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

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Abstract

The Model-Evidence Link (MEL) diagram activities are scaffolds that facilitate students' weighing and coordinating of the connection 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.

Introduction

Earth science includes many controversial topics that are critical socio-scientific issues. Such topics include climate change, fracking, and wetlands protection. Other Earth science topics may be inherently abstract and complex, such as formation of Earth's Moon. Because of complexity, abstractness, and controversy, teaching about some topics can be a challenge for Earth science teachers. The purpose of this article is to introduce an instructional scaffold, called the model-evidence link (MEL) diagram, which may be a particularly useful tool for Earth science teachers when teaching about controversial and complex topics. The mode and structure of the MEL diagram was first developed within the Promoting Reasoning and Conceptual Change project at Rutgers University, by Clark Chinn and colleagues (see, for example, Buckland & Chinn, 2010), for middle school life science topics. Our research and development team has adapted and expanded the MEL diagram into a suite of activities[1] that build students'

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[1] All MEL activities and associated materials may be downloaded for free at our project website: (https://sites.temple.edu/meldiagrams/materials/).

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understanding about fundamental Earth science concepts (Lombardi, Sinatra, & Nussbaum, 2013), and with repeated use, may help build a scientific practice focused on critical evaluation of connections between evidence and explanations.

The MEL diagram activities are scaffolds that facilitate students' weighing and coordinating the connections between evidence and two alternative models explaining a particular phenomenon. At the onset, it should be stressed that the MEL diagram is NOT a tool for "teaching the controversy"—a campaign started to elevate non-scientific viewpoints in the science classroom in a way that legitimizes mythological thinking (Foran, 2014). Rather, the MEL activities give students the tools to weigh the merits of scientific explanations compared to a plausible, but non-scientific, alternative by critically evaluating how well lines of evidence support each alternative. When students engage in such critical evaluation, they are experiencing what the National Academies of Science has identified as a nexus of scientific and engineering activities (NRC, 2012). Indeed, activating students' critical evaluation when confronted with scientific topics is essential for them to effectively engage in many of the scientific and engineering practices—asking critical questions, using model-based reasoning, planning and analyzing scientifically valid investigations, constructing plausible explanations, engaging in collaborative argumentation—which in sum represent a critical dimension used to build the Next Generation Science Standards (NGSS Lead States, 2013).

Prior to discussing the specifics about the MEL activities, a brief discussion about our research and development team's perspectives on some key ideas, including models, evidence, and evaluation is provided. Our viewpoint is built upon a foundation of research into the nature of science and scientific practices, and as such, strongly reflects current science education reform efforts (i.e., A Framework for K-12 Science Education, NRC, 2012; and the Next Generation Science Standards, NGSS Lead States, 2013).

What Are Scientific Models and Evidence?

The MEL research and development team has a broad and encompassing view, which specifies that models are conceptual in nature. From this perspective, scientific models help people understand "the way the natural and human-engineered world operates" (Moulding, Bybee, & Paulson, 2015, p. 63). Because they are based on conceptions, scientific models are "simplifications of complex law or theories that we have translated in our minds as general ideas" to explain a phenomenon (Moulding, Bybee, & Paulson, 2015, p. 64). In the context of a particular activity, the Climate Change MEL (Figure 1), two conceptual models are presented to students, each relating an alternative explanation for the cause of current climate change: Model A, where current climate change is caused by increasing amounts of gases released by human activities; and Model B, where current climate change is caused by an increasing amount of energy received from the Sun. These models are general ideas that facilitate reasoning and thinking about the reason for the rise in mean global surface temperatures and the decrease in global surface ice. See Table 1 for related NGSS standards.

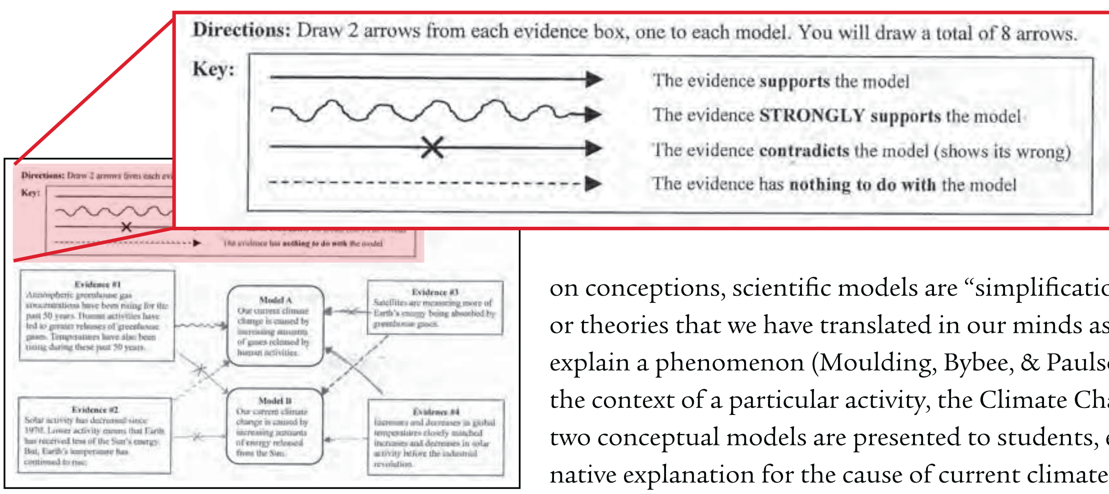

Figure 1. The Climate Change Model-Evidence Link (MEL) diagram: a student example.

Table 1: Connections to the Next Generation Science Standards (NGSS Lead States, 2013, p.125)

NGSS performance expectations related to the Climate Change Model-Evidence Link activity
HS-ESS3-5: Earth and Human Activity
Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.
HS-ESS3-4: Earth and Human Activity
Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.

Models alone are not sufficient to support scientific thinking. Models must be coordinated with lines of evidence to help build an argument about the causes and effects of a particular phenomenon and its systematic relationships (NRC, 2012). Observations, data, and measurement (i.e., information derived empirically) are all involved in building lines of scientific evidence, but are not necessarily evidence in and of themselves. Opinions—the juxtaposition of evidence—can also be based on empirical information. Evaluative standards make evidence scientific, such as interpretations of raw information that have been validated and peer-reviewed by a particular disciplinary community (e.g., climate scientists). In the MEL diagrams, specific lines of evidence are revealed as relatively broad interpretations of empirically-derived and peer-validated information. For example, in the Climate Change MEL, Evidence Statement #1 states that "Atmospheric greenhouse gas concentrations have been rising for the past 50 years. Human activities have led to greater releases of greenhouse gases. Temperatures have also been rising during these past 50 years."

Relations Between Critical Evaluation and Scientific and Engineering Practices

Eight scientific and engineering practices are listed in A Framework for K-12 Science Education (NRC, 2012) and the NGSS (NGSS Lead States, 2013; see Appendix F). These practices represent the thinking skills that students must learn and engage in to understand scientific knowledge. Underlying many, if not most, of these practices is the idea that scientists and engineers actively coordinate between evidence and models by being critically evaluative. Such critical evaluation often involves judgments about the relationship between evidence and alternative explanations of a particular phenomenon (McNeill, Lizotte, Krajcik, & Marx, 2006). 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 evaluations can be made by analyzing how evidence supports not only one singular model, but also how well evidence supports (or refutes) alternative explanations.

Using the MEL Activities

The MEL activities help students to be critically evaluative. Prior to completing the diagram, students complete a quick ranking task (Figure 2) that helps develop understanding about how scientists make judgments about the connection between evidence and models. In this task, students make an initial ranking of the importance of four categories of connections between evidence and models, where a line of evidence (a) strongly supports a model, (b) supports a model, (c) has nothing to do with a model, or (d) contradicts a model. 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 importance of the categories. After re-ranking, teachers can conduct a short discussion with the class on their rankings and directly reinforce the idea that contradictory evidence generally does have the greatest weight in changing judgments about the connections between evidence and models. Through this pre-task, students see that contradictory evidence is as important (or in some cases more important) than evidence that strongly supports a particular model.

Students are ready to complete the MEL diagram after completing the ranking task. In completing the diagram (see Figure 1), students draw arrows in different shapes to indicate their judgments (which correspond to the four categories in the ranking task) about the strength of the connection between each line of evidence and a model. Straight arrows indicate that evidence supports the model; squiggly arrows indicate that evidence strongly supports the model; straight arrows with an "X" through the middle indicate the evidence contradicts the model; and dashed arrows indicate the evidence has nothing to do with the model. Our research and development team has created short expository texts for each line of evidence to assist students with the interpretation of the evidence. The texts are short, one page for each line of evidence, and each page contains at least one figure or graph, drawn in grayscale to ease copying. At this point the teacher may ask students to work in teams to discuss the types of connections made

How do scientists change their plausibility judgments?

Plausibility is a judgment we make about the potential truthfulness of one model compared to another. The judgment may be tentative (not certain). You do not have to be committed to that decision.

Scientists may change their plausibility judgments about scientific ideas.

They do this by looking at the connections between evidence and the idea. Evidence may:

- *Support* an idea
- *Strongly* support an idea
- *Contradict* (oppose) an idea
- 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). Use each number only once.

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.

As a reminder, scientists may change their plausibility judgments about scientific ideas and they do this by looking at the connections between evidence and the idea. Evidence may:

- *Support* an idea
- *Strongly* support an idea
- *Contradict* (oppose) an idea
- Have *nothing to do* with the idea

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

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	

Figure 2. The Plausibility Ranking Task.

Figure 3. The Model-Evidence Link (MEL) explanation task: a student example.

Please work on this individually.

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.

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

between the evidence and models; however, students should be told that if their thoughts lie with an arrow type that's different from their teammates, that they should not change it. Hints and perspectives about group work from our master teachers are discussed further in this issue's companion articles.

Students next use completed MEL diagrams in an Explanation Task (Figure 3) to critically evaluate their links and construct understanding. This task asks students to select and write about evidence-to-model links that they had made on their MEL diagram. In their written explanations, students identify each end of the link, with an evidence statement (which are numbered) at one end and the model (either Model A or B) at the other. Students write their judgment about the strength of the link (i.e., the evidence strongly supports the model, the evidence supports the model, the evidence has nothing to do with the model, or the evidence contradicts the model). Students then provide a justification for their weighting of link strength.

Deepening Understanding of Concepts and Practices

MEL diagrams can be used as efficient replacements for instructional materials that merely provide information (e.g., textbook readings or fill-in-the-blank worksheets). Teachers can employ MEL diagrams in about one 90-minute session and immediately begin building a scientific habit of being critically evaluative in students. Furthermore, MEL diagrams can be easily inserted into existing science curriculum because they support student understanding of the vital connections among disciplinary core ideas and scientific and engineering practices (NRC, 2012). Our research suggests that use of MELs increases students' cognitive engagement when used throughout the school year. The MEL research and development team has also observed that students enjoy completing the activities, and speculate that students are motivated during these activities because they are free to evaluate alternative explanations. They are also free to make judgments about the connections between evidence and these alternative explanations without being given the scientific explanation a priori. Doing so in an instructional setting may seem counterintuitive to many Earth science teachers because we want our students to only consider valid scientific explanations. However, developing a citizenry that is science-literate involves—in part—increasing students' abilities to critically evaluate alterative explanations in a similar manner to what scientists actually do (NRC, 2012). Teachers should make the scientific model and associated explanations clear to all students after completing the MEL activities—remember that this is NOT "Teaching the Controversy"—and students should understand the scientific perspective on all controversial and complex topics. Doing so will prevent teaching non-scientific information to your students (i.e., teaching that current climate change is caused naturally, rather than teaching the overwhelming scientific consensus that current climate change is caused by human activities; Plutzer, McCaffrey, Hannah, Rosenau, Berbeco, & Rei, 2016)

A word of caution: MEL activities are not a "silver bullet," but rather are just one of many activities that students should experience in an instructional unit (e.g., a two-week unit on climate change). But even the relatively short duration of an individual MEL activity (90 minutes) has resulted in meaningful gains in understanding of the fundamental scientific principles, which are sustained many months after instruction (Lombardi, Brandt, Bickel, & Burg, 2016; Lombardi et al., 2013). Repeated use of MEL activities throughout the school year may result in developing a scientific habit of mind that is activated when students encounter complex and controversial topics.

The purpose of this introduction to the MEL special issue was to provide an overview of the MEL activities, using the Climate Change MEL as an example. The remaining articles discuss the other MEL activities our research and develop team has created, which cover the topics of Fracking and Earthquakes, Wetlands and Land Use, and Formation of Earth's Moon. Each of these MEL activities incorporates current scientific evidence and presents compelling alternatives that help students to develop their evaluation skills, which are necessary for classroom engagement in the scientific and engineering practices (NRC, 2012). Being critically evaluative of the connection between evidence and alternative explanations helps students figure out the best of all plausible alternatives and deepen their understanding of controversial and complex Earth scientific content, such as global climate change.

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