WHAT'S THE ALTERNATIVE?

Using model-evidence link diagrams to weigh alternative models in argumentation

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Scientifically literate citizens need to understand how scientists evaluate competing explanations. Likewise, students must learn to critically evaluate the quality of scientific knowledge and weigh alternative explanations. Regrettably, high school graduates often aren't critically evaluative about scientific topics. To help remedy that, this article presents an instruction scaffold—called a model-evidence link (MEL) diagram—designed to promote students' ability to critically evaluate scientific arguments and deepen their understanding of fundamental science concepts. First, however, we discuss the role of critical evaluation in promoting argumentation in the science classroom.

Critical evaluation and argumentation as scientific practices

A Framework for K–12 Science Education (NRC 2012) explains how scientific and engineering understanding develops through multiple approaches used to investigate, model, and explain the world. A fundamental practice of scientists and engineers is coordinating evidence, models, and theories. This coordination occurs through critical evaluation, which involves making judgments about the relationship between evidence and alternative explanations of a particular phenomenon (McNeill et al. 2006). The *Framework* places evaluation at the intersection of (a) investigating and (b) developing explanations and solutions (NRC 2012, p. 45). The *Framework* also states that evaluation requires critical thinking, "whether in developing and refining an idea… or in conducting an investigation. The dominant activities in [evaluation] are argumentation and critique, which often lead to further experiments and observations or to changes in proposed models, explanations, or designs" (NRC 2012, p. 46). Therefore, in science education, critical evaluation is simply the analysis of how evidence supports not only a hypothesis, model, or theory but also how evidence supports (or refutes) alternative explanations.

The selected evidence may support more than one explanation in much the same way a prosecutor and defense attorney in a courtroom, for example, could use the same evidence to support opposing claims. The goal is getting students to critically evaluate the relationships among evidence and claims and to effectively argue about connections between evidence and models. We believe the model-evidence link diagram provides an instructional scaffold to meet that goal.

The model-evidence link diagram

As shown in Figure 1, the MEL diagram helps students evaluate and argue about the connections between evidences and alternative models (Lombardi, Sinatra, and Nussbaum 2013; Chinn and Buckland 2012). The structure and mode of MEL diagrams were originally developed by researchers at Rutgers University under the NSF-supported PRACCIS (Promoting Reasoning and Conceptual Change in Science) project (Chinn and Buckland 2012). Using a MEL diagram, students draw arrows in different shapes to indicate the varying relationships between each piece of evidence and each model. Straight arrows indicate that evidence supports the model, squiggly arrows that evidence strongly supports the model, straight arrows with an "X" through the middle that evidence contradicts the model, and dashed arrows that evidence has nothing to do with the model.

But how do students learn more about the evidences and develop the skill to weigh the connection between evidence and models? Students gain knowledge from readily available instructional materials (e.g., classroom activities, textbooks, or online resources) and can also use any data gathered through their experimentation or other activities. Then they use a quick ranking pre-task to better understand how scientists judge the connection between evidence and models (Figure 2, p. 52). In this pre-task, students rank the importance of each arrow weight. Then they learn about the tentative nature of scientific information through a discussion of falsifiability (the ability for a scientific idea to be proven false), as well as the relationship between contradictory evidence and falsifiability, and then re-rank the arrow weights. After the second ranking, teachers should conduct a short class discussion on the rankings and reinforce the idea that contradictory evidence generally has the greatest weight in changing judgments about the connections between evidence and models. Through this pre-task, students see that contradictory evidence is at least as important as evidence that strongly supports a particular model.

FIGURE 1

Student example of a model-evidence link (MEL) diagram.

Directions: Draw two arrows from each evidence box (one to each model). You will draw a total of 8 arrows.

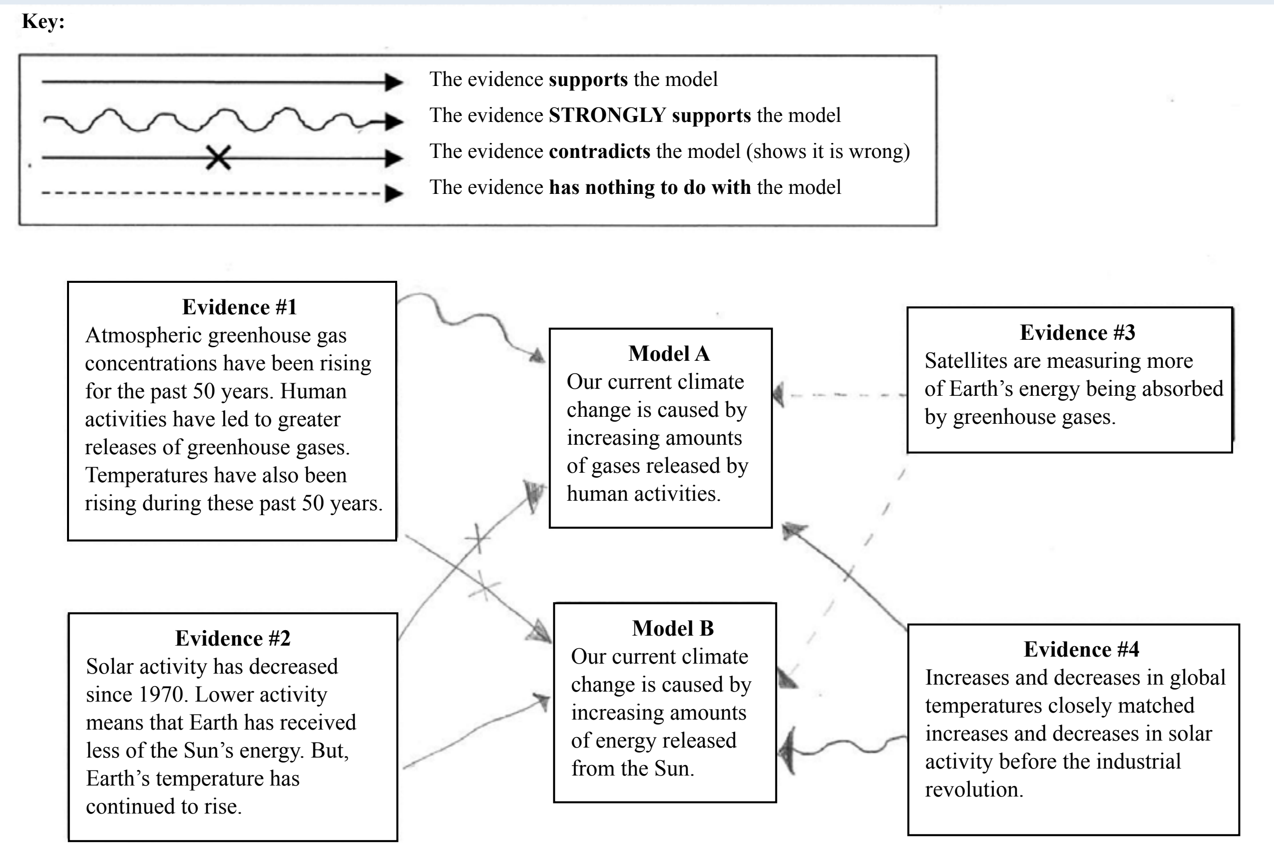

FIGURE 2

Ranking pre-task.

How do scientists change their plausibility judgments?

Scientists may change their plausibility judgments about scientific ideas. They do this by looking at the connections between evidence and the idea. Evidence may:

1. *Support* an idea
2. *Strongly* support an idea
3. *Contradict* (oppose) an idea
4. Have *nothing to do* with the idea

Which type of evidence do you think is most important to a scientist's plausibility judgment? Use numbers 1 to 4 to rank each evidence. (1 = most important and 4 = least important)

Type of evidence	Your ranking
Evidence supports the idea	
Evidence strongly supports the idea	
Evidence contradicts (opposes) the idea	
Evidence has nothing to do with the idea	

Carefully read the following paragraph.
Scientific ideas must be *falsifiable*. In other words, scientific ideas can never be proven. But, ideas can be disproven by opposing evidence. When this happens, scientists must revise the idea or come up with another explanation. Falsifiability is a very important principle when evaluating scientific knowledge.

With falsifiability in mind, *re-rank* each evidence from 1 to 4. (1 = most important and 4 = least important)

Type of evidence	Your ranking
Evidence supports the idea	
Evidence strongly supports the idea	
Evidence contradicts (opposes) the idea	
Evidence has nothing to do with the idea	

Using MEL diagrams to promote argumentation about competing explanations

Students now evaluate the links in their completed MEL diagrams (Figure 3, p. 53), writing about three evidence-to-model links they made. Students identify each end of the link with an evidence (numbered) at one end and the model (either A or B) at the other. Students write their judgment about the strength of the link (i.e., the evidence *strongly supports* the model, *supports* the model, *has nothing to do with* the model, or *contradicts* the model). Students then justify their weighting of link strength. Then they can use their written explanations for collaborative argumentation, by which students work together to compare, critique, and revise explanations (Nussbaum 2008). For example, during discussion, students could use MEL diagrams to present their arguments, and other students could use the diagrams for rebuttal. Using the MEL diagram to help bring collaborative argumentation into instruction may allow for greater elaboration and evaluation when explicitly considering alternative explanations about a particular phenomenon.

A MEL diagram example

A recent research study (Lombardi, Sinatra, and Nussbaum 2013) used a MEL diagram to significantly increase student understanding (measured by pre- and posttest gains) of climate change in less than 90 minutes of instruction. This increased understanding remained when tested again six months later. The MEL diagram used in the study presented students two competing models explaining the causes of current climate change: (A) human-induced climate change (i.e., the scientifically accepted model; Intergovernmental Panel on Climate Change 2007) and (B) increasing solar energy (i.e., a popular skeptic model, Cook 2010). A sample climate change MEL diagram completed by a student is shown in Figure 1 (p. 51); a completed explanatory task appears in Figure 3. Blank templates of this climate change MEL diagram and texts for each of the evidences can be downloaded (see "On the web").

FIGURE 3

Student example of the MEL explanatory task.

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: they're both talking about climate change due to human releasing gasses into the air
they both support ~~human~~ each other

2. Evidence # 2 **strongly supports | supports | contradicts | has nothing to do with Model** B
because: they both talk about the Sun's energy but from different parts. The opposing sides are: Not getting enough Sun or getting to much

3. Evidence # 3 **strongly supports | supports | contradicts | has nothing to do with Model** A
because: Model A is talking about gasses and evidence 3 is talking about satelites and about the energy being absorbed.

4. 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

Developing MEL diagrams for classroom use

MEL diagrams are relatively new and have not been developed for many science topics. However, our experience has shown that teachers can quickly create a MEL diagram by examining two alternatives: (1) the scientifically accepted model and (2) a compelling alternative. The key is to gather reasonable evidence that connects to both models. For example, we recently conducted a workshop for high school science teachers combining a field experience with classroom time to construct MEL diagrams. Participants collected data in Death Valley, California, that related to regional evidence for past and present climate change. As a group, the teachers then developed alternative explanations about regional and global climate change connections. Finally, teams of teachers developed MEL diagrams using the data they collected and the alternative models they developed.

This same process could be used with students in a classroom. Even without the field experience, students could gather data from classroom experiments, online data sets, and other activities. Evidence can also be gathered through research, as in our most recent workshops with high school teachers. These teacher-created MEL diagrams are available for download (see "On the web") and include, for example, the topics of lunar phases and genetically modified food.

Teachers can employ MEL diagrams in one class meeting and immediately foster a scientific habit of critical evaluation. MEL diagrams fit into the science curriculum because they support student understanding of the vital connections among disciplinary core ideas and scientific and engineering practices.

Tips for creating MEL diagrams

Compare only two models, and have six or fewer blocks of evidence. Although many phenomena are supported by more than six lines of evidence, having too many models and evidences can quickly overwhelm students, making the evaluation process difficult and rendering the activity ineffective. Subsequent activities in the instructional unit could address additional lines of evidence.

When developing a Model A and Model B, consider the educational goal. To teach disciplinary core ideas, for example, a model representing a scientifically valid concept could be paired with a common student misconception (e.g., Newton's notion of force versus the impetus notion of force, Mendelian genetics versus Lamarckian inheritance, scientifically accurate explanations for the seasons or phases of the moon versus alternative conceptions). Then, evidence blocks could consist of student experiences from classroom activities.

Avoid non-scientific models that compare opinion-based claims, such as, Model A, "Plastic bags are good for grocery stores," and Model B, "Plastic bags are not good for grocery stores." Such models don't support scientific understanding in that "good" and "not good" cannot be scientifically evaluated as written. Investigating either model won't help students develop a more comprehensive understanding of the nature of science.

Deepening understanding of concepts and practices

MEL diagrams are efficient replacements for instructional materials that merely provide information. Teachers can employ MEL diagrams in one class meeting and immediately foster a scientific habit of critical evaluation. MEL diagrams fit into the science curriculum because they support student understanding of the vital connections among disciplinary core ideas and scientific and engineering practices (NRC 2012). The use of MEL diagrams increases student engagement. We find that students quickly learn to use the MEL diagrams with enthusiasm, perhaps because they are free to evaluate alternative explanations and make judgments about the connections between evidence and these alternative explanations. This may seem counterintuitive to science teachers wanting students to consider only valid scientific explanations. However, science literacy includes the ability to argue about alternative explanations. Furthermore, such critical evaluation can lead to greater understanding of the scientific concepts (Lombardi, Sinatra, and Nussbaum 2013).

In summary, here are suggested steps for incorporating MEL diagrams into classroom instruction:

1. Complete the quick ranking pre-task (Figure 2, p. 52)
2. Complete the MEL diagram (Figure 1, p. 51)
3. Complete instruction (this may include laboratory activities, readings, simulations, and so on)
4. Reevaluate the connections in the MEL diagram (typically in a different color for comparative purposes) (Figure 2)
5. Complete the explanatory evaluation (Figure 3, p. 53)

Connecting the *Framework* and Common Core State Standards with the MEL diagram

Teachers can use MEL diagrams to support students as they evaluate connections among evidence and engage in scientific discourse. This in turn can support the development of scientific thinking (Kuhn and Pearsall 2000), a skill demanded by both the *Framework* (NRC 2012) and the *Common Core State Standards* (CCSS) for English Language Arts and Mathematics (NGAC and CCSSO 2010). The *Framework* elevates engaging in argument from evidence to one of the eight practices of scientists and engineers, stating that in science, reasoning and argument are used to show how data supports a claim as well as to consider possible weaknesses in scientific arguments (NRC 2012, p. 72). The importance of this practice is echoed throughout the *CCSS*. A student who meets the *CCSS* can comprehend as well as critique the veracity of claims and soundness of reasoning presented by an author or speaker, as well as evaluate others' use of evidence (NGAC and CCSSO 2010a, p. 7). In mathematics, students should be able to construct viable arguments and critique the reasoning of others (NGAC and CCSSO 2010b, p. 6). There is therefore a shared importance among the recently established science education *Framework* and the CCSS to support critical evaluation through the perspective of engaging in argumentation using evidence.

The MEL promotes scientific thinking using critical evaluation as a vehicle for students to confront multiple pieces of evidence while considering alternative explanations. Such understanding is essential to developing a society that exhibits scientific habits of mind and is equipped to deal with future socio-scientific challenges (e.g., global climate change and freshwater resource depletion) in a way that is beneficial to our nation and global community. ■

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On the web

Climate change MEL and related texts: *www.nevadangse.net/?p=357*

Teacher-created MELs: *www.nevadangse.net/?p=378*

References

Chinn, C.A., and L.A. Buckland. 2012. Model-based instruction: Fostering change in evolutionary conceptions and in epistemic practices. In *Evolution challenges: Integrating research and practice in teaching and learning about evolution,* ed. K.S. Rosengren et al., 211–232. New York: Oxford University Press.

Cook, J. 2010. Solar activity and climate: Is the sun causing global warming? *Skeptical Science*. Retrieved from *www.skepticalscience.com/solar-activity-sunspots-global-warming.htm*

Intergovernmental Panel on Climate Change. 2007. *Climate change 2007: Synthesis report—summary for policymakers*. Geneva, Switzerland: World Meteorological Organization.

Kuhn, D., and S. Pearsall. 2000. Developmental origins of scientific thinking. *Journal of Cognition and Development* 1 (1): 113–129.

Lombardi, D., G.M. Sinatra, and E.M. Nussbaum. 2013. Plausibility reappraisals and shifts in middle school students' climate change conceptions. *Learning and Instruction* 27: 50–62.

McNeill, K.L., et al. 2006. Supporting students' construction of scientific explanations by fading scaffolds in instructional materials. *The Journal of the Learning Sciences* 15 (2): 153–191.

National Governors Association Center for Best Practices and Council of Chief State School Officers (NGAC and CCSSO). 2010a. *Common core state standards for English language arts and literacy in history/social studies, science, and technical subjects*. Washington, DC: NGAC and CCSSO.

National Governors Association Center for Best Practices and Council of Chief State School Officers (NGAC and CCSSO). 2010b. *Common core state standards for mathematics*. Washington, DC: NGAC and CCSSO.

National Research Council (NRC). 2012. *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: National Academies Press.

Nussbaum, E.M. 2008. Collaborative discourse, argumentation, and learning: Preface and literature review. *Contemporary Educational Psychology* 33 (3): 345–359.