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

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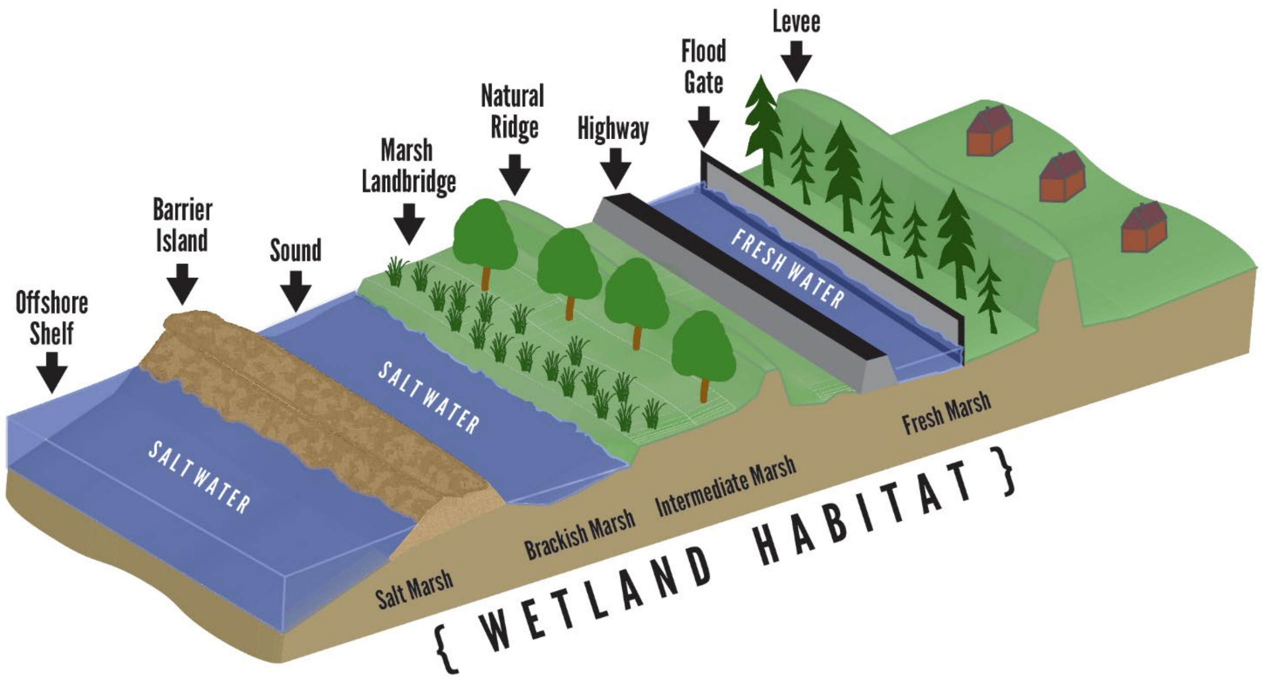

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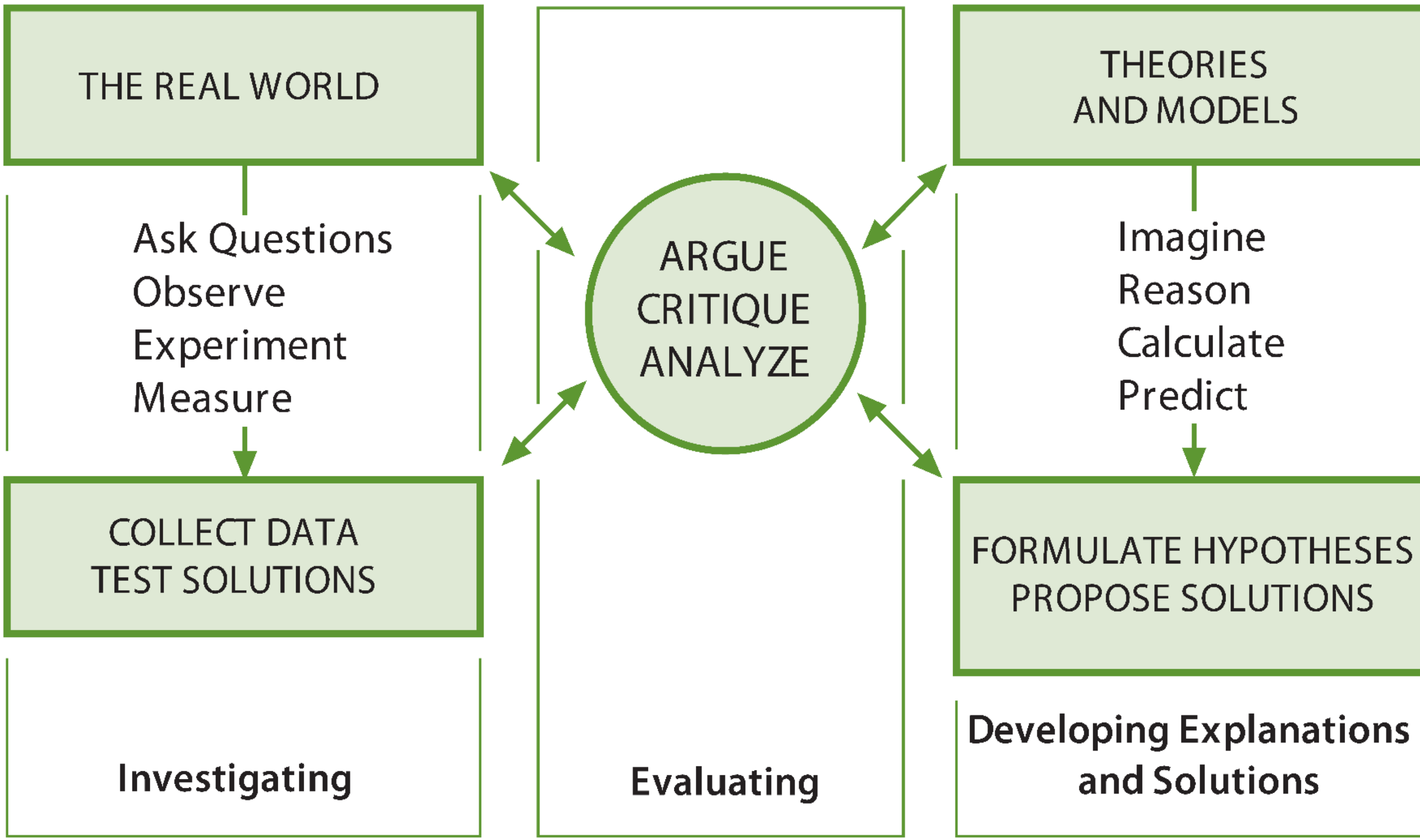
Scaffolding is a metaphor related to the idea that people construct knowledge both cognitively & socially

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

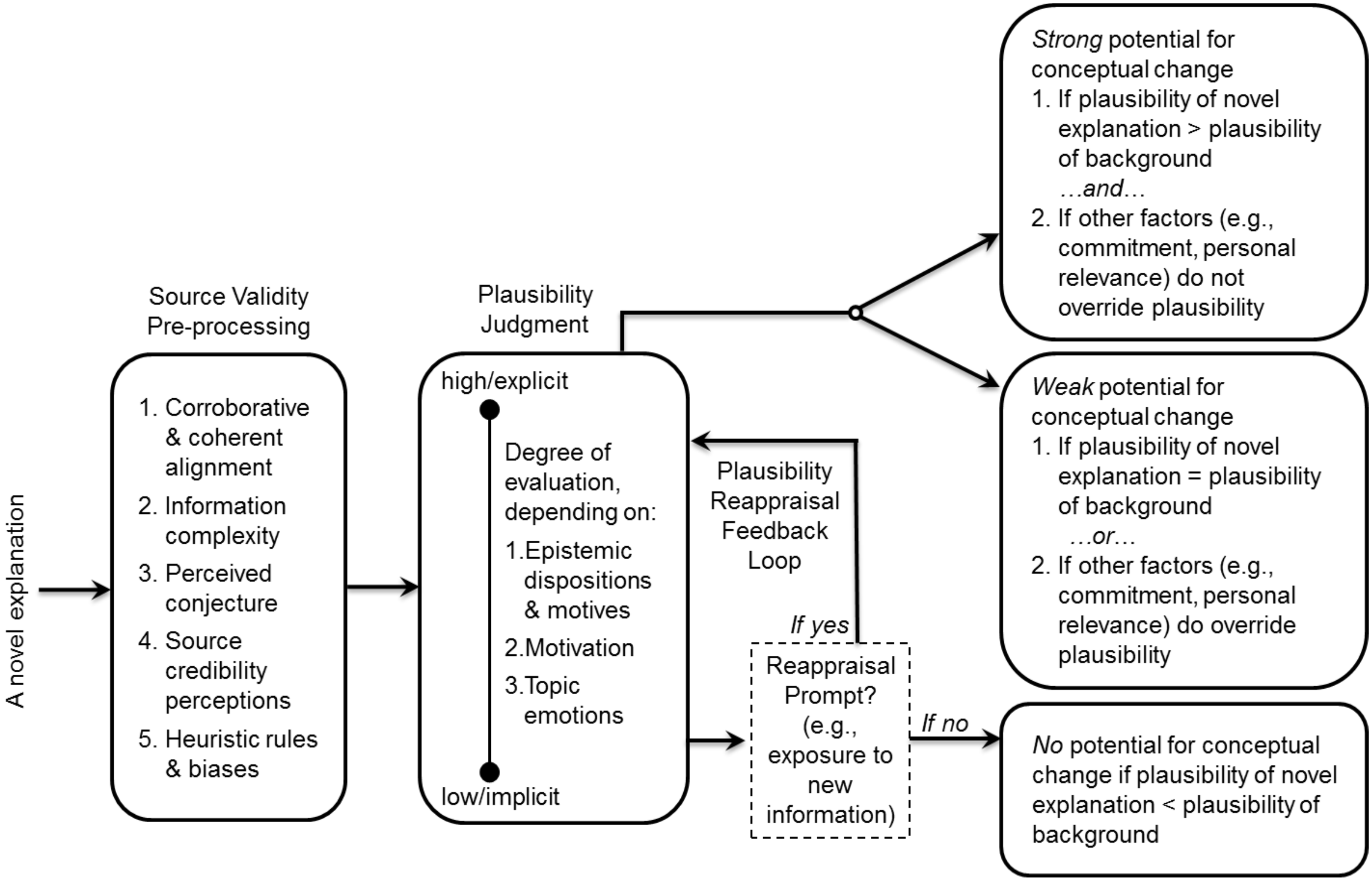


Evaluation as argument, critique, and analysis is central to scientific thinking and knowledge construction (NRC, 2012)

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)

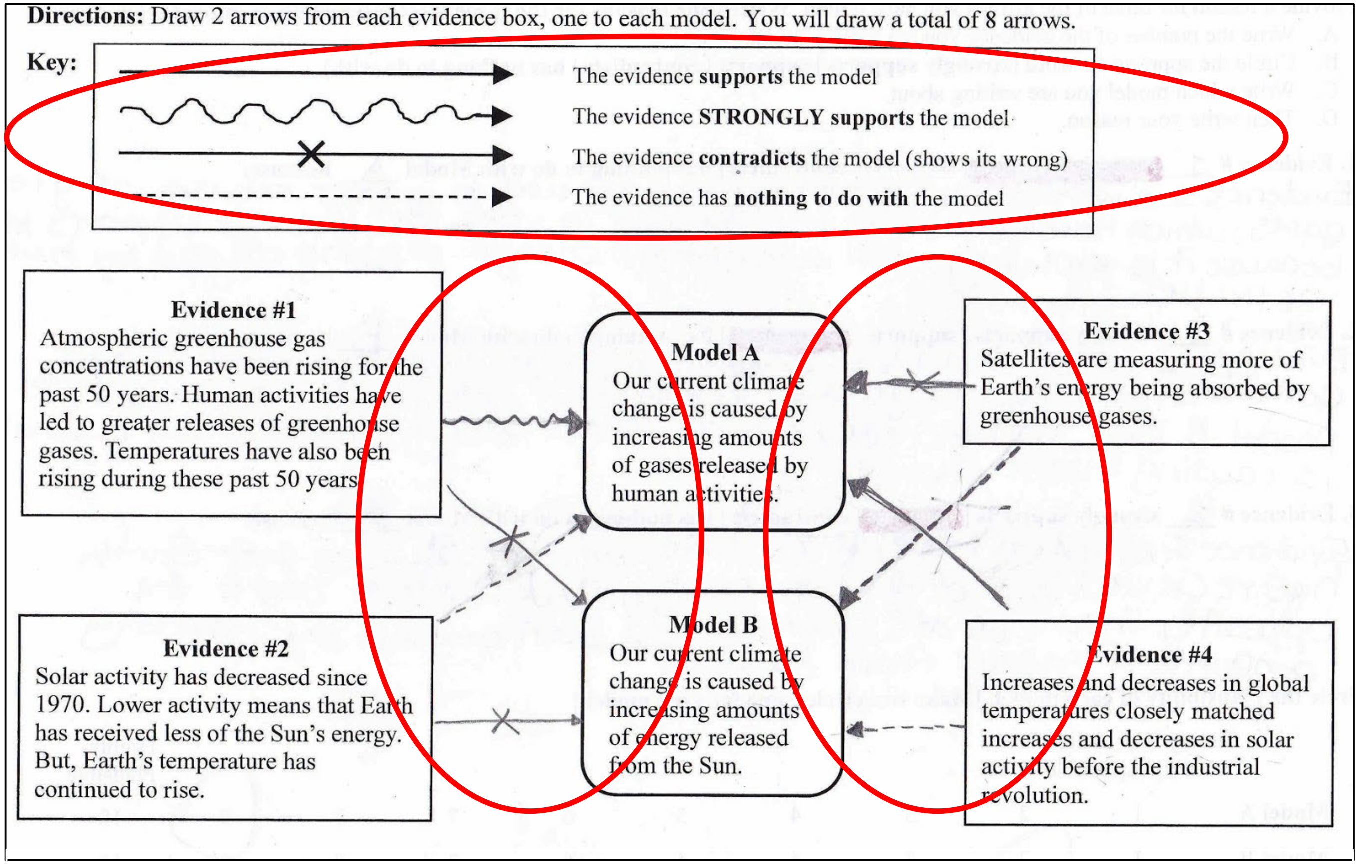
With explicit reappraisal, plausibility-a tentative epistemic judgment about explanations-may facilitate change



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

Classroom instructional scaffolds can help make students' evaluations explicit, thoughtful, & scientific

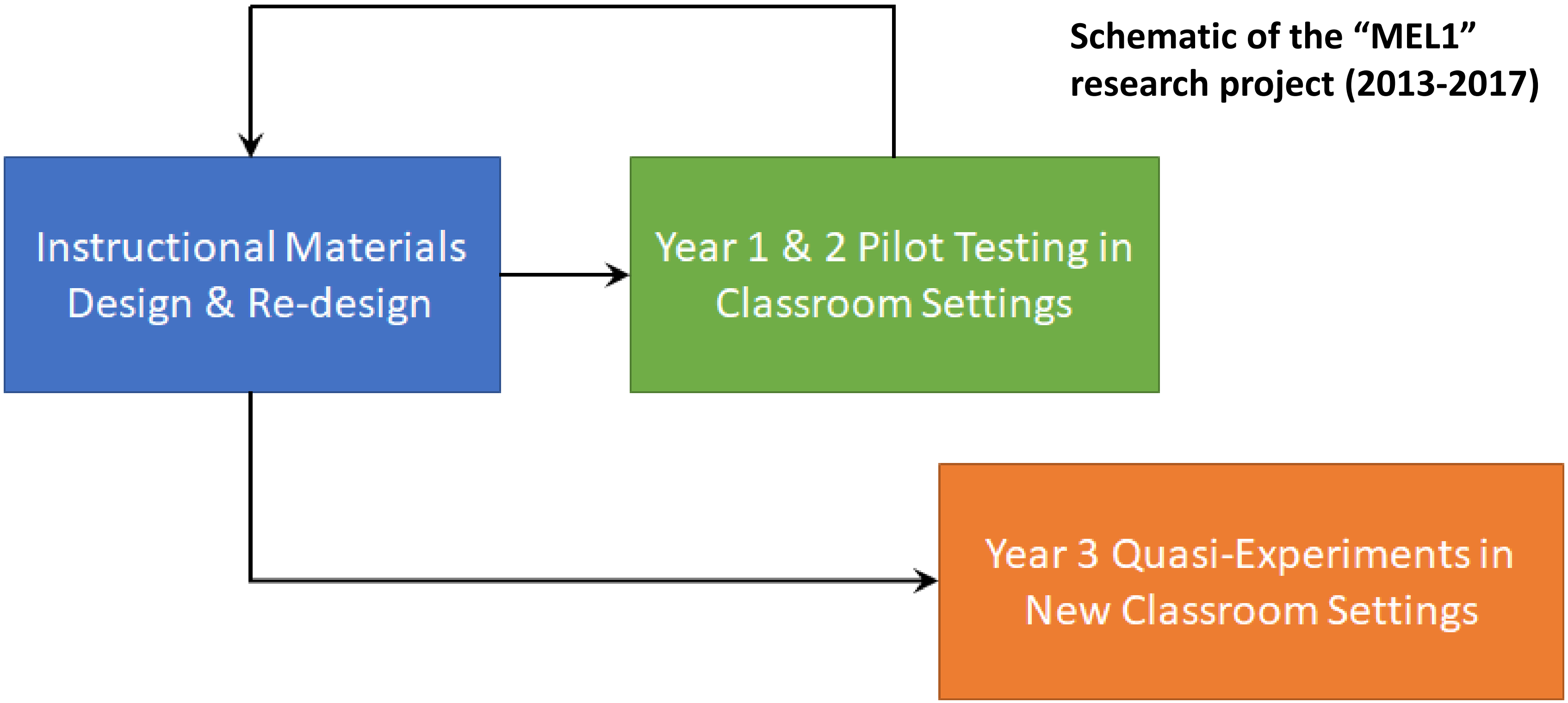
Chinn & colleagues (2012, 2014)



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)

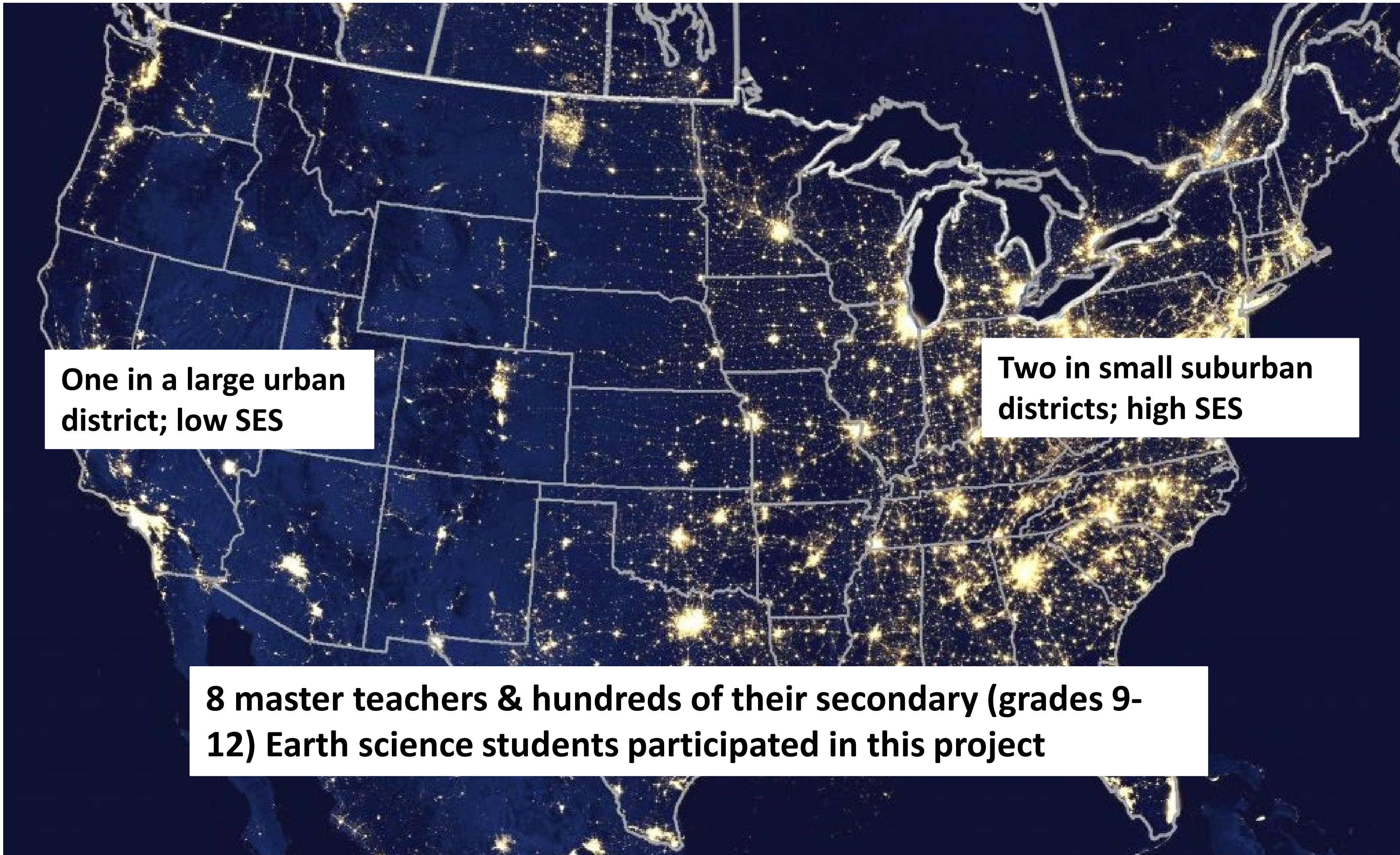
My projects investigate students' evaluations, plausibility, & knowledge about Earth science topics



Schematic of the "MEL1" research project (2013-2017)

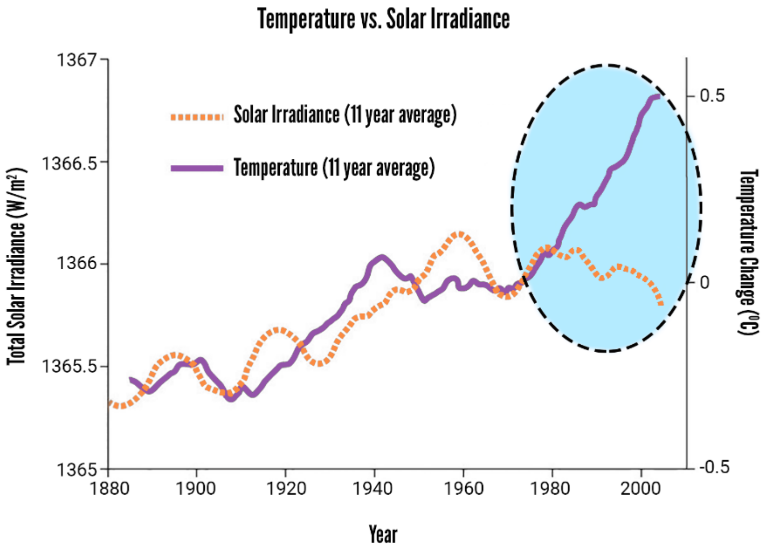
Research question: How does instruction promoting evaluation result in plausibility reappraisal and knowledge changes about Earth and space science topics?

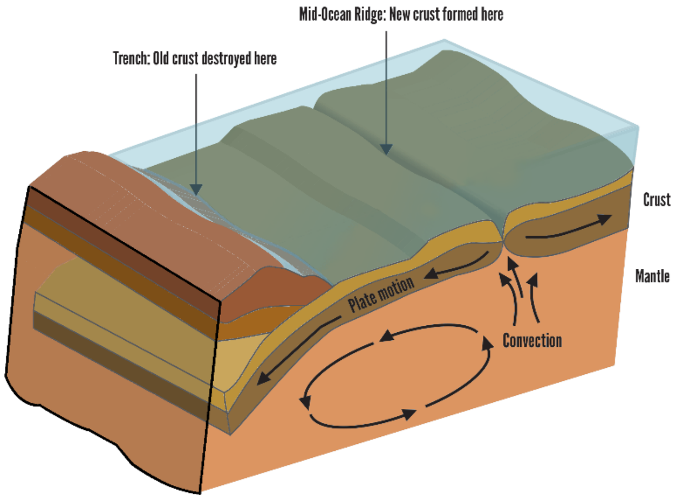
This first project involved three school districts from very different parts of the US



Secondary students experienced instruction about four topics during the course of a school year

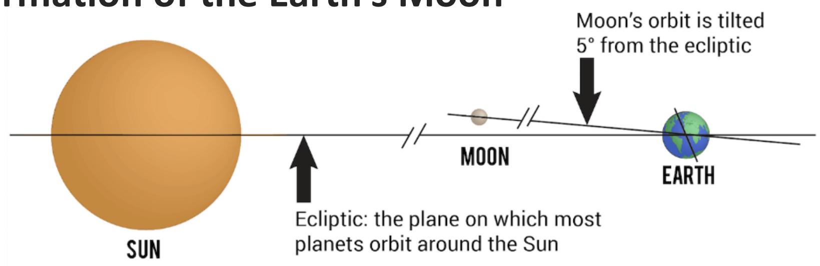
Causes of current climate change

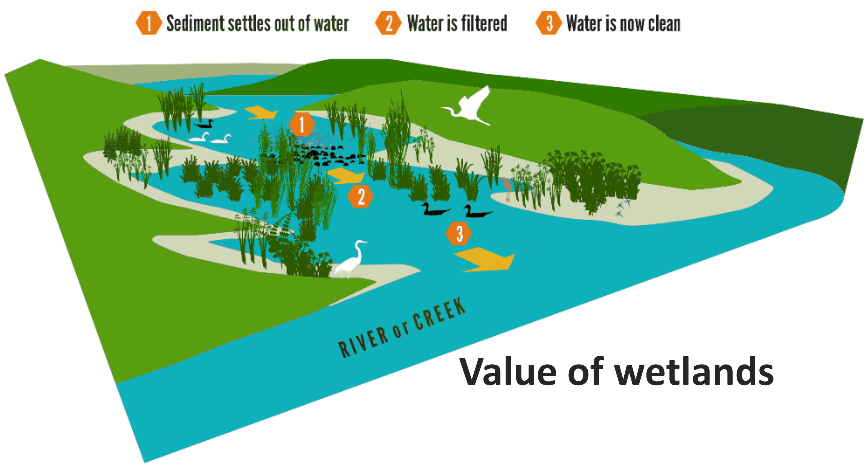




Hydraulic fracturing & earthquakes

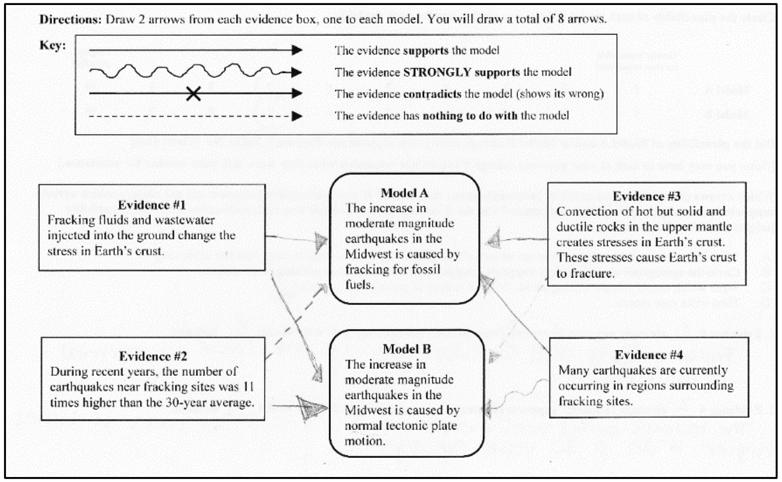
Formation of the Earth's Moon



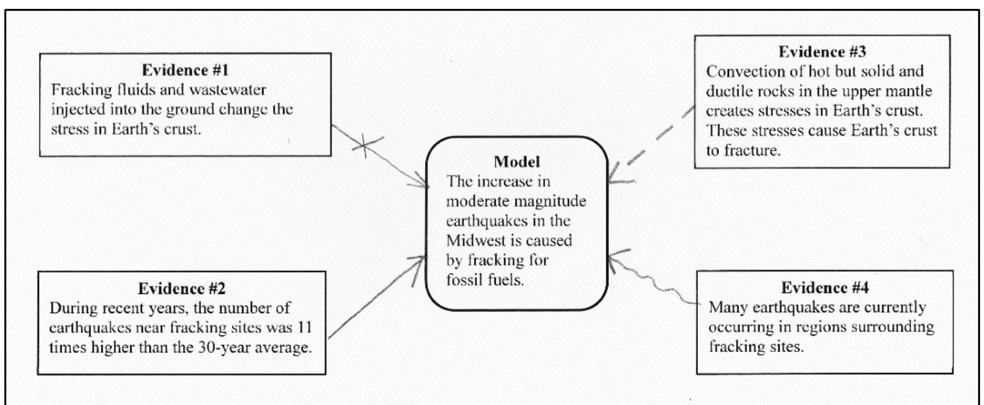


Value of wetlands

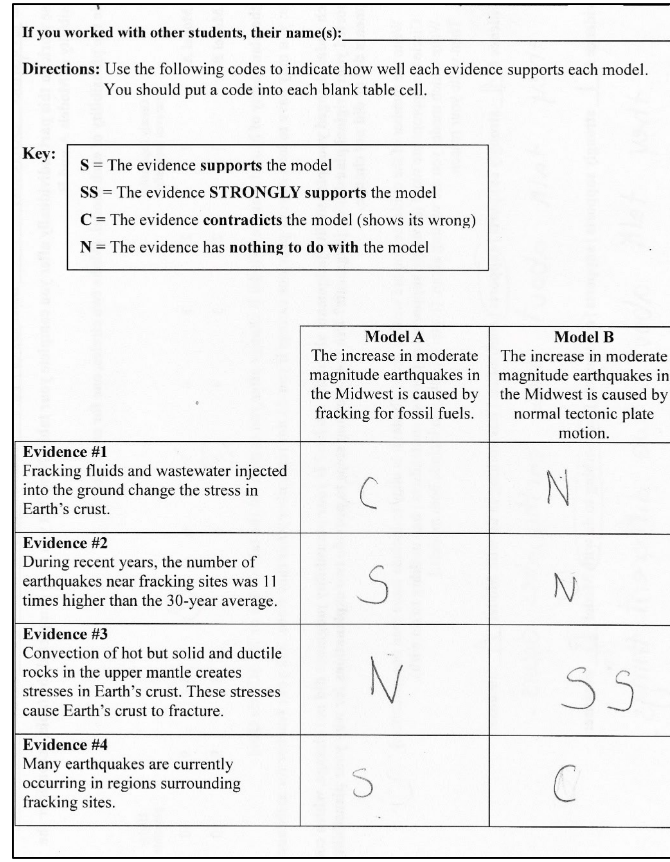
In the project's third year, we conducted a quasi-experiment comparing three different tasks



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



The Mono-MEL diagram, 4 lines of evidence, only 1 alternative



If you worked with other students, their name(s):____________________

Directions: Use the following codes to indicate how well each evidence supports each model. You should put a code into each blank table cell.

Key:

- **S** = The evidence **supports** the model
- **SS** = The evidence **STRONGLY supports** the model
- **C** = The evidence **contradicts** the model (shows its wrong)
- **N** = The evidence has **nothing to do with** the model

	Model A The increase in moderate magnitude earthquakes in the Midwest is caused by fracking for fossil fuels.	**Model B** The increase in moderate magnitude earthquakes in the Midwest is caused by normal tectonic plate motion.
Evidence #1 Fracking fluids and wastewater injected into the ground change the stress in Earth's crust.	C	N
Evidence #2 During recent years, the number of earthquakes near fracking sites was 11 times higher than the 30-year average.	S	N
Evidence #3 Convection of hot but solid and ductile rocks in the upper mantle creates stresses in Earth's crust. These stresses cause Earth's crust to fracture.	N	SS
Evidence #4 Many earthquakes are currently occurring in regions surrounding fracking sites.	S	C

The Model-Evidence Link Table (MET), 4 lines of evidence, 2 alternatives

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 # _1_ strongly supports | supports | contradicts | has nothing to do with Model _B_ because:
Evidence 1 contradict Model B, because evidence one says that human activities have led 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 contridicts Model B because evidence 2 says that Earth has recieved less of the suns energy, and mode 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

Category	Description	Score
Erroneous Evaluation	Explanation contains an incorrect model-to-evidence link and/or is mostly inconsistent with scientific understanding.	1
Descriptive Evaluation	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.	2
Relational Evaluation	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.	3
Critical Evaluation	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.	4

Lombardi et al. (2016b,2017)

Students rate the plausibility of two alternative explanatory models that explain a phenomena

Case 1: Probabilistic Reasoning

Circle the plausibility of each model. [Make two circles. One for each model.]

	Greatly implausible (or even impossible)									Highly Plausible
Model A	1	2	3	4	5	6	7	8	9	10
Model B	1	2	3	4	5	6	7	8	9	10

Case 2: Plausibilistic Reasoning (common)

Circle the plausibility of each model. [Make two circles. One for each model.]

	Greatly implausible (or even impossible)									Highly Plausible
Model A	1	2	3	4	5	6	7	8	9	10
Model B	1	2	3	4	5	6	7	8	9	10

Case 3: Plausibilistic Reasoning (uncommon)

Circle the plausibility of each model. [Make two circles. One for each model.]

	Greatly implausible (or even impossible)									Highly Plausible
Model A	1	2	3	4	5	6	7	8	9	10
Model B	1	2	3	4	5	6	7	8	9	10

Short knowledge surveys probe students' understanding for each topic

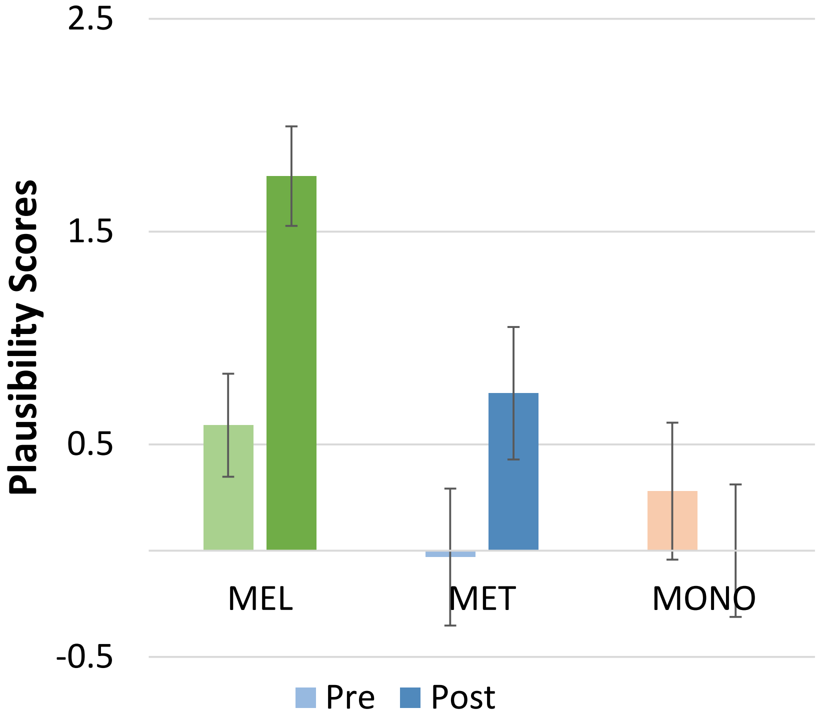
Below are statements about climate change. Rate the degree to which you think that *climate scientists* agree with these statements.

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
1. The Sun is the main source of energy for Earth's climate.	A	B	C	D	E
2. We cannot know about ancient climate change.	A	B	C	D	E
3. Burning of fossil fuels produces greenhouse gases.	A	B	C	D	E
4. Greenhouse gases absorb some of the energy emitted by Earth's surface.	A	B	C	D	E
5. Earth's climate is currently changing.	A	B	C	D	E

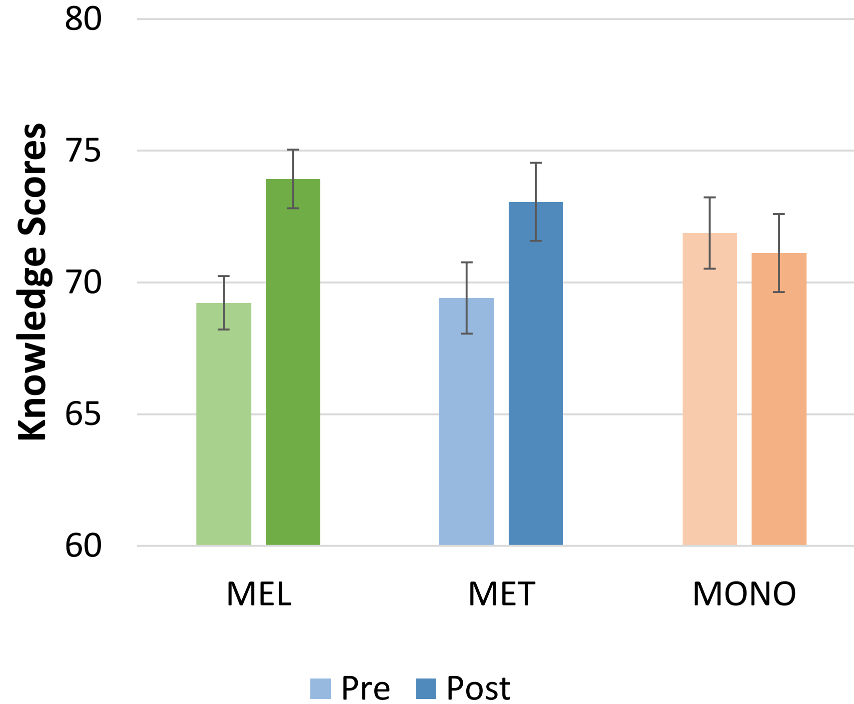
Although short, we have calibrated these with longer forms and classroom testing reveals instrument validity for research purposes

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)

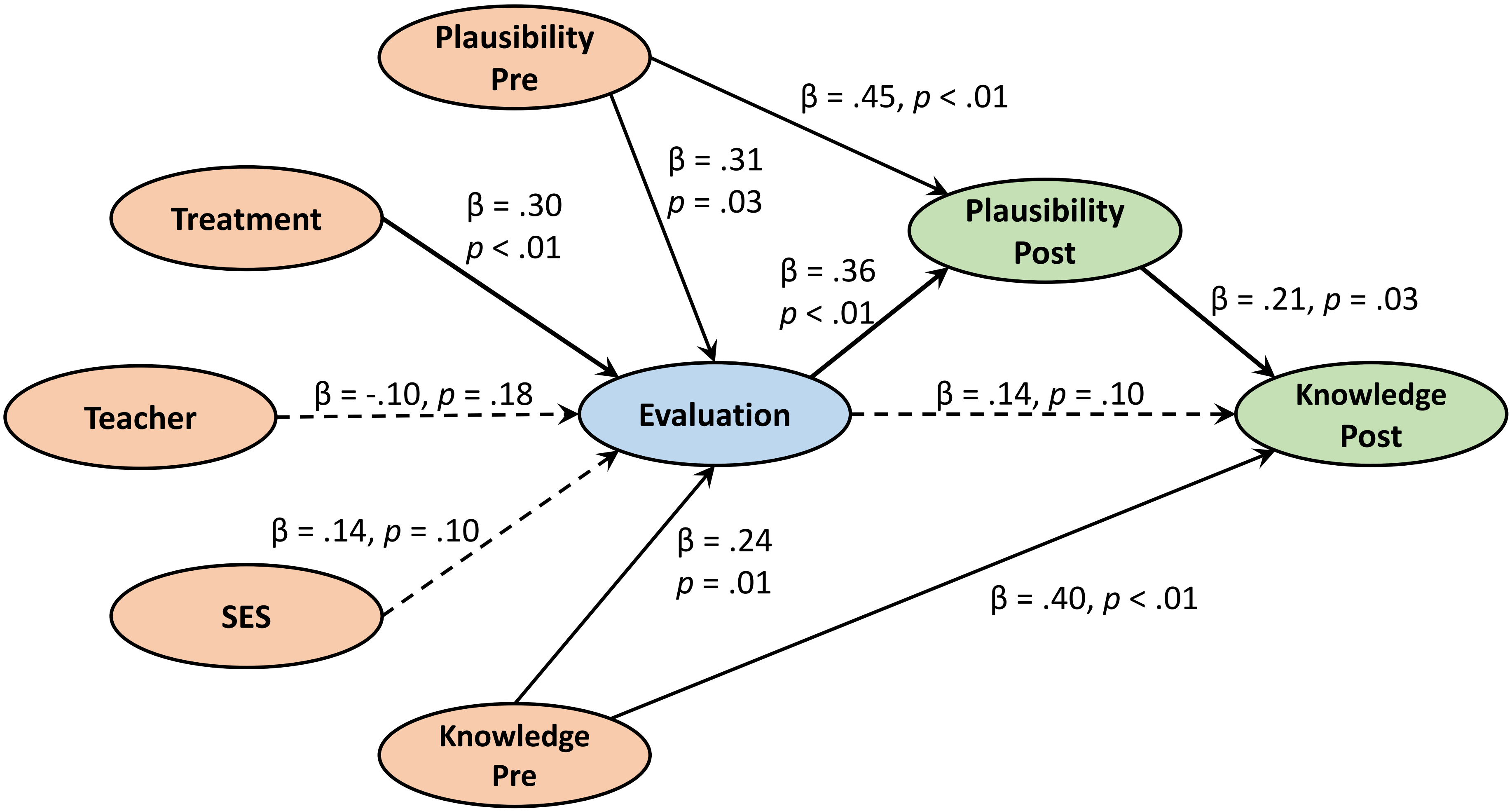


Wilks' λ = .843, *F*(2,61) = 5.67, *p* = .006, medium effect size (η^2 = .157)



Wilks' λ = .893, *F*(2,61) = 3.67, *p* = .03, medium effect size (η^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)

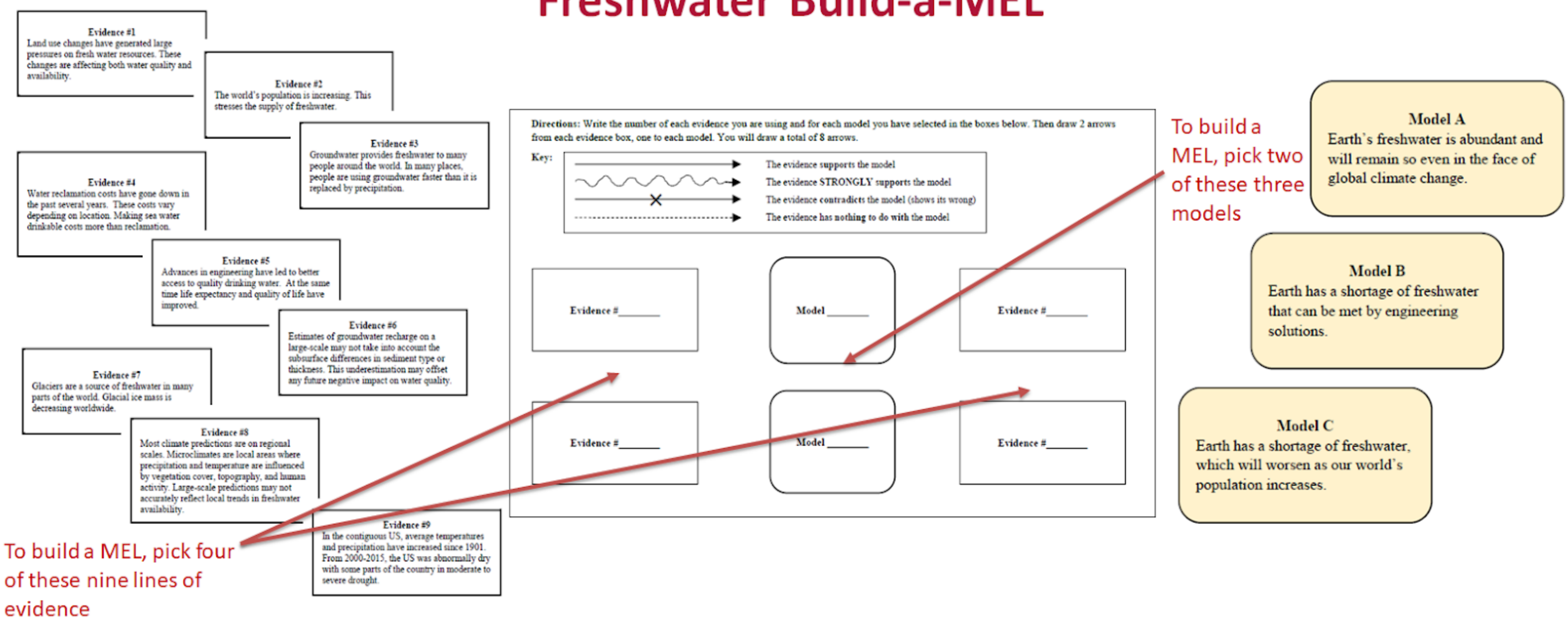
These results are aligned with and complementary to several empirical studies and recent theory…

…(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

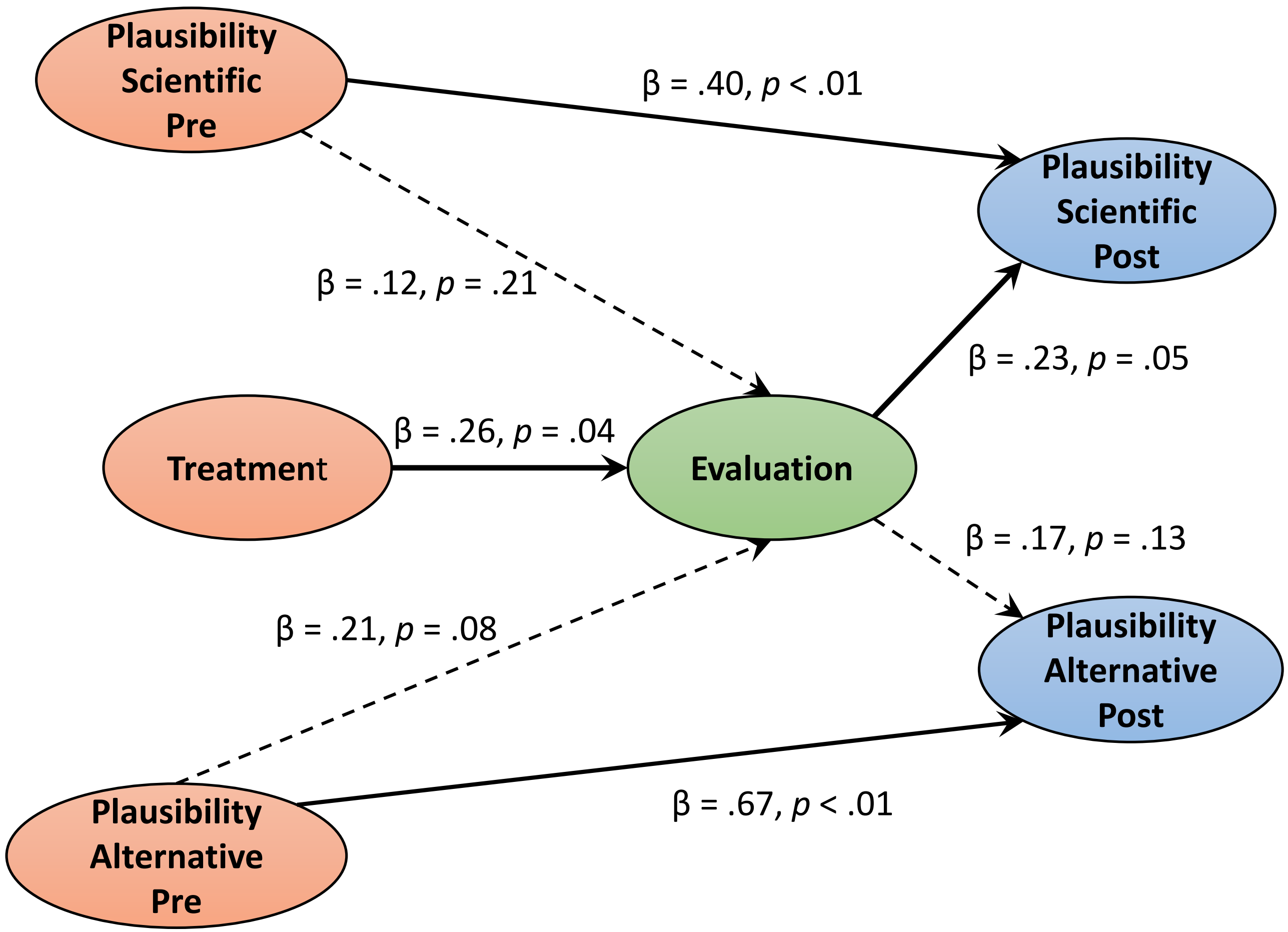
Our current project examines scaffolds that increase students' "conceptual agency" (Pickering, 1995)

Freshwater Build-a-MEL



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…

Volume XXXII, Issue 2 Page 5

Beyond the Controversy:
Instructional Scaffolds to Promote Critical Evaluation and Understanding of Earth Science

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…and development of scientific thinking practices are essential for all so that we can equitably address current and future global challenges

tion between evidence and models. MELs help students learn about fundamental Earth and space science content that underlies socio-scientific, complex, and abstract issues. Our project team has been developing and testing four MELs about socio-scientific issues (climate change, wetlands and land use, fracking and earthquakes) and abstract ideas (formation of Earth's Moon) for use in high school classrooms. These MEL activities facilitate students' critical evaluations of alternatives, which is a skill necessary to engage in many scientific and engineering practices. Being critically evaluative allows students to go beyond the controversy and reason scientifically through coordination of evidence and models.

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