water safe for humans to use.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item 2</td>
<td>Engineers will solve current problems of freshwater.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item 3</td>
<td>Freshwater is abundant and will remain an issue in the face of global climate change.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item 4</td>
<td>Lack of decision by Earth's leaders but have little impact on the water cycle.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item 5</td>
<td>Technology advances make water safe for human use.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item 6</td>
<td>Groundwater recharge rates are easier than prior to plan because soils are generally too thin.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item 7</td>
<td>Over the past 100 years, lower amounts of water have occurred across the US. This means that greater amounts of climate change, affixed by droughts in the last 20 years.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item 8</td>
<td>Current shortages of freshwater will get worse around the globe as world populations increase.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item 9</td>
<td>Climate change and increasing population will lead to more freshwater shortages.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item 10</td>
<td>Depletion of groundwater causes head to sink. Depletion also causes freshwater to be contaminated.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Models and Evidence¹

Models
Model A: Non-scientific alternative
Model B: Engineering alternative
Model C: Scientific Model (UNESCO, 2015)

Evidences
Developed from scientific information

1. Once the participants completed the initial plausibility rating for each model, they worked in groups to choose two of the three models to compare and four of eight lines of evidence for the freshwater baMEL used to evaluate the models. Models and lines of evidence teachers provided to the participants. Students received additional material about each line of evidence in the form of one-page texts, including data tables or figures as appropriate. The participants then determined the relationship between each of their selected lines of evidence and each chosen model. Potential relationships were that the evidence supports, strongly supports, contradicts, or has no relationship with the models.

2. Of the three presented models, Model C (Earth has a shortage of freshwater, which will worsen as our world’s population increases) has been identified as the scientifically accepted model. Even considering that some geographical location may received more rainfall due to climatic changes and technological innovations, the unsustainable increase in water usage for consumption and industrial purposes cause by population growth will contribute to overall global shortages (UNESCO, 2015).
Findings

Knowledge Gains¹

Overall knowledge gains:
(K_pre: M=3.24, SD=0.44)
(K_post: M=3.49, SD=0.41)
t(75) = 4.46 , p < .001, (d= 0.51)

Significant item changes:
Positive: 1, 3, 5, 6, 9, and 11
Negative: 2

1. The difference between pre-knowledge (K_pre, M=3.24, SD=0.44) and post-knowledge (K_post, M=3.49, SD=0.41) was significant; t(75) = 4.46, p < .001, with a medium effect size, (d= 0.51). Of the eleven items, only items 1, 3, 5, 6, 9, and 11 showed individual gains and item 2 showed a significant knowledge loss (see Table 3). Items 2 and 11 exhibited quite large effect sizes (d= 0.95 and d= 1.45, respectively). These are of note, as each targeted at an explanatory model. Item 2 focused on model B (Earth has a shortage of freshwater that can be met by engineering solutions.) and Item 11 focused on model C (Earth has a shortage of freshwater, which will worsen as our world’s population increases.) We will discuss the implications of these meaningful plausibility shifts and knowledge gains in a later slide.
Findings

Plausibility Shifts

<table>
<thead>
<tr>
<th>Calculation</th>
<th>Formula</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original MEL</td>
<td>$P_{pre} = [P_{sci} - P_{alt}]_{pre}$</td>
<td>Not significant</td>
</tr>
<tr>
<td></td>
<td>$P_{post} = [P_{sci} - P_{alt}]_{post}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$P_{shift} = P_{post} - P_{pre}$</td>
<td></td>
</tr>
<tr>
<td>baMEL</td>
<td>$P_{pre} = [P_c - (P_B + P_A)/2]_{pre}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$P_{post} = [P_c - (P_B + P_A)/2]_{post}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$P_{shift} = P_{post} - P_{pre}$</td>
<td></td>
</tr>
</tbody>
</table>

However, we looked knowledge scores and found outsized effects for items 2 and 11.

Focused on models

Led us to look at the relative plausibility shifts for each model pair.

- C-A: 1.22 [$t(75)= 2.66, p < .001, d = 0.30$]
- B-A: 1.34 [$t(75)= 2.94, p = .004, d = 0.33$]
- C-A: Not significant

*Plausibility shifts* - The plausibility shift represents the change in the plausibility gap between explanatory models. In the previous MEL projects (Lombardi et al., 2013, 2018), this gap was determined by calculating the initial difference between the students' plausibility rating of the scientifically accepted model and the alternative model. The plausibility shift was the difference in the plausibility gap pre-instruction vs post-instruction. A positive plausibility shift indicates a movement in plausibility towards the scientific model. Due to the addition of a third model in the baMEL, the plausibility gap was calculated as the difference between the plausibility of scientific model and the average of the two alternative models. The plausibility shift in this case was not significant.

However, the large effect sizes of knowledge items 2 and 11 led us to look more closely at the plausibility changes between individual models rather than a combined approach. The plausibility shift between models C and A, 1.22 [$t(75)= 2.66, p < .001, d = 0.30$], and models B and A, 1.34 [$t(75)= 2.94, p = .004, d = 0.33$] were both significant. The plausibility shift between models C and B, however, was not. Upon further analysis, there was no interaction between the plausibility shift of models C and A and the change in plausibility of model B. There was a significant
interaction between the plausibility shift of models B and A and the change in plausibility of model C [Wilks’ Lambda = 0.902, F(1, 74) = 8.07, p = 0.006].

The students’ plausibility judgements moved away from the model that espoused that there was not future problem with the availability of freshwater resources. However, they were collectively unable to distinguish between the plausibility of models of how the problem could be addressed. This finding emphasizes the difficulty that students have with evaluating multiple scientific explanatory models (Lee, 2018).
For NARST Members

- Consideration of students’ difficulties
- Elucidates the need to continue to study how students use explanatory models
- Enables us to provide instructional supports to teachers and students

For Teaching

- Critical evaluation and Deeper Learning
- Students struggle with evaluation
- The MEL and baMEL provide scaffolds for evaluation
- Teachers need to guide students through subtleties

1. This study helps us consider students’ difficulties surrounding explanatory models and how we can develop strategies and scaffolds to enhance their learning of science content. The baMEL, and the preceding MEL, have been shown to enhance student knowledge gains in Earth science topics. This investigation also elucidates the need for further study into how students approach the evaluation of scientific models and distinguish between them. Helping students develop their critical thinking skills is difficult; therefore, instructional tools and methods that facilitate this important 21st Century skill would be of great benefit to educators. In the science classroom, being critical involves evaluating the validity of explanations based on lines of evidence. Engaging students in critical evaluations may deepen their understanding about content and practices needed to construct valid scientific knowledge.

2. Deeper learning of science knowledge requires the critical evaluation of explanatory models of scientific phenomena (NRC, 2012), however students struggle with that making scientific evaluations (Lombardi et al., 2018; Lee, 2018). The baMEL provides students with the scaffolding necessary to enact such scientific evaluations as they begin to encounter multiple models surrounding one
phenomenon. An implication of this study may be that it is incumbent upon teachers to guide students through the subtleties of the differences between such models.
Where are we going from here...

We are currently in manuscript preparation.
We are looking at how students use models to construct their science knowledge.
We are also looking at how students discard various alternative models through the process of winnowing.
References


