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

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

Background

Constructivist Learning[1] -

Active, intentional, engages agency (Roth, 2007)

Critique and Evaluation[2] -

Essential to the process of learning both scientific practices and disciplinary core ideas (NRC, 2012)

Often under emphasized

Plausibility[3] - DL3

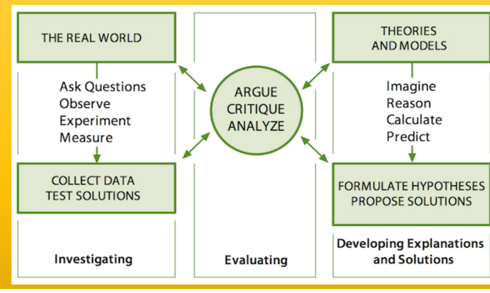
Epistemic judgment about the potential truthfulness of scientific explanations (Lombardi et al.,2013, 2016)

To this end[4] -

We developed instructional scaffolds to facilitate students' evaluations about the connections between lines of scientific evidence and alternative explanations, called …

Model-Evidence Link (MEL) Diagram activities

Preconstructed MEL and the Build-a-MEL (baMEL) Diagrams



The three spheres of activity for scientists and engineers (NRC, 2012, p. 45), with critique and evaluation at the nexus

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, p. 44), 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.

Slide 2

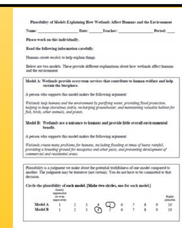
DL3 Doug Lombardi, 3/27/2020

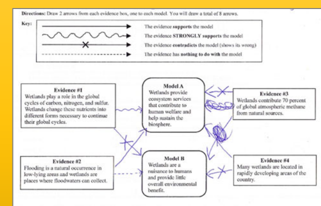
Background

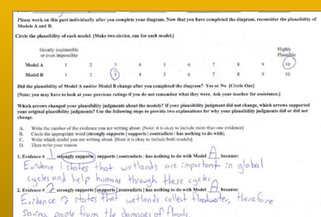
The MEL-Diagram[1]

Chinn & Buckland, 2012; Lombardi et al., 2018

The Build-a-MEL Diagram (baMEL)[2]







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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).

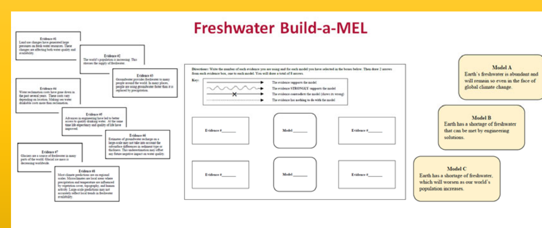
Background

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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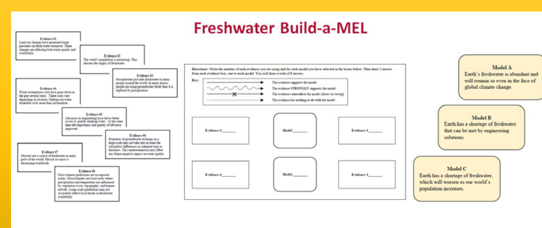

5

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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]

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

N = 76

School 1 (MA)
- n = 57
- Mid-Atlantic State
- Middle level

School 2 (SE)
- n = 19
- Southeastern State
- High school level

Methods

Up to 4 MEL activities in the school year

Student undertakings
- Pre-knowledge survey[1]
- Rated plausibility[2]
- Completed the MEL activity[3]
- Reappraised plausibility[4]
- 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

Knowledge Items for Freshwater Resource Availability baMEL

Item	Text	Item	Text
Item 1	Water reclamation makes contaminated water safe for humans to use.	Item 7*	Global temperatures have increased. But there has not been an overall decrease in global glacial ice.
Item 2*	Engineers will solve current shortages of freshwater.	Item 8	Microclimates have various levels of precipitation. This affects how much water is available for human use.
Item 3*	Freshwater is abundant and will remain so even in the face of global climate change.	Item 9*	Over the past 100 years, lower amounts of rainfall have occurred across the US. This means that greater amounts of land have been affected by drought in the last 20 years.
Item 4*	Land use decisions affect Earth's surface but have little impact on the water cycle.	Item 10	Current shortages of freshwater will get worse around the globe as world population increases.
Item 5	Technology advances have made water safer for human use.	Item 11	Climate change and increasing populations will lead to more freshwater shortages.
Item 6*	Groundwater recharge rates are similar from place to place because soils are generally uniform.	**Item 12**	**Depletion of groundwater causes land to sink. Depletion also causes freshwater to be contaminated.**

Notes: * denotes a negatively worded item, **Bold** denotes removed item.

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)

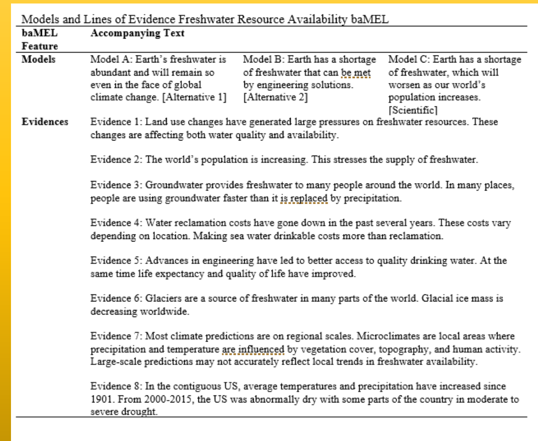
Models and Evidence[1]

Models

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

Evidences

- Developed from scientific information



Models and Lines of Evidence Freshwater Resource Availability baMEL

baMEL Feature	Accompanying Text		
Models	Model A: Earth's freshwater is abundant and will remain so even in the face of global climate change. [Alternative 1]	Model B: Earth has a shortage of freshwater that can be met by engineering solutions. [Alternative 2]	Model C: Earth has a shortage of freshwater, which will worsen as our world's population increases. [Scientific]
Evidences	Evidence 1: Land use changes have generated large pressures on freshwater resources. These changes are affecting both water quality and availability.		
	Evidence 2: The world's population is increasing. This stresses the supply of freshwater.		
	Evidence 3: Groundwater provides freshwater to many people around the world. In many places, people are using groundwater faster than it is replaced by precipitation.		
	Evidence 4: Water reclamation costs have gone down in the past several years. These costs vary depending on location. Making sea water drinkable costs more than reclamation.		
	Evidence 5: Advances in engineering have led to better access to quality drinking water. At the same time life expectancy and quality of life have improved.		
	Evidence 6: Glaciers are a source of freshwater in many parts of the world. Glacial ice mass is decreasing worldwide.		
	Evidence 7: Most climate predictions are on regional scales. Microclimates are local areas where precipitation and temperature are influenced by vegetation cover, topography, and human activity. Large-scale predictions may not accurately reflect local trends in freshwater availability.		
	Evidence 8: In the contiguous US, average temperatures and precipitation have increased since 1901. From 2000-2015, the US was abnormally dry with some parts of the country in moderate to severe drought.		

9

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 Gains[1]

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

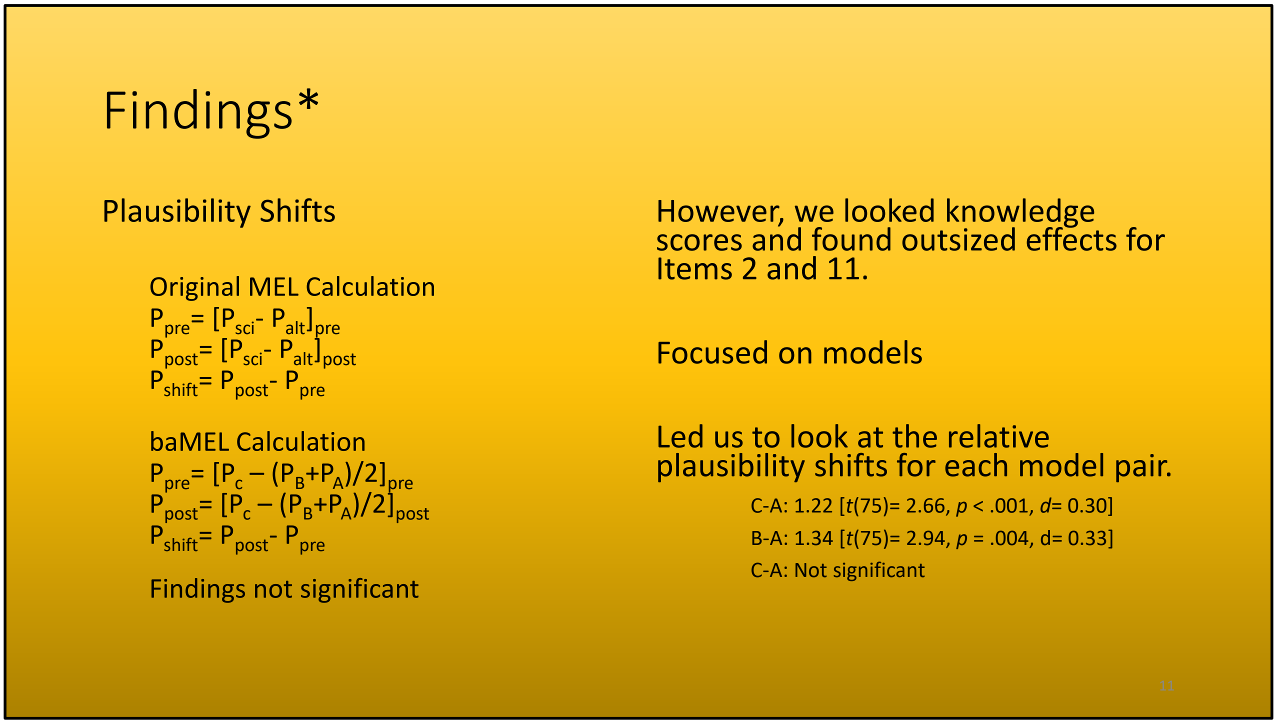
Significant Changes in Knowledge by Item

	Mean	SD	t	df	p	d
Item 1	.446	1.262	3.039	73	.003	0.35
Item 2*	-1.16	1.223	-8.256	75	.000	0.95
Item 3	.635	1.267	4.313	73	.000	0.50
Item 5	.446	1.036	3.704	73	.000	0.43
Item 6	.360	1.291	2.415	74	.018	0.28
Item 9	.533	1.349	3.424	74	.001	-0.40
Item 11	2.382	1.641	12.653	75	.000	1.45

Note: * denotes negative knowledge gain

10

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.



**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= .902, $F(1, 74)= 8.07$, $p = .006$].

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).

Meaning for us…

For NARST Members[1]

- 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[2]

- 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.

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