Scaffolding scientific thinking to facilitate students' knowledge construction about Earth and space science topics

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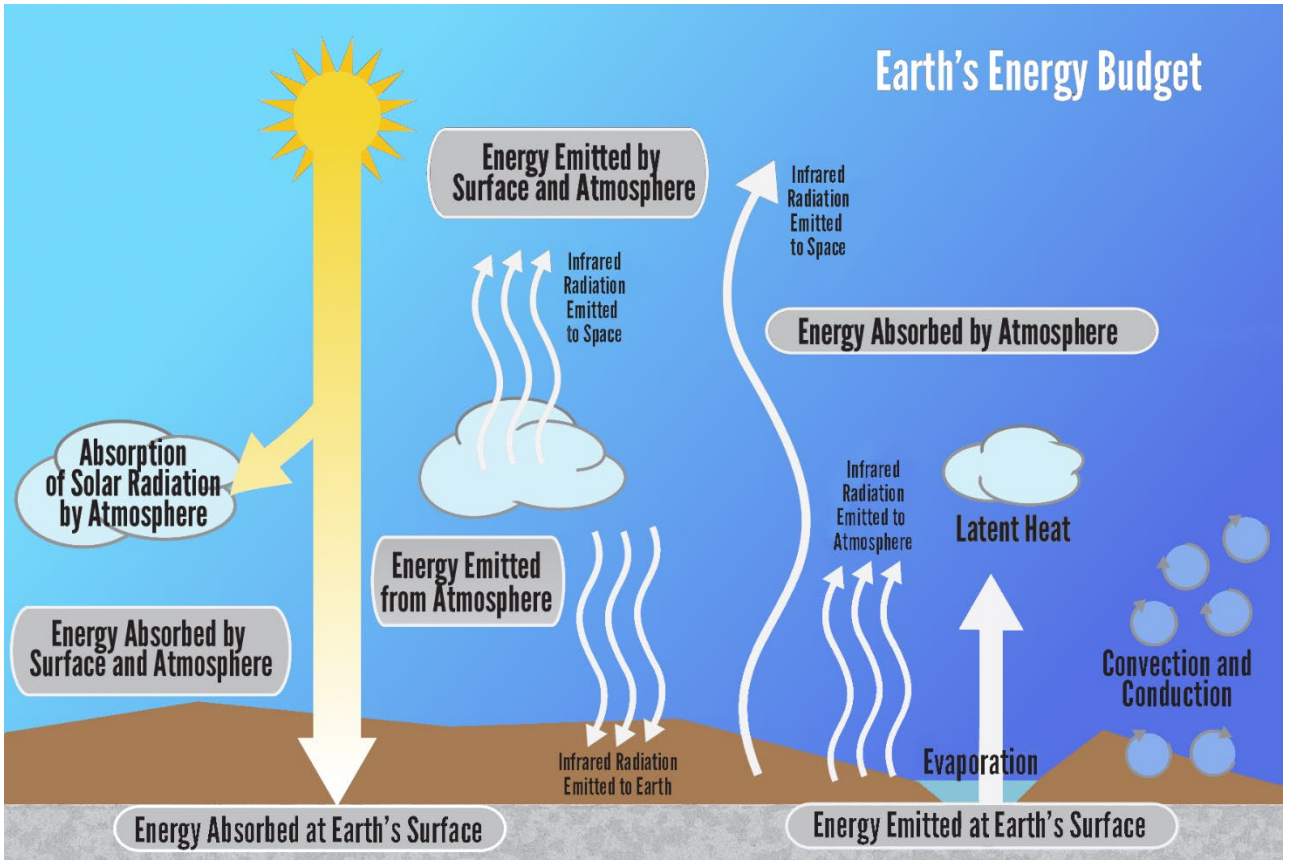

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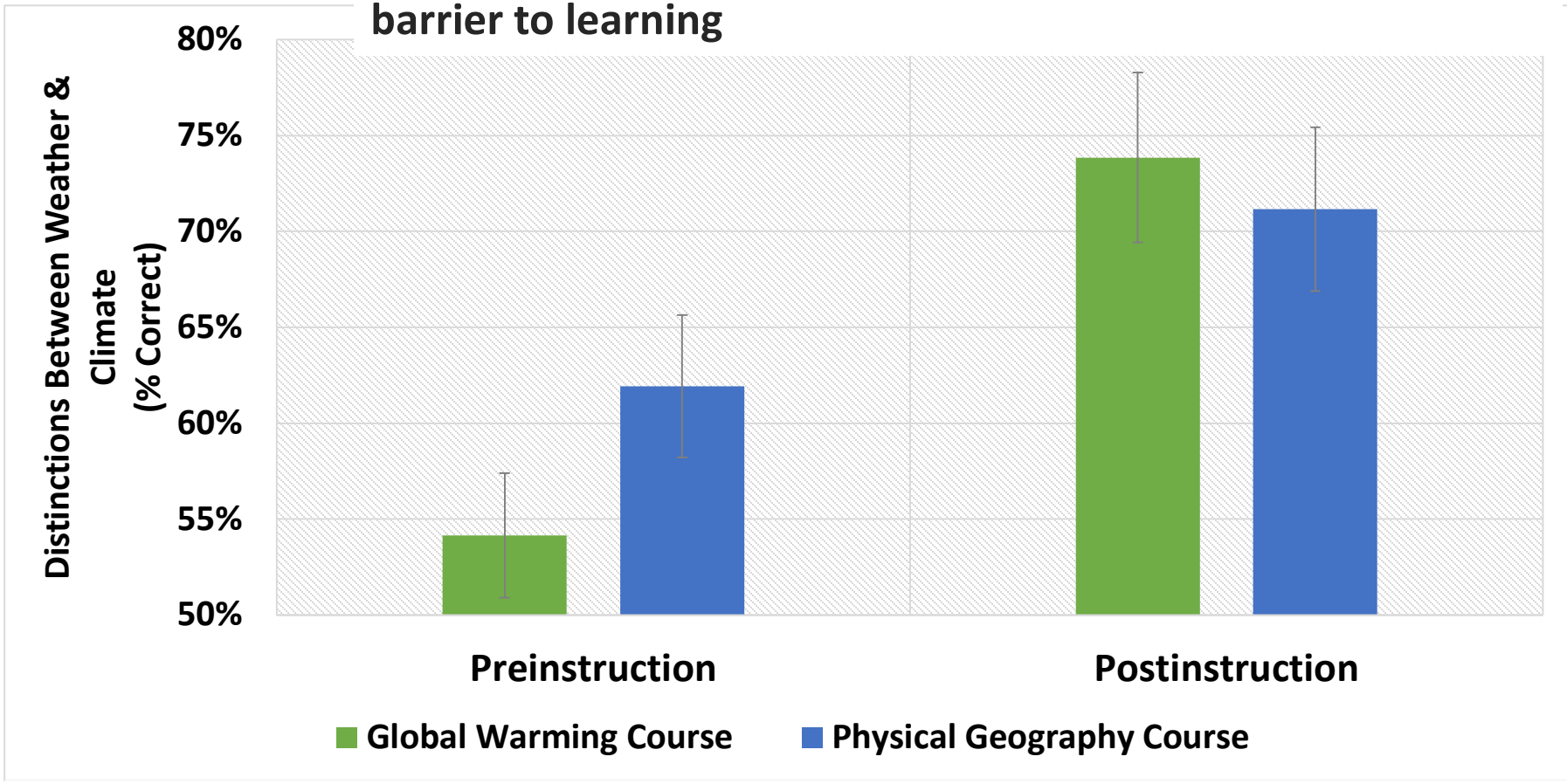
Scaffolding is a metaphor related to the idea that people construct knowledge both cognitively & socially

In education and educational research, scaffolding consists of instructional materials and strategies that facilitate students' knowledge construction

Students' knowledge may be different than scientifically accurate conceptions…

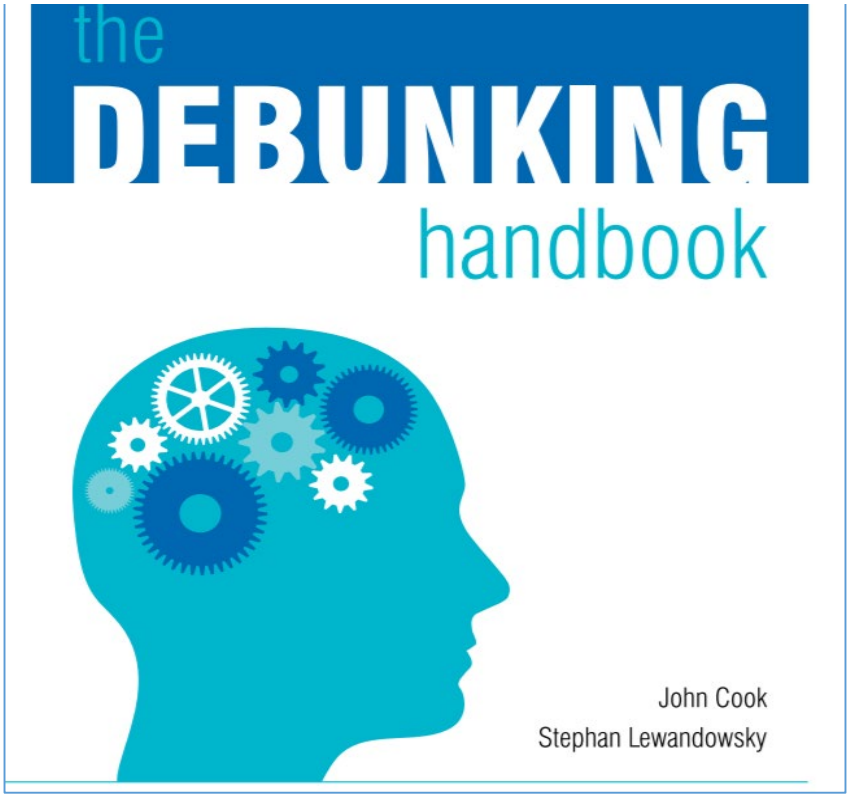
…and in some situations, prior knowledge may act as a barrier to learning



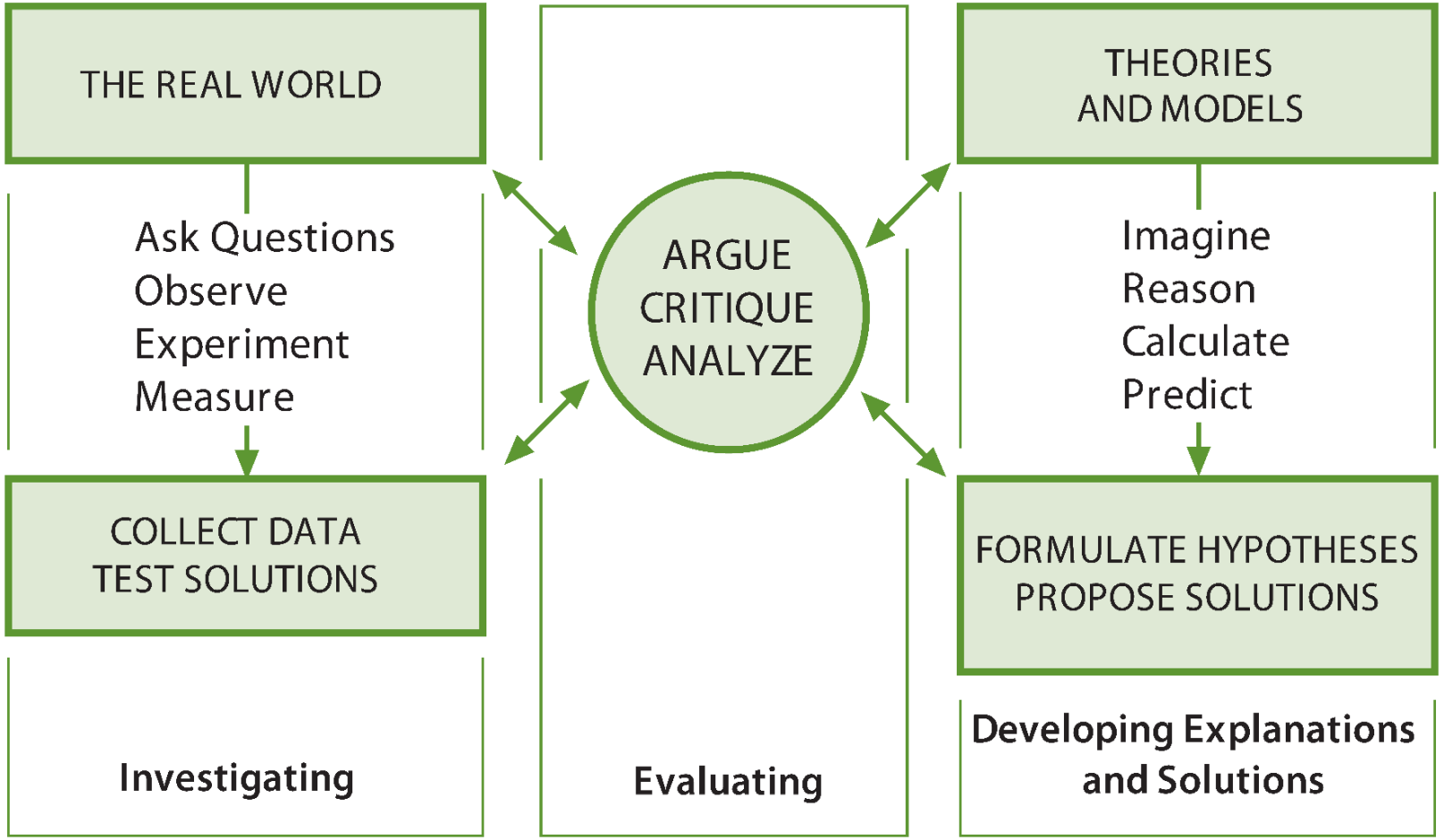
Main effect: $F(1,80) = 16$, $p < .01$, $\eta^2 = .17$; interaction: $F(1,80) = 3.2$, $p = .08$; Lombardi & Sinatra (2012)

However, the “Information Deficit” model of misunderstanding is essentially incorrect

“Educators need to understand how people process information, how they modify their existing knowledge and how worldviews affect their ability to think rationally”



Scientific literacy involves knowing both (1) *what* scientists know & (2) *how* scientists know

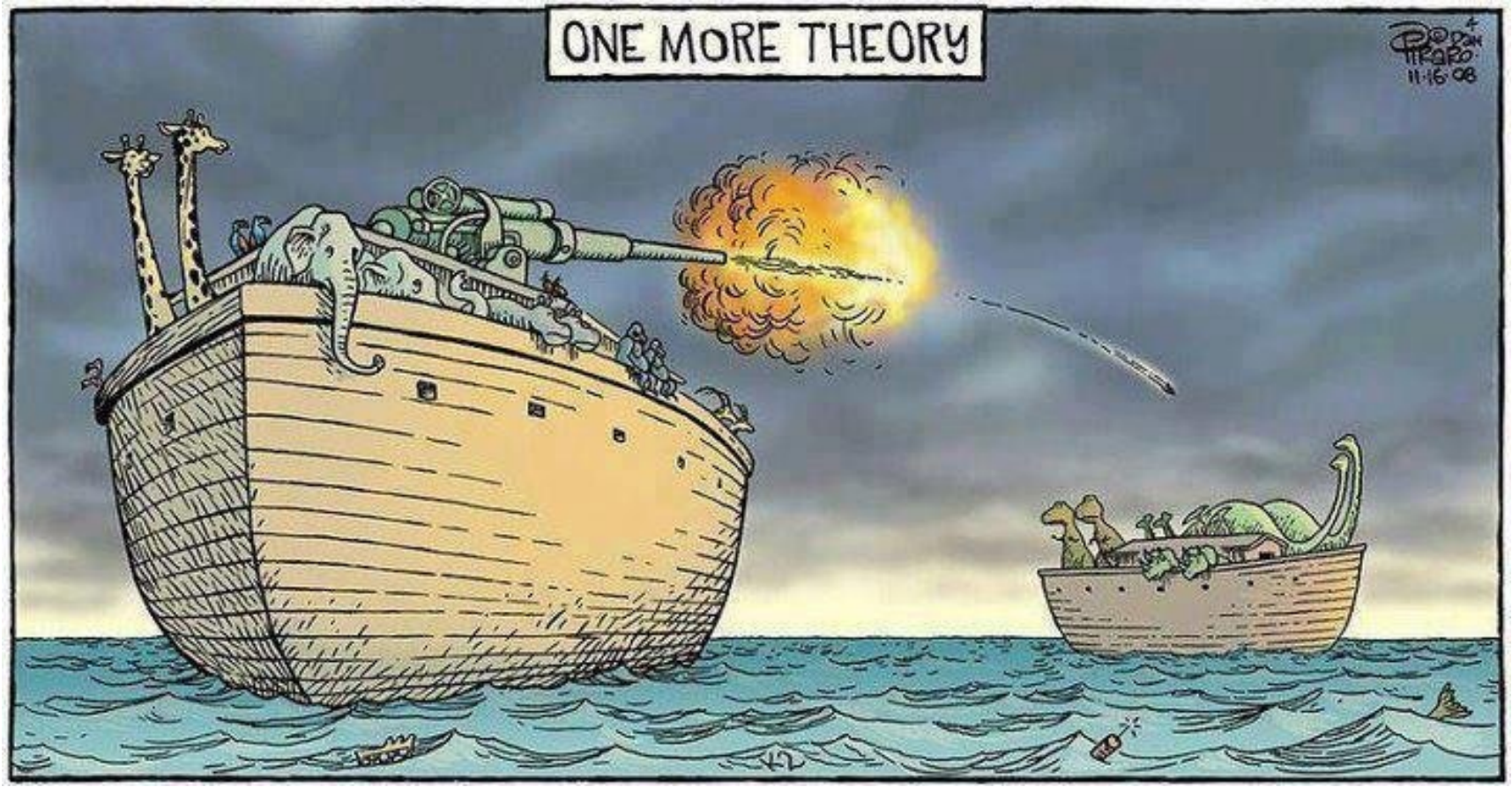


Evaluation as argument, critique, and analysis is central to scientific thinking and knowledge construction (NRC, 2012)

Relatedly, students may find scientific explanations to be implausible

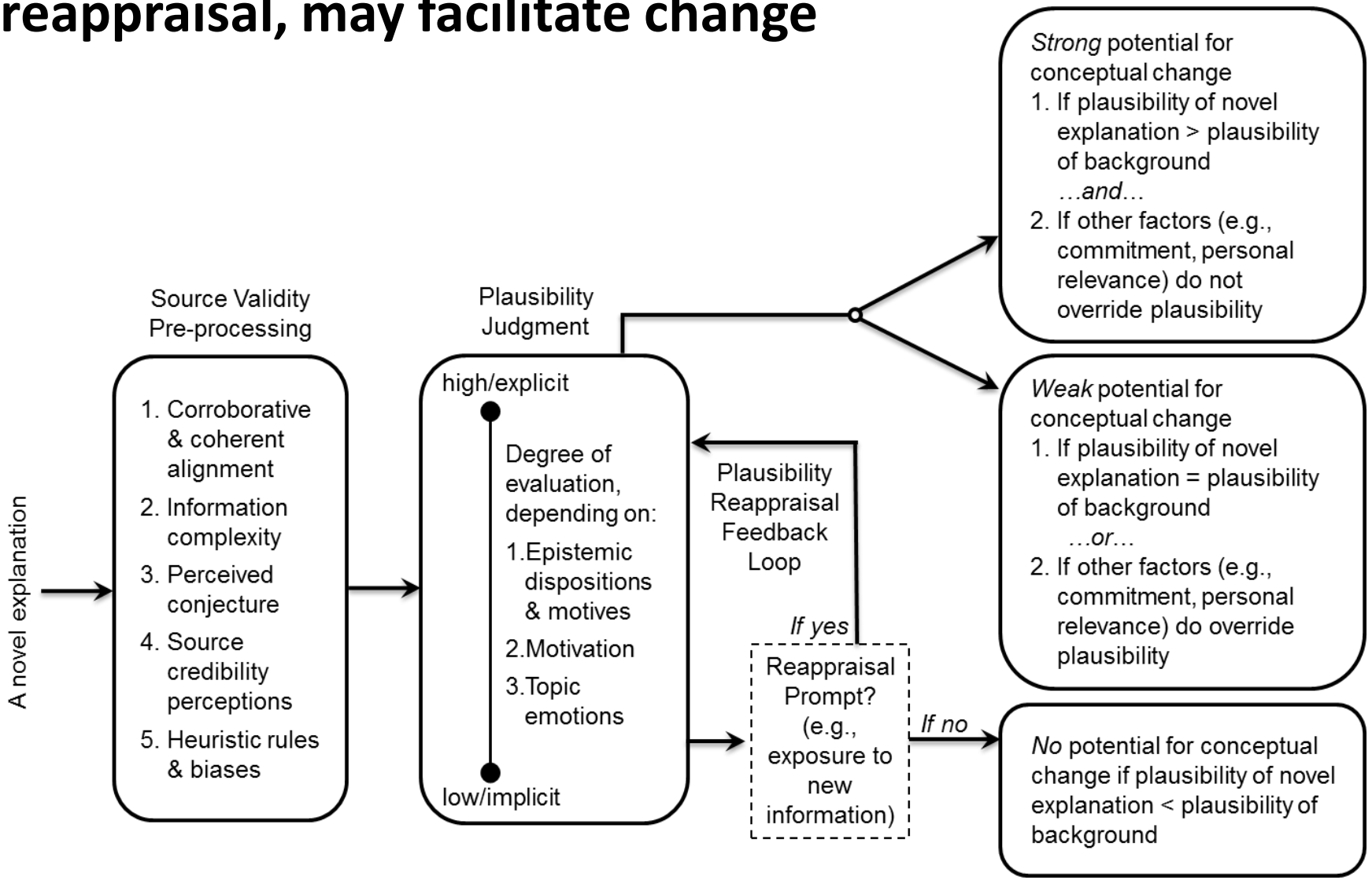
Epistemic judgments (e.g., plausibility) are often formed through automatic cognitive evaluations with little purposeful thinking (Lombardi et al., 2016a)

Plausibility is specifically an epistemic judgment associated with explanations



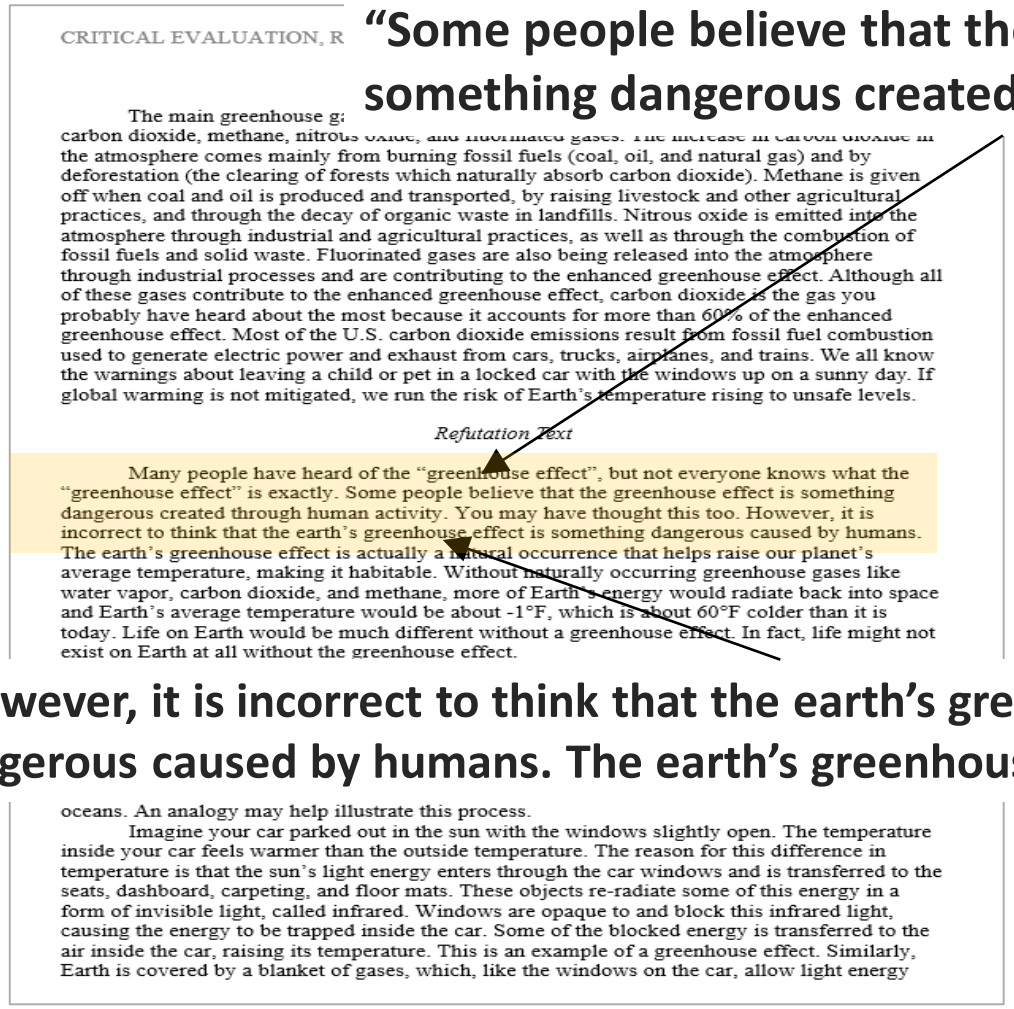
Other types of epistemic judgments are associated with evidence (e.g., credibility, trustworthiness, and reliability; Lombardi et al., 2016a)

Plausibility is a tentative epistemic judgment, and with reappraisal, may facilitate change



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

Refutation texts are experimental tools to investigate cognitive co-activation of prior and scientific knowledge



CRITICAL EVALUATION, R

The main greenhouse g
carbon dioxide, methane, nitrous oxide, and fluorinated gases. The increase in carbon dioxide in the atmosphere comes mainly from burning fossil fuels (coal, oil, and natural gas) and by deforestation (the clearing of forests which naturally absorb carbon dioxide). Methane is given off when coal and oil is produced and transported, by raising livestock and other agricultural practices, and through the decay of organic waste in landfills. Nitrous oxide is emitted into the atmosphere through industrial and agricultural practices, as well as through the combustion of fossil fuels and solid waste. Fluorinated gases are also being released into the atmosphere through industrial processes and are contributing to the enhanced greenhouse effect. Although all of these gases contribute to the enhanced greenhouse effect, carbon dioxide is the gas you probably have heard about the most because it accounts for more than 60% of the enhanced greenhouse effect. Most of the U.S. carbon dioxide emissions result from fossil fuel combustion used to generate electric power and exhaust from cars, trucks, airplanes, and trains. We all know the warnings about leaving a child or pet in a locked car with the windows up on a sunny day. If global warming is not mitigated, we run the risk of Earth's temperature rising to unsafe levels.

Refutation Text

Many people have heard of the "greenhouse effect", but not everyone knows what the "greenhouse effect" is exactly. Some people believe that the greenhouse effect is something dangerous created through human activity. You may have thought this too. However, it is incorrect to think that the earth's greenhouse effect is something dangerous caused by humans. The earth's greenhouse effect is actually a natural occurrence that helps raise our planet's average temperature, making it habitable. Without naturally occurring greenhouse gases like water vapor, carbon dioxide, and methane, more of Earth's energy would radiate back into space and Earth's average temperature would be about -1°F, which is about 60°F colder than it is today. Life on Earth would be much different without a greenhouse effect. In fact, life might not exist on Earth at all without the greenhouse effect.

oceans. An analogy may help illustrate this process.

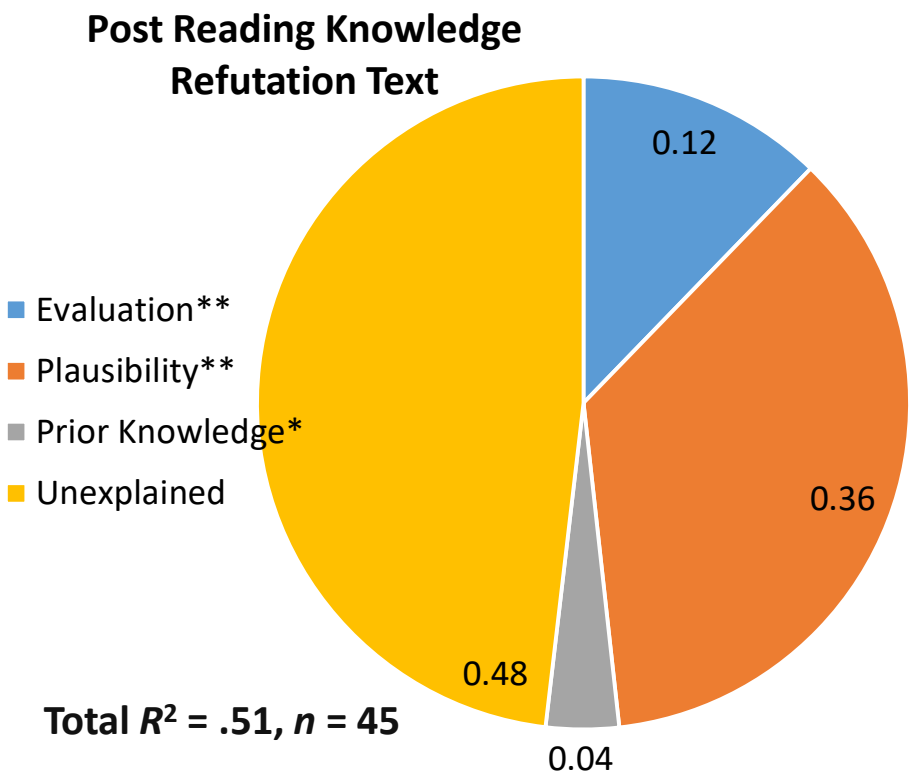
Imagine your car parked out in the sun with the windows slightly open. The temperature inside your car feels warmer than the outside temperature. The reason for this difference in temperature is that the sun's light energy enters through the car windows and is transferred to the seats, dashboard, carpeting, and floor mats. These objects re-radiate some of this energy in a form of invisible light, called infrared. Windows are opaque to and block this infrared light, causing the energy to be trapped inside the car. Some of the blocked energy is transferred to the air inside the car, raising its temperature. This is an example of a greenhouse effect. Similarly, Earth is covered by a blanket of gases, which, like the windows on the car, allow light energy

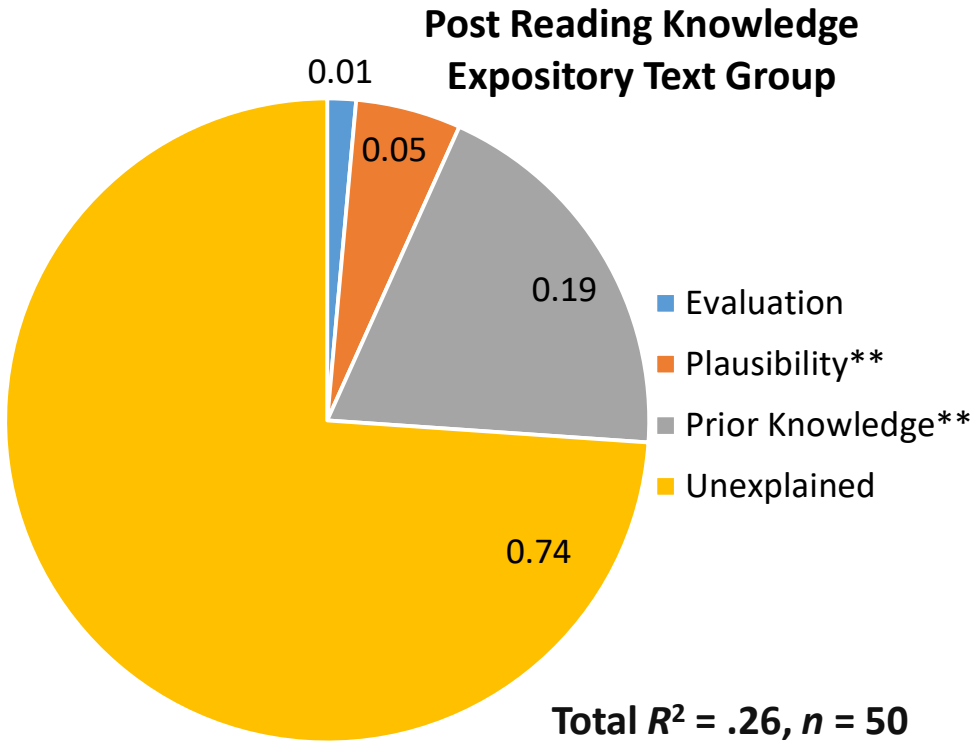
"Some people believe that the greenhouse effect is something dangerous created through human activity."

"However, it is incorrect to think that the earth's greenhouse effect is something dangerous caused by humans. The earth's greenhouse effect is actually…"

Lombardi et al. (2016b)

Student who were more evaluative and reappraised plausibility shifted toward more scientific knowledge...

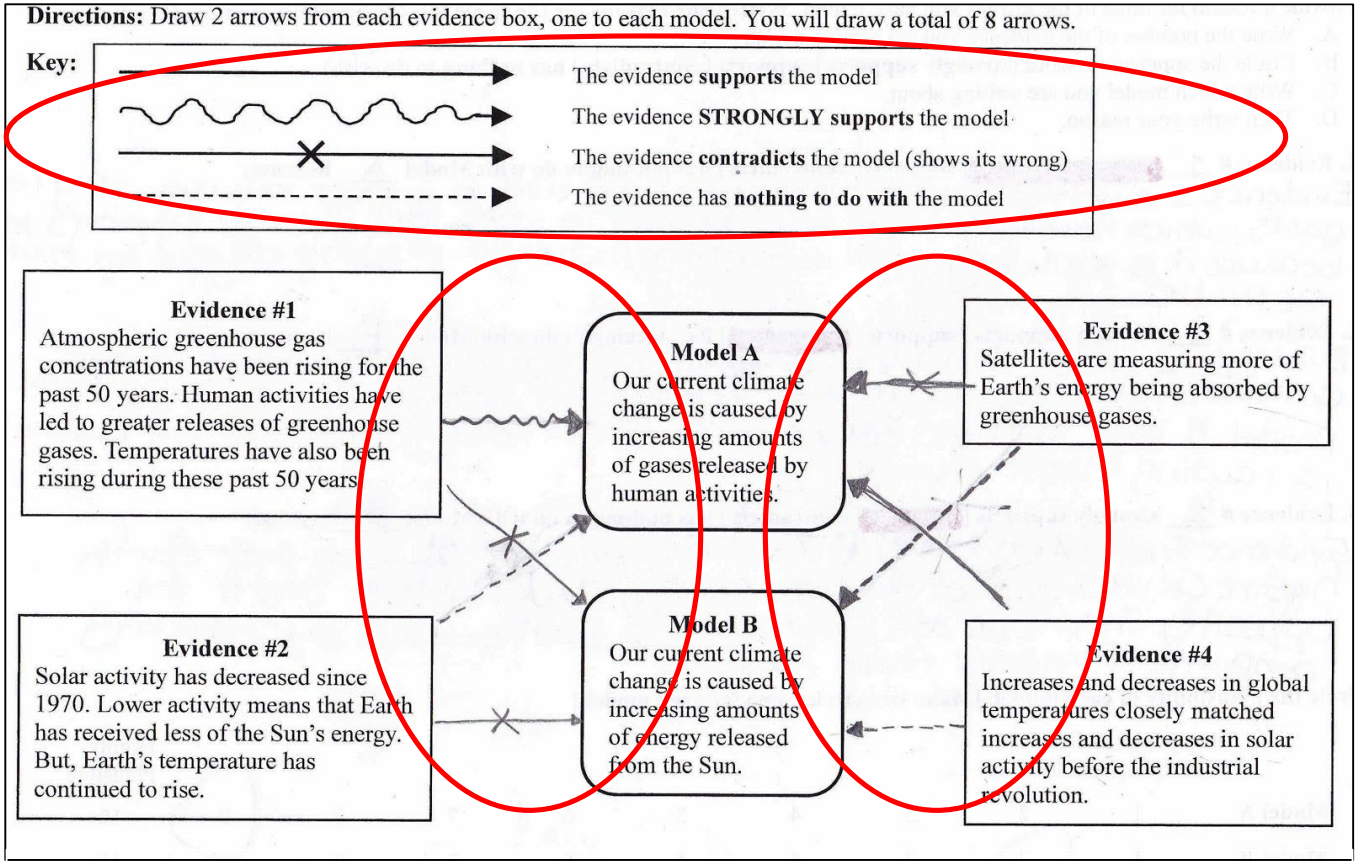




…but only after reading a refutation text…and refutation texts are difficult to design and use effectively in authentic classroom instruction

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

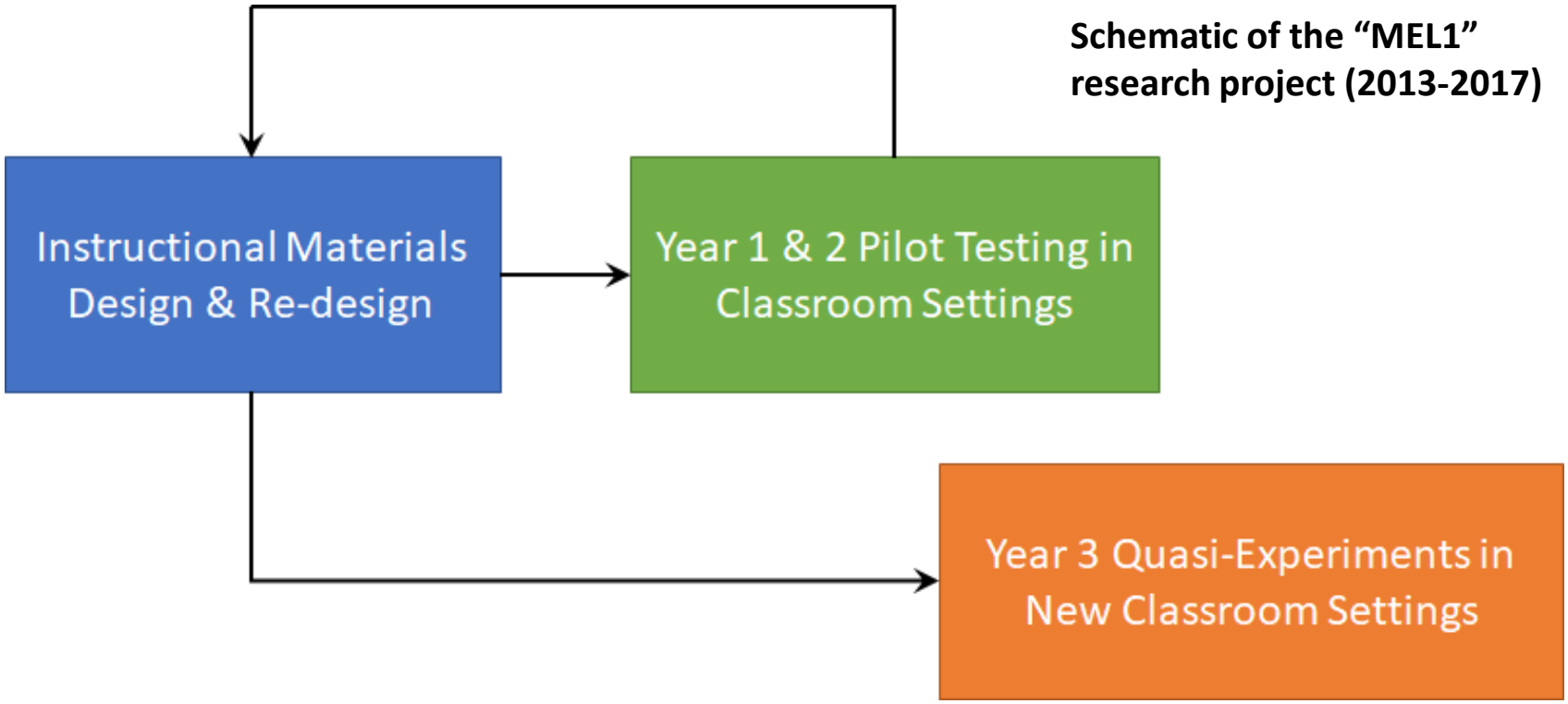
Chinn & colleagues (2012, 2014)



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)

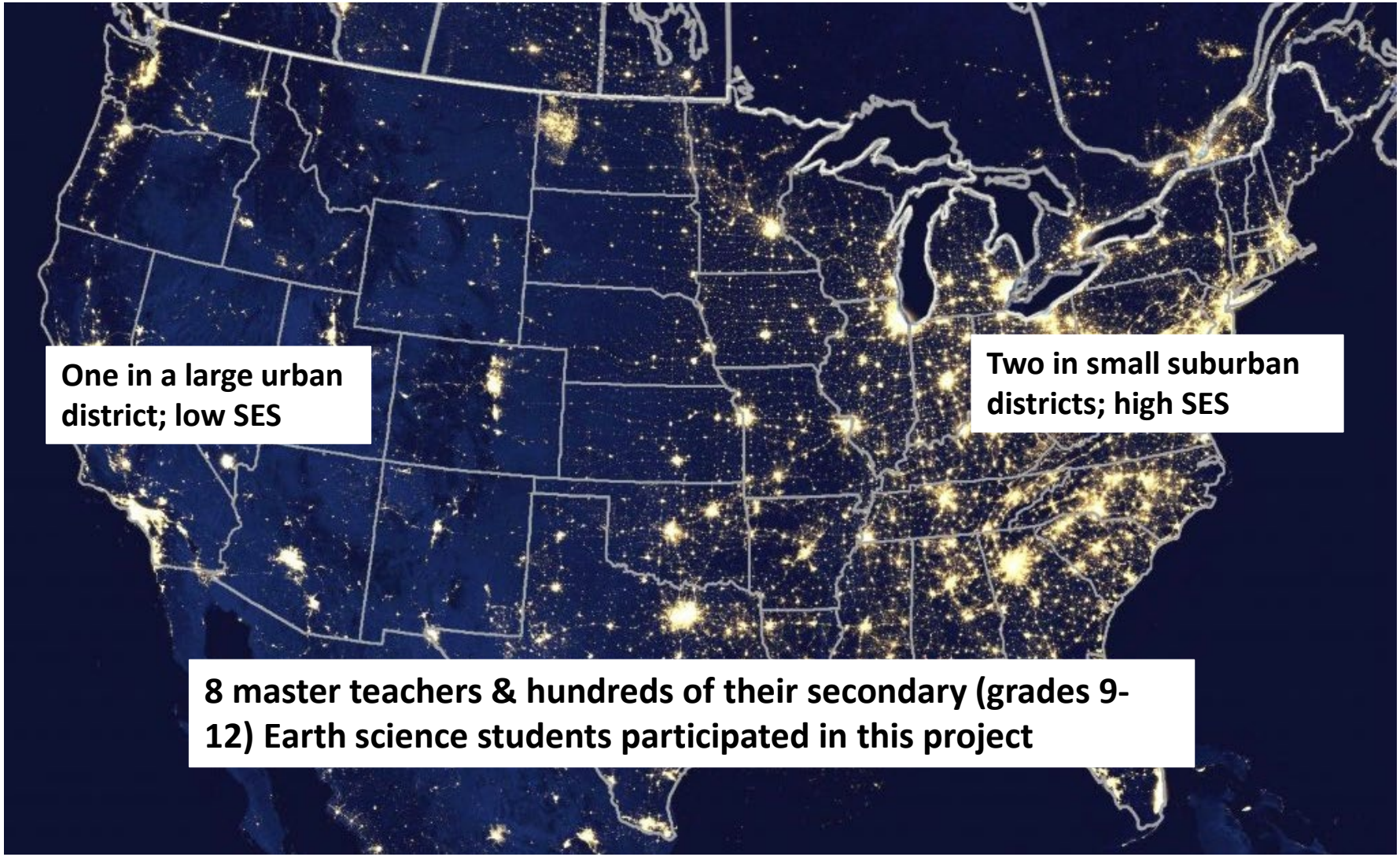
My projects investigate students' evaluations, plausibility, & knowledge about Earth science topics



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

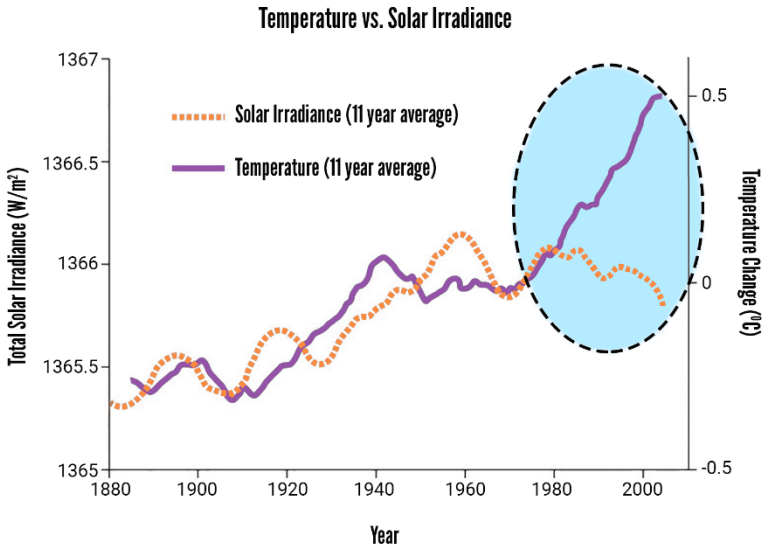
Research question: How does instruction promoting evaluation result in plausibility reappraisal and knowledge changes about Earth and space science topics?

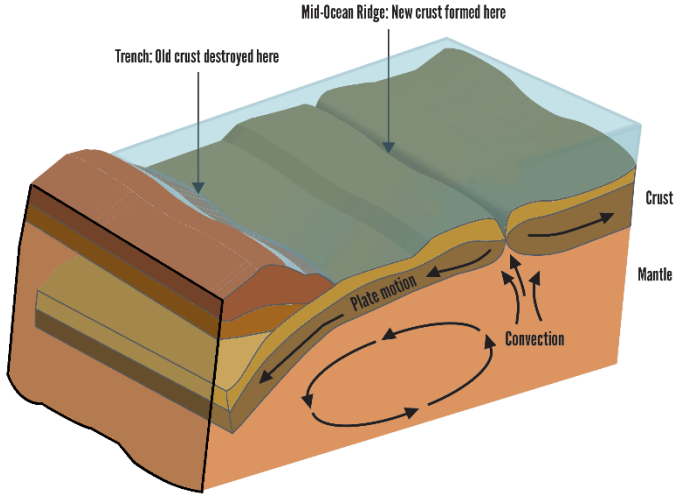
This first project involved three school districts from very different parts of the US



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

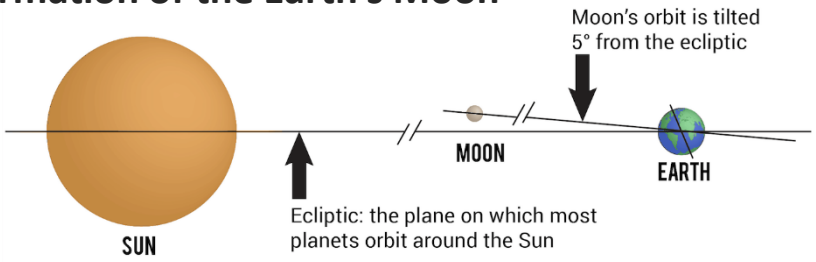
Causes of current climate change

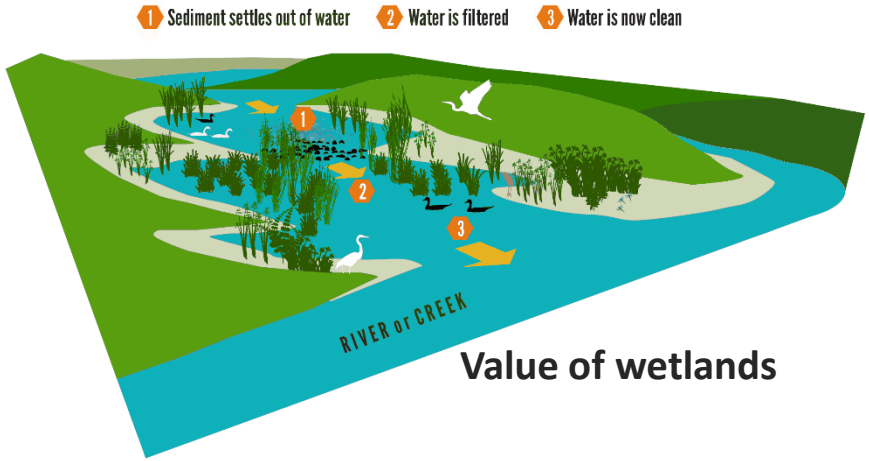




Hydraulic fracturing & earthquakes

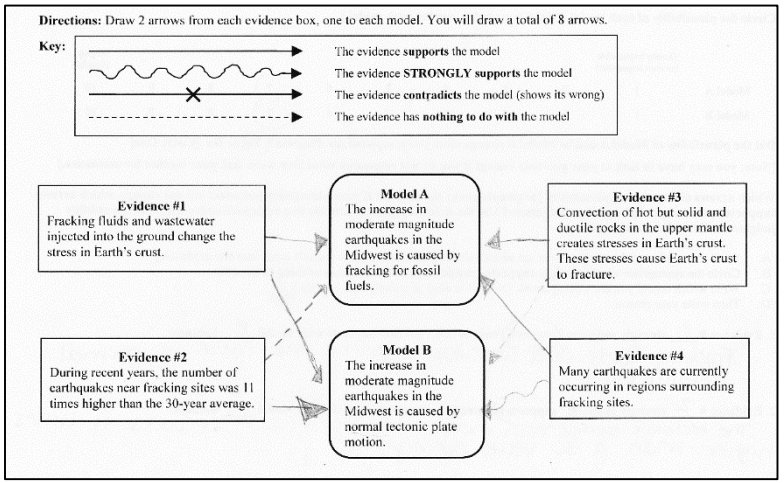
Formation of the Earth's Moon



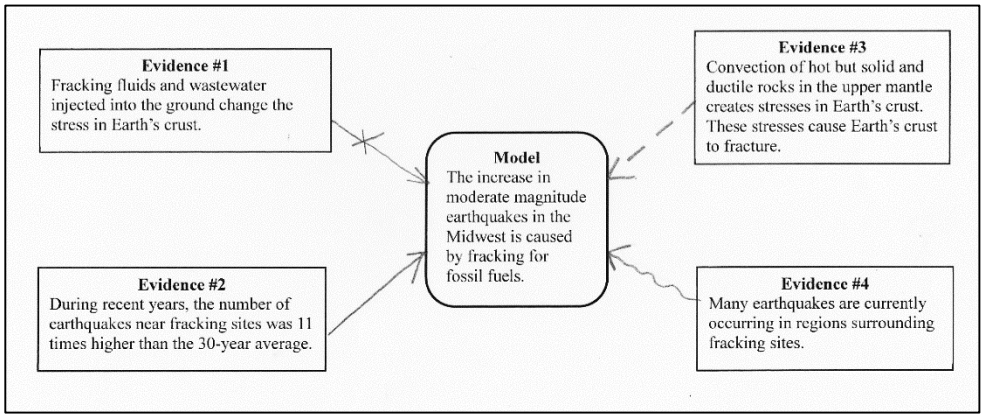


Value of wetlands

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 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 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

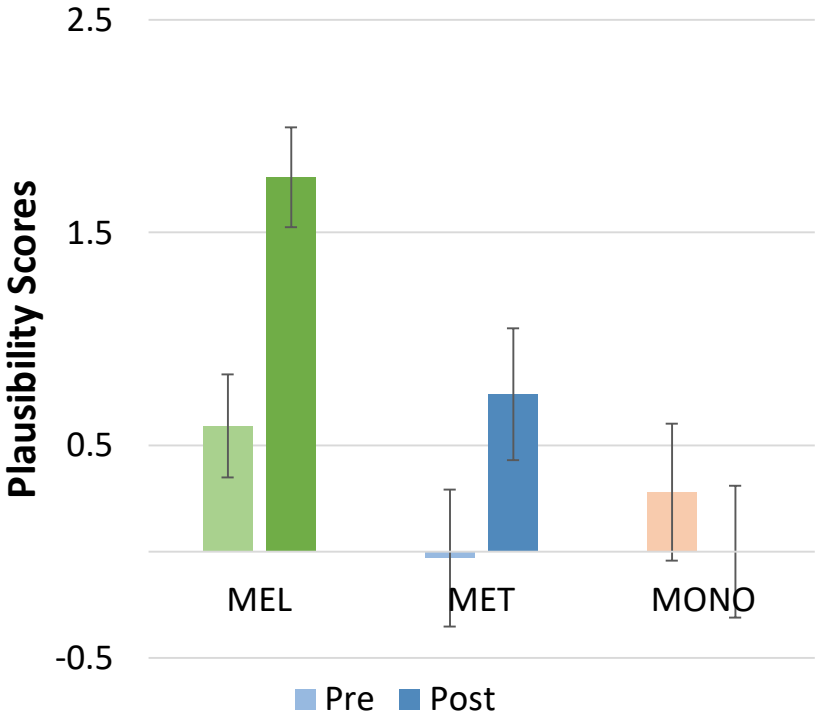
Below are statements about climate change. Rate the degree to which you think that *climate scientists* agree with these statements.

	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

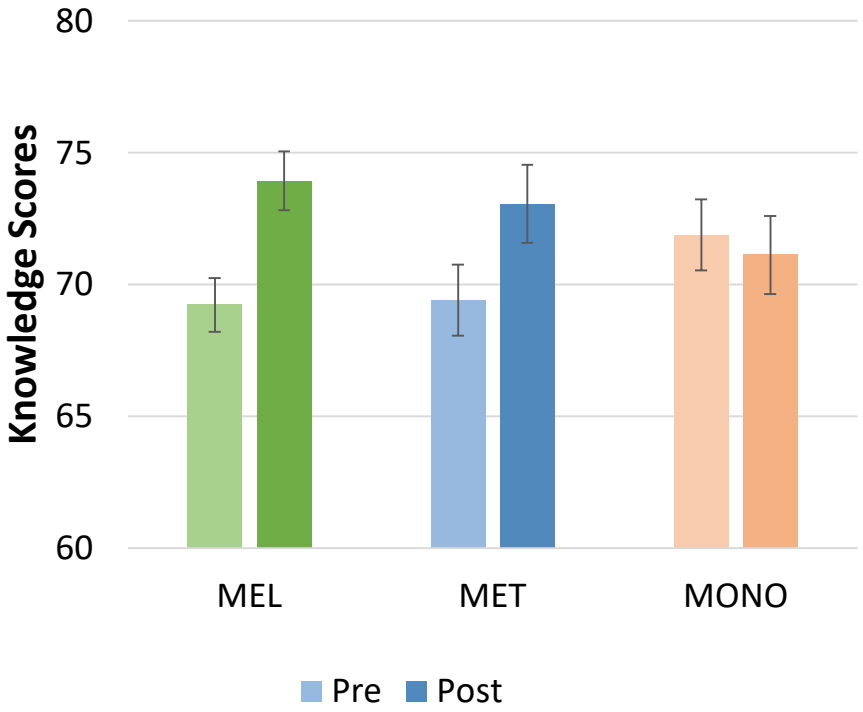
Although short, we have calibrated these with longer forms and classroom testing reveals instrument validity for research purposes

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)

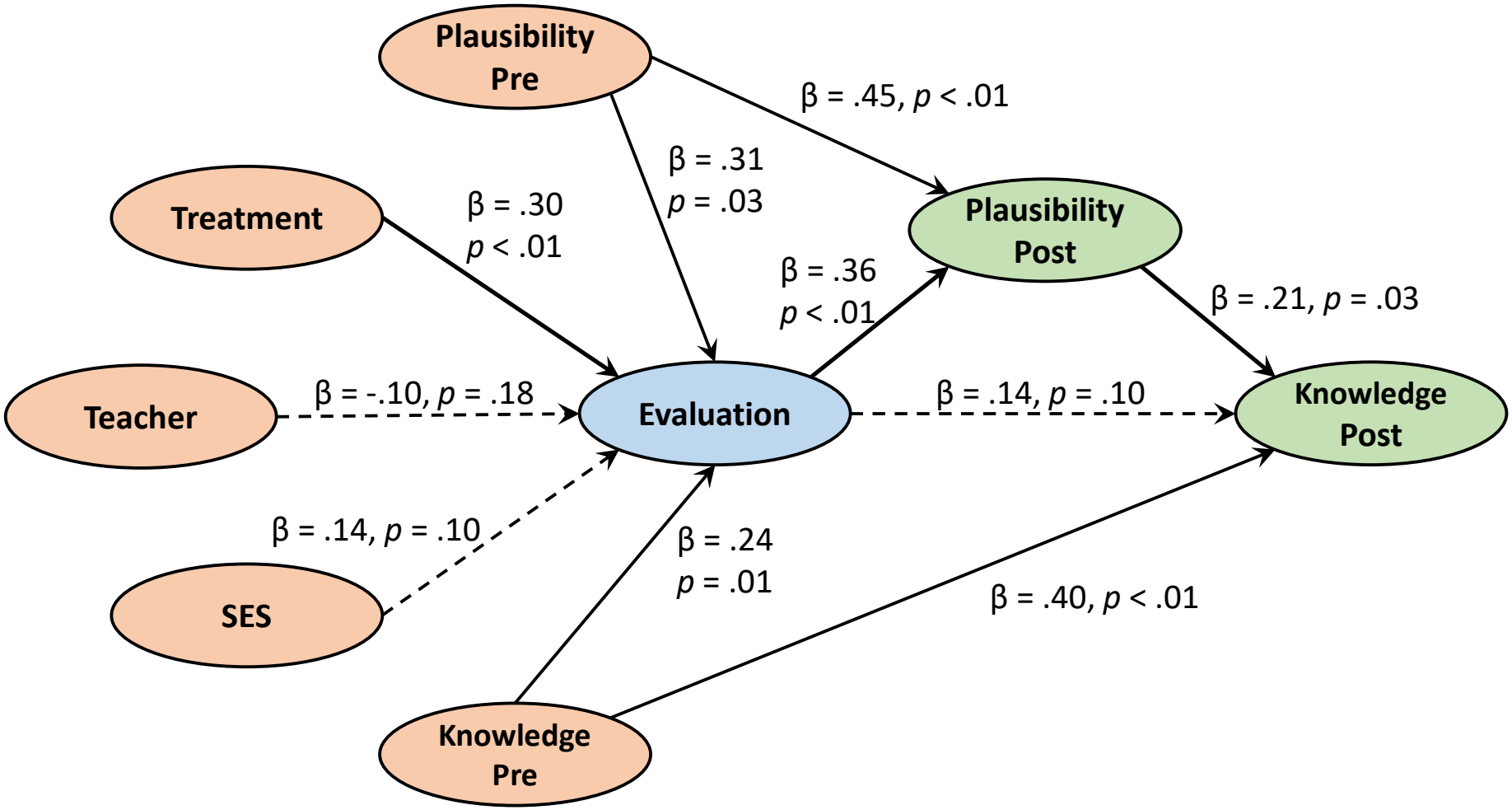


Wilks' λ = .843, $F(2,61) = 5.67$, $p = .006$, medium effect size ($\eta^2 = .157$)



Wilks' λ = .893, $F(2,61) = 3.67$, $p = .03$, medium effect size ($\eta^2 = .107$)

Deeper evaluations facilitated participants' plausibility reappraisals and greater knowledge



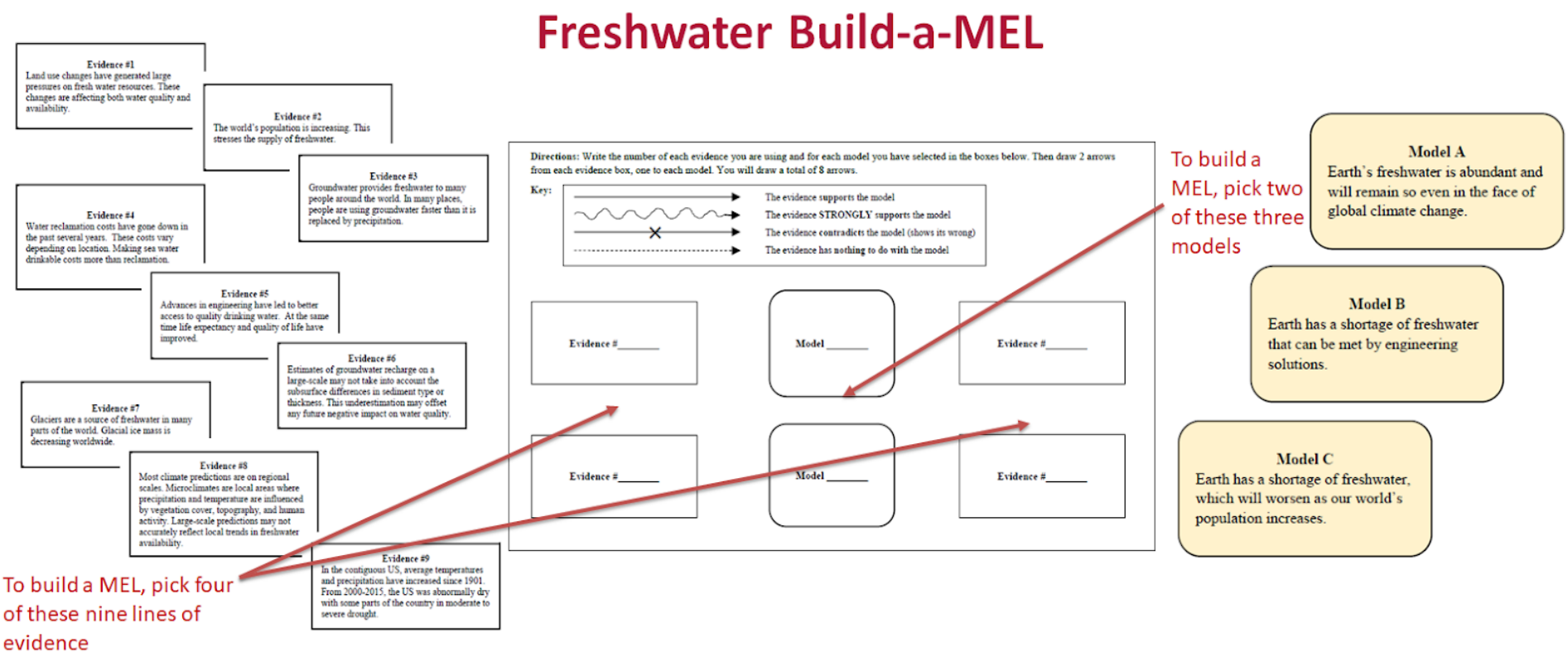
GoF = .437 (large explanatory power); APC = .265, *p* < .001; ARS = .330, *p* < .001; AVIF = 1.12; AFVIF = 1.46; and NLBCDR = 1.0; Lombardi et al. (2018a)

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)

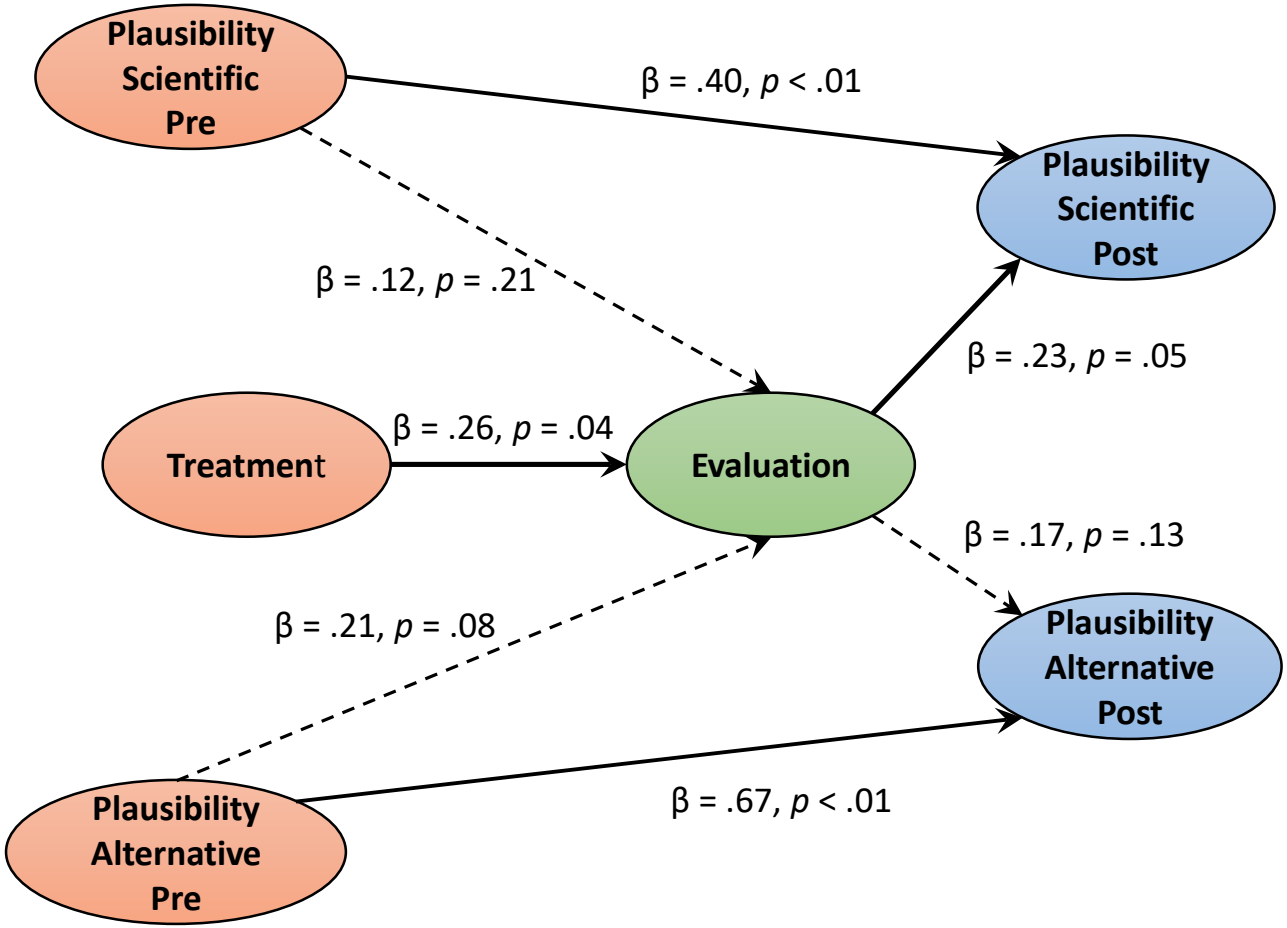
But we are unsatisfied, because unpublished results suggest that students are not transferring their evaluative thinking outside of the classroom context

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

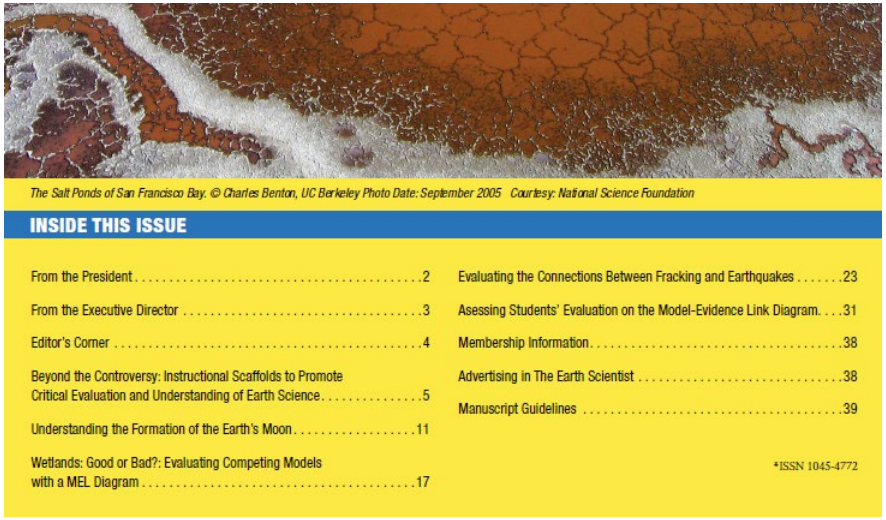
Researchers & teachers need to help students scientifically evaluate & reappraise their epistemic judgments…

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

An open-access issue in *The Earth Scientist* facilitates access to our project's instructional materials

This issue has five articles (one discussing our first four pre-constructed MELs and one providing assessment guidance for teachers)

Many of the project team (master teachers, undergraduate RAs, graduate RAs, and faculty researchers) authored these articles



The Salt Ponds of San Francisco Bay. © Charles Benton, UC Berkeley Photo Date: September 2005 Courtesy: National Science Foundation

INSIDE THIS ISSUE

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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