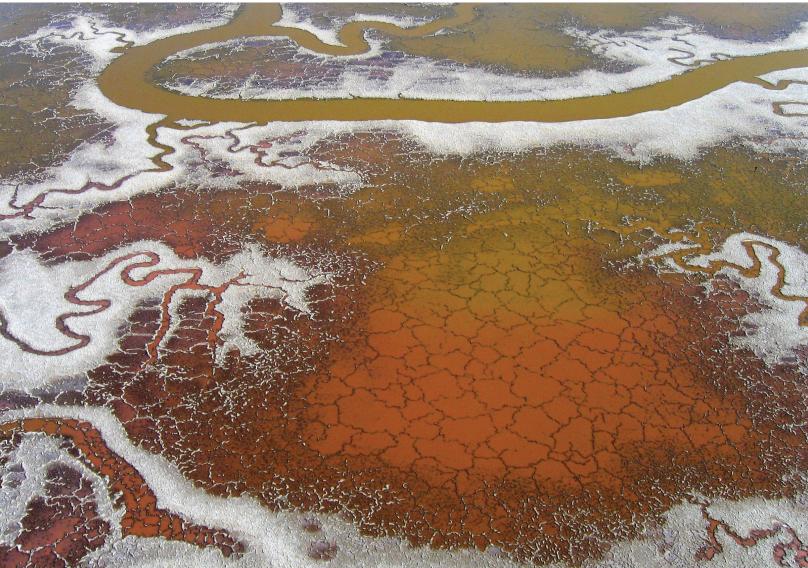
THE EARTH SCIENTIST



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

INSIDE THIS ISSUE

From the President
From the Executive Director
Editor's Corner
Beyond the Controversy: Instructional Scaffolds to Promote Critical Evaluation and Understanding of Earth Science5
Understanding the Formation of the Earth's Moon
Wetlands: Good or Bad?: Evaluating Competing Models with a MEL Diagram

Evaluating the Connections Between Fracking and Earthquakes 23
Asessing Students' Evaluation on the Model-Evidence Link Diagram 31
Membership Information
Advertising in The Earth Scientist
Manuscript Guidelines



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FROM THE PRESIDENT

Refilling an Empty Well by Engaging, Exploring, and Connecting

My students are all convinced that I am devastatingly lonely through the summer but they couldn't be more wrong. While summer may be celebrated by my students, it is I who truly cherishes the down time. Summer is the season when we teachers are given the opportunity to recharge our curiosity, reconnect with our own learning needs, and recreate ourselves. Summer is when we refill the well that will be drawn from in the next school year.

This "re-creation" that teachers engage in is not just about traveling, camping, or getting to the beach. We also engage is unique learning opportunities, some informal explorations of the world around us, some formal explorations of pedagogy, content, and best practices. In the cold dark of winter, we started signing ourselves up for teacher summer camps, field courses, and summer conferences. We fill our summers with learning opportunities that hone our skills, enliven our minds, and even tone our bodies.

This summer I have the opportunity to attend three significant formal science education opportunities. The second annual Earth Educators Rendezvous is being held in Madison, Wisconsin in mid-July. This relatively young conference is rich with opportunities to learn about geoscience education research, implementation of the Next Generation Science Standards, sustainability education, service learning and many other topics applicable to Earth Science teachers. I attended the Rendezvous in Boulder, Colorado in 2015 and am heartened by the networking and community building that happens between secondary educators, community college faculty, and university professors and researchers. Keep your eye open for information regarding the 2017 Rendezvous and plan to attend if you can.

As the new NESTA President, I will represent NESTA at the National Congress on Science Education, an annual gathering of delegates from NSTA chapters and associated groups. I will have the opportunity to discuss issues and make recommendations regarding science education. I am looking forward to meeting and networking with other science leaders from North America, attending workshops, and advocating for the Earth and Space Sciences.

The 5th Annual NSTA STEM Forum and Expo, also in Denver, is a focused event that brings together formal and informal educators and STEM industry professionals to share our collective vision for STEM education. NESTA is sponsoring two sessions, STEM Games and Simulations for Earth and Space Science, presented by Randy Russell of UCAR Center for Science Education; and I will be presenting on Using the CLEAN Collection of Resources to Inspire Climate and Energy Solutions.

I encourage all teachers to attend one of the many state and regional science education conferences that might be happening around the country. There are two major Earth Science conferences book-ending Autumn, 2016. The Geological Society of America meeting, September 24-28, has programming for Earth Science teachers that include workshops and fieldtrips. The American Geophysical Union meeting is December 12-16 and NESTA is again working with AGU to offer the GIFT workshop on December 14-15. You can also find NESTA folks presenting at this year's NSTA Area conferences:

- October 27-29 in Minneapolis, Minnesota
- November 10-12 in Portland, Oregon
- December 1-3 in Columbus, Ohio

There is a perception that teachers have the summers "off". We all know this to be untrue. As we move through the short, precious weeks of summer our energy comes back, new ideas creep into our psyche, and we look forward to a new year of guiding students towards a greater appreciation of science, the Earth, and learning. This is possible because we have taken the time to engage in our own learning, explore the world around us, and connect with others who are enthusiastic about teaching.

Cheryl Manning NESTA President

FROM THE EXECUTIVE DIRECTOR

Summer Reflections

Summer is a time for us to relax, reflect, and prepare for the next school year. We think about what we did with students the past school year and consider how we might improve our teaching for the upcoming year. We look for ways to enhance our own learning so we might better serve our students. During summer, many of us take advantage of professional development opportunities that invigorate us, strengthen our teaching, and enable us to return to our classrooms with new ideas and resources to impact student learning.

This summer NESTA leadership took part in the Earth Educators' Rendezvous in Madison, Wisconsin. We led and attended sessions focused on a wide range of topics including geoscience education research, implementation of the Next Generation Science Standards, spatial reasoning, geoscience workforce issues, and environmental issues such as sustainability of the Earth system. Browse the program schedule to find presentation slides, documents, and other resources from the meeting (<u>http://serc.carleton.edu/earth_rendezvous/2016/program/index.html</u>)

We also attended NSTA's National Congress on Science Education, advocating for Earth Science education at all levels of K-12 education. Plus we presented at NSTA's annual STEM Forum and Expo.

It is almost fall and for many of us school has either started or will begin after Labor Day. Our summer experiences are critically important in providing us that needed "down time" from teaching. In addition, they motivate us to meet the challenges of a new school year, renewed with energy and enthusiasm.

Dr. Carla McAuliffe Executive Director, NESTA

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EDITOR'S CORNER

Some issues have a way of taking their own sweet time to come into print – and this is worth the wait. In collaboration with Temple University, we've put together an amazing issue with articles all about methods that you can use in the classroom right now. Summer is over, school has started, and as teachers we are already well into finding the best way to reach our students – whether that be with tried and true methods or testing out a new idea to add to our proverbial "toolboxes". These research proven and classroom tested methods will provide you with a jumpstart to your year as well as give you year-long options. I truly hope you enjoy this issue of *The Earth Scientist* and we all look forward to hearing how you put it to use to engage and inspire our students.

TES Editor David Thesenga

Twenty-five Years Ago in TES

Twenty Five years ago, in 1991, TES was in its eighth year of publication. This cover features an image of Struthiomimus, a toothless Cretaceous herbivore who was an unusual member of a more familiar family of carnivorous Theropods. This article was

accompanied by a 7 page article which updated discoveries, current thinking about, and opportunities to see dinosaurs.

There was an opening "Comment" about "The Importance of Teaching Earth Science in Our Public Schools." Written by Mr. Lee A. Mishkin, this 1991 column is well worth reading, today.

Also included, was an article describing a teacher's summer time trip to the "living geologic laboratory of Iceland." This article was followed by an open invitation to sign on to go to Iceland the following summer under the direction of Len Sharp, who was NESTA's President at that time.

Finally, there was an informational

blurb encouraging membership participation in NESTA's Share-A-Thons at the three 1991 NSTA Regional (now called Area) Conferences (Vancouver, Reno, and New Orleans), as well as the NSTA National Conference held in Boston, in the Spring of 1992.

By Tom Ervin

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HE EARTH SCIENTIST

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

Doug Lombardi, Temple University

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 socioscientific, 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 socioscientific 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 activities¹ 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 under-

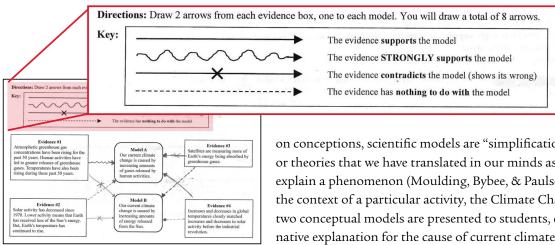


Figure 1. The Climate Change Model-Evidence Link (MEL) diagram: a student example.

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.

stand "the way the natural and

human-engineered

(Moulding, Bybee,

& Paulson, 2015,

p. 63). Because

they are based

world operates"

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

How do scientists change their plausibility	y judgments?
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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 Contractic (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 numl 1 to 4 to <i>rank</i> 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:
C

 Support an idea 	
 Strongly support an idea 	
 Contradict (oppose) an idea 	
 Have nothing to do with the idea 	
With <i>falsifiability</i> in mind, <i>re-rank</i> each evidence from 1 to 4. (1 = mo Use each number only once.	ost important and 4 = least important
Type of evidence	Your ranking
Evidence supports the idea	
Evidence strongly supports the idea	
Evidence contradicts (opposes) the idea	

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

Figure 2. The Plausibility Ranking Task.

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

Please work o	n this individ	dually.									
A. Write thB. Circle thC. Write with	on for three of e number of the appropriate hich model you ite your reaso	he evidence y word (stron) ou are writing	you are wr gly suppo	iting about.					ıg or importan	t arrows.	
1. Evidence # Evidence gases, u because activi	1 strongh 2 1 says which has it is ex	y supports is that no ve beer eplaining	supports uman c unsinc j that	contradic activi- por por our	ties has noth ties has the pass climate	ing to do v we lead t so yl e chan	with Mode a to g ears. A ge 13	I <u>A</u> bec reater his str being	ause: releases angly sup caused	of gre ports by hu	tode 1 A main
2. Evidence #	1 strongly	y supports s	supports	contradict	s has noth	ing to do v	with Mode	I B bec	ause:		
Evidenc	e 1 con	tradic	t Mod	eren	ecause	evide	nce or	e says	s that he	man,	
activiti	eshavi	e led +	o gre	ater	releast	es of	green	rouse	gases,	white	
mandal	Q Onin	Host in	ACCOR	Cinn a	mount	SOF	approx	y from	the sun	is who	t-
1 NOURI	Doug	True i the	ner co	sing a			0.00,	/	e Aqlaca dan 1	and several se	
is cau	sing cl	imone Cr	range	*				0			
3. Evidence #	2_strongly	y supports s	upports	contradict	has nothi	ing to do w	vith Mode	B bec	ause:		
Evidence	2 contr	id ots M	loole i	3 becl	wer f	viden	ce to	SAVG-	that Ea	rth	
hasre	CIEVIED!	11055 0	of the	SIMSE	neral.	ant	mod	PRO	ause: that Ea avy 5 th 1 in area	2	
	te tha	tain	ate c	hana	0 600	1000	100		'samon	sind	
opposi	in al	C. Churl	acon	110	2030	peen	caus	ied by	/ iricaece	0	
Orman	ms of 1	energy	TYON	THES	SCV 1.						
Circle the plaus	ibility of eac	h model. [M	ake two c	ircles, one	for each mo	del.]					
	eatly implausi even impossi									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, 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.

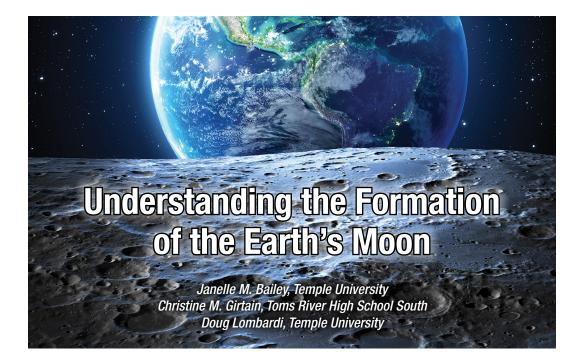
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Abstract

Understanding how the Moon formed supports understanding of Earth's formation and early history. The Moon Model-Evidence Link (MEL) diagram is an activity that has students weighing the connections between four lines of evidence and two different models explaining the Moon's formation—capture theory and giant impact theory. By evaluating alternative models, students can improve upon their scientific literacy and understanding of scientific practices. Suggestions from classroom use of the Moon MEL will help teachers use this activity in a productive manner.

The Science of the Moon's Formation

Four main theories of the Moon's formation have been considered over the years (Clery, 2013). The capture theory suggests that the Moon may have been a traveling body, such as an asteroid, that was pulled into a stable orbit by Earth's gravity. Co-formation is the idea that the Moon formed simultaneously as Earth in the primordial solar system, about 4.5 billion years ago, much in the same way that Earth itself formed through a process of collisions and accretions. Similarly, the fission theory suggests that the Moon was formed at the same time as Earth—not through accretion but by a spinning Earth ejecting a large blob of material into space which then developed into the shape and orbit of the Moon. These three theories seemed largely unsettled until a fourth was proposed by Hartmann and Davis (1975): the giant impact or collision theory, in which a large impactor crashed into Earth and material from both mixed to create the Moon.

Today, planetary scientists generally agree that the giant impact theory is the likely scenario for our Moon's formation, though the other theories are still viable mechanisms for the formation of other planets' moons. Evidence from the Apollo missions, including the collection and analysis of lunar samples, have propelled the giant impact theory into the forefront. Determination of the details—such as the size of the impactor, the percentage of material from each original body (proto-Earth and impactor) ending up on each final body (Earth and Moon), or the spin



Figure 1. Images of Earth's Moon (left) and Mars's moons Phobos (center) and Deimos (right). Not to scale. The photos of Phobos and Deimos are color-enhanced. Credit: NASA. rate of the proto-Earth at the time of the collision—is an active area of research within planetary science.

Moon's Formation in the High School Classroom

The formation of the Moon is not a large part of the typical high school Earth science curriculum, but it is a piece of the discussion of Earth's formation (see Table 1 for the relevant

NGSS). The Moon's formation can also be a springboard to understanding the relationship between other planets and their satellites—for example, Mars's moons Phobos and Deimos are very different in appearance than the Moon (Figure 1), so should another formation theory be considered for them? This type of discussion can also support understanding and implementation of scientific and engineering practices such as engaging in argument from evidence (NGSS Lead States 2013; NRC, 2012).

Table 1: Connections to the Next Generation Science Standards (NGSS Lead States, 2013, p.119)

NGSS performance expectations related to the Moon Model-Evidence Link (MEL) diagram

HS-ESS1-6: Earth's Place in the Universe

Apply scientific reasoning and evidence from ancient Earth materials, meteorites, and other planetary surfaces to construct an account of Earth's formation and early history.

Creating a Model-Evidence Link (MEL) Diagram on Moon Formation

The Model-Evidence Link (MEL) diagram provides a scaffolded approach for students to compare competing models and to what extent evidence supports each model, leading to a critical evaluation of each model and ultimately an informed judgment about which model is more plausible. The MEL was originally designed by Clark Chinn and colleagues (Chinn & Buckland, 2012) for use in middle school life science, and has since been adapted for use in Earth science topics in middle and high school grades¹ (Lombardi, Sibley, & Carroll, 2013; Lombardi, Sinatra, & Nussbaum, 2013; and other articles in this issue). A more detailed description of how to use the MEL in high school classrooms is provided by Lombardi (<u>this issue</u>).

The MEL requires that students make judgments about how certain evidence supports, contradicts, or has nothing to do with each of two different models that explain the topic at hand. Although there have been four major models proposed for the Moon's formation, the MEL contains only two—the giant impact model (considered the scientifically correct model) and the capture model. Capture was chosen over the co-formation and fission models because it provides a clearer distinction from the giant impact model, although it would be possible to create a MEL with either of these other two models instead.

Using the Moon Formation MEL

The Moon MEL includes three components: the MEL diagram itself (Figure 2), supporting Evidence Texts, and an associated Explanation Task (Figure 3). We generally have students work in groups of two to four to share the Evidence Texts and discuss their ideas, although

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

Materials were developed through support from the National Science Foundation (NSF) under Grant No. DRL-1316057. Any opinions, findings, conclusions, or recommendations expressed are those of the author(s) and do not necessarily reflect the NSF's views. we have each student complete their own MEL diagram and Explanation Task. Students should look at the MEL diagram and read the two models and the four evidence boxes. They will then draw one of four arrow types between each evidence box and each model, for a total of eight arrows.

Each page of Evidence Text expands upon one of the evidence boxes; each includes a figure, graph, or table to further support students' understanding of the evidence and their scientific reading skills. Some students will

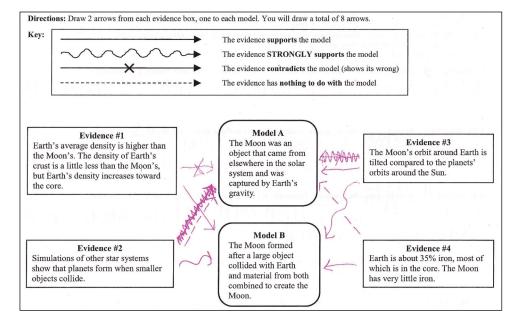


Figure 2. Example of a studentcompleted Moon MEL diagram.

want to read the supporting Evidence Text before making a judgment about how the evidence connects to each model and drawing the appropriate arrow; others will want to jump into drawing the arrows and change them later if needed. You might have students simply share the pages of evidence text among themselves, or you might use a jigsaw or round-robin strategy for reading them in a more systematic approach.

Figure 3. Student example of the Moon MEL explanation task.

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 # <u>3</u> ROCKS	strongly s	supports (ing -	supports c from	contradicts CCVF	has nothing the second se	ng to do wi MCA	th Model	B_becau its		orbi	t
2. Evidence #2 Because As' it or	itsta	tes du	ustar	nd oth	1 has nothing	Heria	1 beg	$\frac{B}{h}$ becau	ise: COU(ide	
3. Evidence # <u>4</u> Because Same	strongly's H H H H H H	upports 16 +Al Of h	KS A Nater	ontradicts bout	has nothin LAVH	ng to do wi	th Model_ 1 HVe	<u>B</u> becau MOC	se: >h ha	aving	the
Circle the plausibi	lity of each ly implausit	100	Aake two ci	ircles, one f	for each mo	odel.]				Lichly	
	en impossil									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	

After they have completed the MEL diagram (i.e., drawn all eight arrows), students should now complete the Explanation Task. Students should select three model-evidence combinations, i.e. arrows drawn, and write about what kind of arrow they drew and why. We recommend that they choose arrows that they feel are particularly important or interesting, such as ones where there was disagreement among the group. You should encourage as much detailed writing as possible on this portion of the activity.

Management Tips and Other Suggestions

Because there are four evidence boxes and thus four supporting texts, a group size of four can work well—but groups larger than four should be avoided because some students may be left with nothing to do while their group members read the Evidence Texts. Smaller groups (two or three) can also work well. The extent to which you let students explore the Evidence Texts and MEL diagrams on their own versus provide them some kind of structure for the reading and discussion of them depends on your own style as well as your students' experience working in small groups. Both approaches have been successfully used across various classrooms.

Students might want to use different colors for their arrows to help distinguish between the two models (e.g., use red for Model A and black for Model B, or pen versus pencil or highlighter). This can make it easier for them to identify which is which when they begin working on the Explanation Task, as well as to verify that they have completed all of the required arrows. It can also help you review their drawings quickly if arrow colors are assigned ahead of time. Be careful to make the color options appropriate if you or any of your students are colorblind.

When working on the Explanation Task, students may want to choose arrows of "nothing to do with" because it is easy to write about, but this has limited utility for both their understanding and your assessment of it. You might suggest that these arrows should not be used or perhaps limited to a single explanation (not two or three). This part of the activity is what could be used for assessment, if so desired, thereby encouraging rich and robust explanations that would help you better determine students' understanding and reasoning processes. A discussion of a rubric that can provide insights into students' reasoning and evaluation processes is found later in this issue (Bickel & Lombardi, this issue).

You should have a general debriefing of the activity, but it is not necessary to go through each of the eight arrows to ensure that students get "the right answer." In other words, reducing the activity to a discussion of each arrow would be counterproductive because it moves students away from the scientific practice of evaluating several lines of evidence with alternative models. Focus instead on completion of all eight arrows and providing detailed responses on the explanation task, encouraging students to back up their claims with material from the evidence text (and prior knowledge). However, at the end of the explanation task, make sure you discuss that the scientifically accurate model, supported by overwhelming consensus of astronomers and planetary scientists, is the giant impact theory (Model B).

Potential Problem Areas and Extensions

Students have many alternative conceptions about the Moon (see Kavanagh, Agan, & Sneider, 2005, for a review of this literature); most of this research is focused on lunar phases and the nature of the Sun-Earth-Moon system rather than the Moon's formation. That doesn't mean, however, that students will be free of alternative conceptions that can interfere with this activity!

Evidence Statement #1 focuses on the density of the materials that make up Earth and the Moon. Students' understanding of density and why it makes a difference in the structure of these bodies could create challenges in their understanding and use of this evidence. Pilot studies have shown some students think Evidence Statement #1 has nothing to do with Model A or Model B, perhaps because of a lack of sufficient understanding that molten materials will separate into layers based on density. If Earth and the Moon had the same densities this evidence could support co-formation, whereas different densities support both Model A capture and Model B giant impact.

Other students may have prior knowledge that Earth's density is higher than the other inner planets. As a post-activity discussion, teachers may want to show a graph of the densities of the inner planets. It is important to note that not only is Earth's density higher than the Moon's, Earth's density is higher than all the other inner planets—thus Earth's density is an outlier from the trend in the densities of the other planets. Could Earth's higher density imply added materials from an impact? The teacher could then revisit each model and discuss how the trend in densities of the inner planets relates to each model. For Evidence Statement #4 students may miss the connection between the percentage of iron on Earth and the Moon. Most students do not have previous knowledge that silicates (SiO4)4- from Earth's crust would vaporize more easily on impact and be put into orbit whereas heavy metals like iron would not, making the silicon and oxygen amounts higher and iron lower for materials that coalesced to form the Moon. As a result, in our experience some student groups thought Evidence Statement #4 had nothing to do with either model. Instead, the different percentages of the various materials implies different origins of Earth and the Moon—thus supporting both Models A and B.

The Moon MEL is a tool that can be used to discover student alternative conceptions and lack of knowledge, spurring important classroom debates. A follow up activity, such as one described by Murphy and Bell (2013), could focus on understanding how the Moon's surface has changed over time.

Conclusions

The Moon MEL enables students to explore the Moon's formation and relates to a larger discussion of the solar system formation, a topic important to astronomy and Earth sciences as evidenced by its inclusion in the NGSS but that may not have been addressed through an engaging activity in the past. Additionally, as part of a broader approach to provide students the opportunity to critically evaluate different models within science, the Moon MEL can contribute to students' scientific literacy and critical thinking skills.

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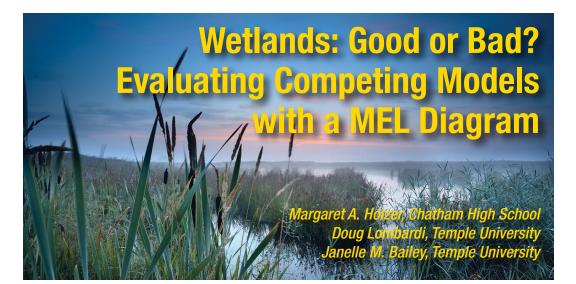
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Abstract

Teaching with socio-scientific issues can be a challenge given the tug-of-war between the scientific, social, economic, and political perspectives upon which many topics can be viewed. However, in an Earth science classroom, socio-scientific issues provide a rich stage upon which various lines of scientific evidence can be weighed against alternative viewpoints. This article describes how a Model-Evidence Link (MEL) lesson can effectively be used to assist learners in weighing the plausibility of different viewpoints of the uses of wetlands, a socio-scientific issue.

Our wetlands are caught in the middle of competing viewpoints. For example, a visit to our coastal and inland wetlands generates an olfactory concussion for some and a sense of pleasure for others. The scents created as a by-product of the activity of microbial inhabitants living in them may be perceived as a nuisance to some, and beneficial to others. Some people value what wetlands offer the local environment, such as habitats for all types of organisms and a place for floodwaters to collect away from where people live. Others perceive them as property to develop or as a breeding area for mosquitoes.

These two competing views of wetlands set the stage for a rich lesson on how to evaluate the plausibility of evidence supporting competing socio-scientific models, a scientific practice worthy of developing in our students as noted in the Next Generation Science Standards (NGSS Lead States, 2013). Wetlands, by definition from the Clean Water Act, are "those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs and similar areas" (United States Environmental Protection Agency, 2013). To some, the ecological services, or benefits, provided by wetlands outweigh the economic losses created by not developing these potentially viable pieces of property. As odoriferous as these regions are, they offer our planet numerous ecological services, from their existence. For example, wetlands purify water, control flood waters, and provide habitats for numerous aquatic, avian, and mammalian species. However, some people perceive wetlands as a nuisance and a breeding ground for mosquitoes, and that financially valuable property is lost because many wetlands offer views to city skylines and open-space.

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

Materials were developed through support from the National Science Foundation (NSF) under Grant No. DRL-1316057. Any opinions, findings, conclusions, or recommendations expressed are those of the author(s) and do not necessarily reflect the NSF's views. The Model-Evidence Link (MEL) lesson discussed in this article differs from the other lessons that our research and development team have designed¹ (see Lombardi, <u>this issue</u>). Specifically, the Wetlands MEL uses two different conceptual models of a socio-scientific issue that focus on value to society, as opposed to two different models of a scientific phenomenon. Even though these may be thought of more as "viewpoints," we will continue to call them models because they evoke mental/conceptual models of the issue that can assist someone in analyzing a situation. Like scientific models, they are productive because they have both predictive and explanatory power for those holding these viewpoints. For example, someone holding

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

NGSS performance expectations related to the Wetlands MEL

HS-ESS3-3: Earth and Human Activity

Create a computational simulation to illustrate the relationship among the management of natural resources, the sustainability of human populations, and biodiversity.

HS-ESS3-4: Earth and Human Activity

Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.

the "wetlands as a nuisance" model as their conceptualization of wetlands will not consider the nutrient cycling that occurs there as necessary for the cycling of matter in our ecosystems.

For a science lesson to be congruent with the approaches defined in the

NGSS, the lesson should blend disciplinary core ideas, science and engineering practices, and crosscutting concepts. The wetlands MEL blends core ideas from ESS3-C: Human Impacts on Earth Systems with the science and engineering practice of engaging in argument from evidence, and the crosscutting concept of stability and change. Collectively this lesson helps to develop proficiency in multiple high school performance expectations (Table 1) and can serve as one lesson within a larger unit on human impacts.

Introducing the Wetlands MEL Lesson

To begin this lesson, familiarize the students with wetlands if they have not had experience with the concept. Most students have a mental model of wetlands as a coastal phenomenon; however, wetlands can be found in most areas of the United States. As a way to familiarize students with the location of wetlands, consider using a digital mapping program, such as ArcGIS Online where a data layer of the locations of wetlands can be imported and displayed. Students will be surprised to find how predominant wetlands are across the United States. Next, place a population layer on top of the wetlands layer to connect students to the relationship between populations relative to the proximity of wetlands. Brainstorm with the students a number of challenges related to living near wetlands. Now, students should be ready to complete the MEL portion of the lesson.

If students have not completed the plausibility ranking pre-task, they should do so before starting this lesson (see Lombardi, <u>this issue</u>, for more details on this activity). The ranking pre-task introduces the students to the scientific principles of plausibility and falsifiability, principles which govern the evaluation of scientific evidence. In the case of this MEL, it is a person's perception which will govern the plausibility and falsifiability of the evidence presented in the lesson.

Evaluating the Models

This lesson is similar to the other MEL lessons in that students begin by evaluating the two models central to the lesson. They evaluate the models based on a scale of 1-10 where a 10 is equated to highly plausible, and a 1 is equated to greatly implausible (or even impossible)

(Figure 1). Students complete this initial ranking individually, and set it aside until they are finished with the next part of the lesson. Next, pass out the MEL diagram, and ask students to use a pencil to make their initial connections between each model and line of evidence (which we call Evidence Statements, as described in Lombardi this issue). The students are linking four lines of evidence to each of the two models using one of four types of lines, each depicting a level of agreement between the evidence and the model. Now provide students with the evidence texts, and ask them to read the explanations associated with each line of evidence. This can be done as a class, in small groups, or in a way that utilizes cooperative group techniques such as jigsaw. Lead a class discussion on the lines of evidence to clarify any difficult concepts within the evidence text. It is important to this lesson that the clarification focus only on the

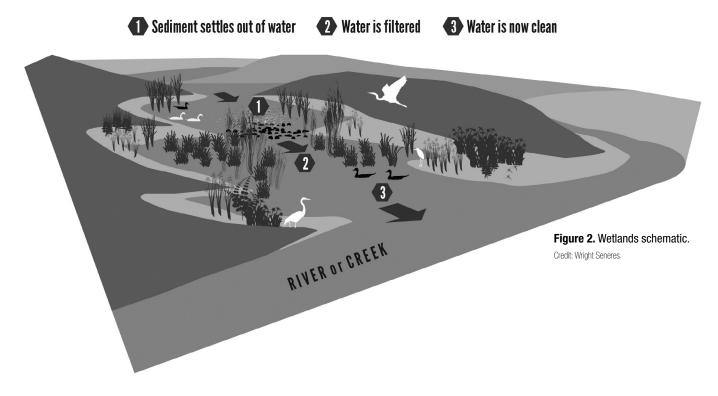
Model A:	Model B:
Wetlands provide ecosystem services that contribute to human welfare and help sustain the biosphere.	Wetlands are a nuisance to humans and provide little overall environmental benefit.
A person who supports this model makes the following argument:	A person who supports this model makes the following argument:
Wetlands help nature and the environment by purifying water, providing flood protection, helping to keep shorelines stable, recharging groundwater, and maintaining valuable habitat for fish, birds, other animals, and plants.	Wetlands create many problems for humans, including flooding at times of heavy rainfall, providing a breeding ground for mosquitos and other pests, and preventing development of commercial and residential areas.

Figure 1. Model A and Model B for the Wetlands MEL lesson.

content of the evidence without swaying the students to side with one model or the other.

Lines of Scientific Evidence

The four lines of evidence were selected to challenge students in thinking about the competing views of wetlands. In Evidence Statement #1, students view wetlands as a place where nutrients are cycled, and the supporting Evidence Text #1 provides a little background on the processes taking place in wetlands to enhance the cycling of nutrients. Figure 2, which is from Evidence Text #1, is a schematic of this nutrient cycling process. Wetlands by definition are areas that remain wet, and thus during times of flooding or peak flow of a nearby water body, these areas can be inundated, protecting the surrounding populated areas from flooding. Evidence



Statement #2 describes this aspect of wetlands. Evidence Statement #3 connects wetlands with methane production and greenhouse gas concentrations in our atmosphere. Evidence Statement #4 connects populations living in wetlands and the potential harm to life and property should these wetlands become inundated during flood events, but these wetlands can be valuable pieces of property as well as homes to numerous people who have settled along rivers. This fourth line of evidence addresses the issue regarding developing these areas of real estate, noting that developers who follow regulations set in place by the federal agencies protecting the wetlands should be permitted to convert existing wetlands into commercial and residential property. Collectively, these four lines of evidence provide students with plenty to consider as they argue about the two models of wetlands.

After the content is clarified, break the class up into groups of three or four students to reevaluate the lines of evidence and the connections they made between the evidence and models. Students may change the types of arrows they use in their connections based on the discussion; however they should not be compelled to change the type of arrows they use simply because their group members have different arrows or have changed their arrows. This is especially important for this MEL lesson since it involves socio-scientific models, and conceptual models held by the students may be more complex based on their personal experiences with wetlands.

Completing the Explanation Task

Once students have completed the MEL diagram, they are ready to complete the Explanation Task. Ask them to rank the plausibility of the models again. Next, refer them back to their initial rankings, and have them complete the balance of the Explanation Task. After they finish, wrap up the lesson by having a discussion about the competing models, addressing the lines of evidences and their connections. This MEL lesson addresses competing models of a socio-scientific phenomenon, and therefore there are many stakeholders and embedded issues that need to be considered when addressing it. Because of this, allow the class discussion to drift to include comments by students agreeing with either of the two models, but focus students on evidence-based claims as opposed to mere conjecture and opinions. Be sure to debrief all four lines of evidence as there may be a disparity in the way that students viewed each line of evidence, and therefore the arrow they decided to employ in their connections. Evidence Statement #4 may elicit the greatest differences. Listen closely to the students' reasoning to ensure they are interpreting both the models and the lines of evidence in the way they were intended to be interpreted.

Using MEL Diagrams to Address Socio-Scientific Issues in the Classroom

The Wetlands MEL lesson was designed to assist students in developing skills to evaluate opposing conceptual models by weighing evidence against claims, and in so doing they are developing scientific reasoning skills as outlined by the NGSS. For example, by the end of twelfth grade, students who are proficient in the scientific practice of engaging in argument from evidence will be able to

- Compare and evaluate competing arguments or design solutions in light of currently accepted explanations, new evidence, limitations (e.g., trade-offs), constraints, and ethical issues.
- Evaluate the claims, evidence, and/or reasoning behind currently accepted explanations or solutions to determine the merits of arguments.

Respectfully provide and/or receive critiques on scientific arguments by probing reasoning and evidence and challenging ideas and conclusions, responding thoughtfully to diverse perspectives, and determining what additional information is required to resolve contradictions. (adapted from NRC, 2012, pp. 50-53; see also NGSS Appendix F, NGSS Lead States, 2013).

The Wetlands MEL lesson assists students in developing proficiency in this practice, and by using other MEL lessons throughout the year it will reinforce this skill. The order of the MELs used should align to local curricular sequencing and pacing.

Socio-scientific issues with competing viewpoints are prevalent in the newspapers as well as in environmental science courses. Students can easily develop a viewpoint that resonates with one side without considering multiple competing lines of evidence that may exist for the issue. The MEL diagram approach is a way to encourage students to seek beyond what is initially evident to them and consider those opposing viewpoints. Teachers are encouraged to develop their own MEL lessons related to socio-scientific issues germane to their courses and their locations. For example, agricultural practices, carbon footprints, and competing views of "commons" are a few issues that would lend themselves to the evaluation of evidence in support of competing models. By the end of the school year, students could demonstrate their proficiency in evaluating evidence by creating their own MEL diagram, or by crafting a research paper demonstrating their skill in evaluating multiple lines of evidence.

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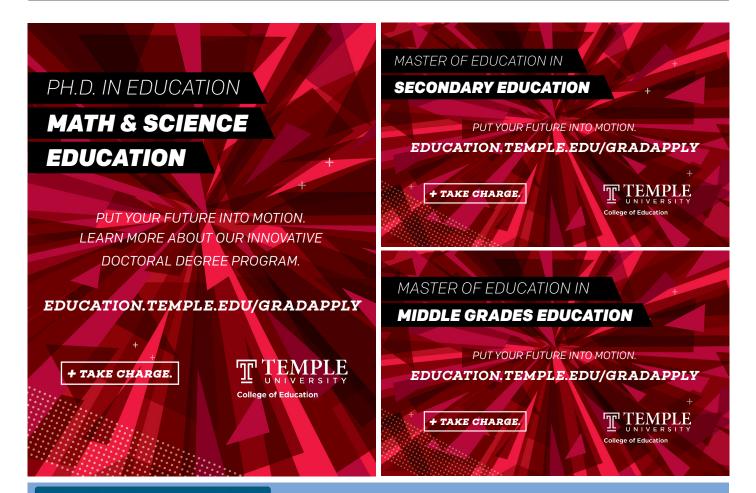
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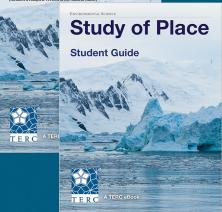
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Evaluating the Connections Between Fracking and Earthquakes

Jenelle Hopkins, Shadow Ridge High School Petya Crones, Green Valley High School Shondricka Burrell, Janelle M. Bailey, and Doug Lombardi, Temple University

Abstract

The Fracking Model-Evidence Link (MEL) activity engages students in a scientific discussion around the topic of whether or not there is a relation between hydraulic fracturing (fracking) operations and increases in moderate magnitude earthquakes in Midwestern US. With increases in fracking operations, it is important for students to understand how to weigh the connection between evidence and alternative explanations about associated phenomena. The two models presented in the Fracking MEL allow students to engage in scientific discussions just as researchers also examine relations between fracking and earthquakes.

The recent boom in US oil and natural gas production is due to the increase of hydraulic fracturing (fracking). With this process, oil and natural gas that is tightly bound in shale formations is mechanically released when pressurized fluids containing silica sand and other chemicals are forced into the formation. The high pressure forces naturally occurring fractures to open up and the sand keeps them open, releasing the oil or natural gas (US Department of Energy, 2013).

Fracking is not a new process. The basic technology can be traced back to the Civil War when Colonel Edward Roberts patented his "Exploding Torpedo." By lowering an iron case filled with blasting powder down into an existing drilled oil well, the resulting explosion increased oil production up to 1200% (Hicks, 2013). In the 1970s and 1980s, George Mitchell refined this fracking procedure so that oil-bearing shale deposits would release the trapped hydrocarbons. Today's fracking processes are based on Mitchell's idea of keeping naturally occurring fractures open so that the oil and natural gas can flow out. In the past 150 years, more than four million oil and natural gas wells have been drilled worldwide; up to 95% of the new wells drilled today use hydraulic fracking (Hackett, 2011). For an in-depth explanation of fracking, see Barrow and Schaffer (2015).

There are many socio-scientific issues associated with fracking. For example, scientists are actively investigating the connection between fracking and the increase in moderate sized earthquakes near drilling locations. The purpose of this article is to present an instructional activity that engages students in this active area of scientific investigation: the Fracking Model-Evidence Link (MEL) diagram (Figure 1). In the Fracking MEL, students evaluate the connections between lines of evidence and two alternative explanations about the earthquake

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

Materials were

developed through support from the National Science Foundation (NSF) under Grant No. DRL-1316057. Any opinions, findings, conclusions, or recommendations expressed are those of the author(s) and do not necessarily reflect the NSF's views. phenomenon: (1) The increase in moderate magnitude earthquakes in the Midwest is caused by fracking for fossil fuels; and (2) The increase in moderate magnitude earthquakes in the Midwest is caused by normal tectonic plate motion. These models present plausible alternatives that relate to recent scientific activities. See Lombardi (this issue) for more details about the MEL diagram and project.¹

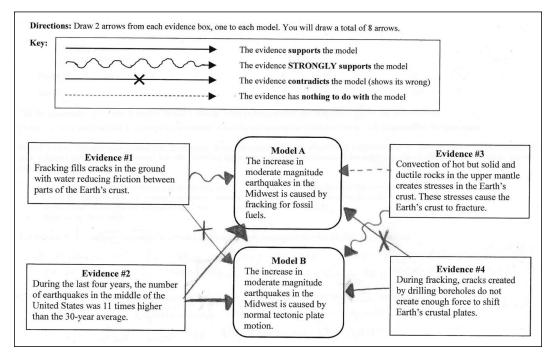
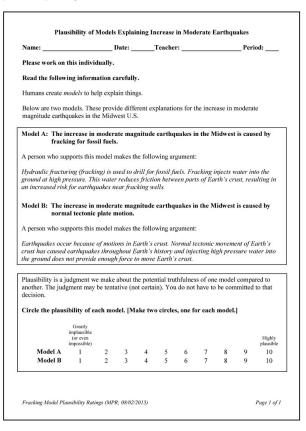


Figure 1. Example of a student-completed Fracking MEL diagram.

Figure 2. Fracking model plausibility ratings.



The Fracking MEL Lesson

The presentation of the fracking MEL in our classes (general and honors Geoscience) followed a basic format. To initially engage the students and introduce the alternatives, we asked them to work alone and rate the plausibility of each model based on their prior knowledge (see Figure 2). Students rated each model on a scale of 1 (greatly implausible) to 10 (highly plausible). Although many students have an intrinsic understanding of plausibility, we found it helpful to review the definition, where plausibility is a tentative judgment that scientists make about explanations they construct to understand a particular phenomenon (e.g., increases in the number of earthquakes in the Midwestern US). We also let students know that plausibility ratings of each model can be completely different (unrelated), the same, or diametrically opposed.

We then divided students into teams of four and asked the teams to examine four lines of evidence related to Midwestern earthquakes. In addition to the evidence statements on the MEL diagrams, we also supplied each team with one page of descriptive text and figures for each line of evidence (available at our website; see Sidebar). Using these evidence texts, teams evaluate the strength of the connection between each line of evidence and each of the two models; i.e., the

Please work on thi Models A and B.	s part indiv	idually after	you complet	e your diag	ram. Now t	hat you hav	e completed	the diagram	ı, reconside	r the plausibility o	f
Circle the plausibi	lity of each	model. [Mak	e two circles	, one for ea	ch model.]						
	implausible 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	
Did the plausibilit	of Model A	A and/or Mo	del B change	after you o	ompleted th	ne diagram?	Yes or No	[Circle One	1		
[Note: you may ha										2.]	
B. Circle the ap	propriate wo model you	evidence you ord (strongly are writing ab	supports su	pports co	ntradicts h	as nothing		vidence]			
1. Evidence # <u>1</u> it explai crust,	ns how	sing th	king ri e cl	educes	frict of e	ion be arthqu	rakes	occur.	s of	Eurth's Ksinkhole	Forming
2. Evidence # Z	strongly su	pports sup	oorts contra	dicts has	nothing to d	o with Mod	el <u>A</u> bec	cause:		lint of	4
it show: US	s the where	expone most	ntial	incre US fr	ase of ackine	is is	operate	el.	e mil	lwest of	W

evidence (a) strongly supports, (b) supports, (c) has nothing to do with, or (d) contradicts a model. As shown in Figure 1, students draw different types of arrows between a line of evidence and a model that represents their evaluation of the connection. When evaluating the connection, students should be familiar with the concept of falsifiability and the power of contradictory evidence in science. This knowledge will help facilitate the critical perspectives that the student groups use when reading the evidence texts and evaluating the connections between lines of evidence and the alternative models. While engaged in small group discussions, students were encouraged to discuss among themselves the plausibility of each model based on their own interpretation of the evidence. Student teams were asked to see if they could come to a consensus about the connections, but they did not have to all agree.

After the teams had examined all four pieces of evidence and drawn their connections on the MEL, each student was asked to rate the plausibility of each model again and write an explanation as to why they changed (or didn't change) from their initial ratings (Figure 3).

Classroom Delivery of the Fracking MEL

The development of the fracking MEL activity and four evidence texts took many revisions by the project team, which included master teachers and educational researchers. Two rounds of pilot testing provided feedback that assisted us in fine-tuning the descriptions and graphics for clarity and understandability. We expected student teams to examine the evidence text with minimal teacher guidance, so it was critical that the illustrations and texts were clear and concise. Figure 3. Example of a studentcompleted explanation task.

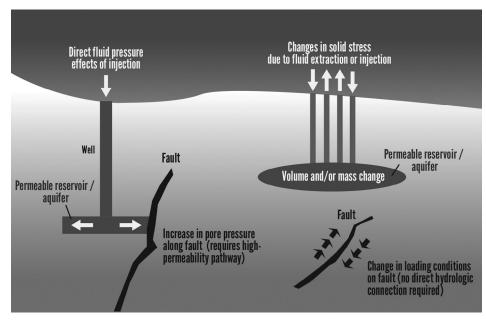


Figure 4. Stresses in Earth's crust potentially caused by wastewater injection. Credit: Wright Seneres

When the Fracking MEL was first introduced to the students, we realized that the geologic processes involved in fracking were unfamiliar to most students in our Geoscience classes. Because it is critical for students to understand the four lines of evidence presented in order for them to thoughtfully draw links between the evidence and the alternative models, teachers should examine each evidence text to determine if prior lessons would be needed for their students. Depending on the background understanding of students and the time of year when the fracking MEL is introduced, teachers may want to consider conducting whole class instruction

to introduce the fundamental concepts underlying this activity. After basic understanding is established, student teams can work together to draw the MEL connections. Below are some specific areas in which students might have difficulties and our suggestions for assisting students with their understanding.

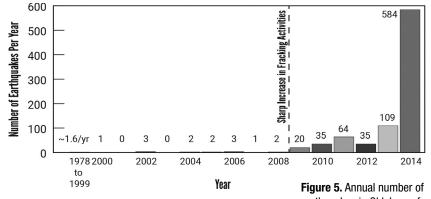
Evidence Text #1

This evidence text illustrates the process of fracking and is centered on the idea that fracking fluids and wastewater injected into the ground change the stresses in Earth's crust. The diagram on this evidence text (Figure 4) uses arrows and text to show the movement of hydraulic fracking fluids into the rock reservoir, causing the hydrocarbons to be pushed out of the rock formation. Discussions among the student groups emphasized the need for conceptual understanding of aquifers, permeability, and porosity. These are important and basic geologic concepts associated with underground water movement and are part of most secondary Geoscience curricula. Our students needed to have hands-on opportunities in order to understand these concepts, so we decided to use the Fracking MEL after we had done lab activities on permeability and porosity. This provided the foundation for students to understand the direction of water movement shown in Figure 4.

Another important concept discussed in Evidence Text #1 is the idea of how stress is associated with faulting—specifically that rock can move when this stress is applied. A key argument among opponents to fracking is the belief that fracking fluids can "lubricate" existing faults, such that less stress is needed to cause the rock to move along these faults. This argument is countered with the idea that tectonic stresses associated with faulting are not necessarily linked to fracking fluids, but may be a natural adjustment occurring at an existing plate boundary (Oskin, 2015).

Evidence Text #2

This line of evidence is centered on data showing that the recent number of earthquakes near fracking sites was 11 times higher than the 30-year average. With this evidence text, students analyzed a graph that showed the annual number of earthquakes in Oklahoma from 1978 to 2014 (Figure 5), without much difficulty. The data showed an obvious increase in earthquakes after 2008, where there also was a sharp increase in fracking activities. Some students questioned the "lag time" of over five years between the increase in fracking and the sharp increase in earthquakes. These students felt that this illustrated no direct cause and effect between fracking and earthquakes. In our interactions with the groups, we answered their concern by emphasizing that their discussions were similar to real-life, scientific discussions, and



how this particular MEL activity was focused on an active and evolving issue in which scientists are currently engaged and for which there is not yet scientific consensus.

earthquakes in Oklahoma from 1978 to 2014.

Credit: Wright Seneres

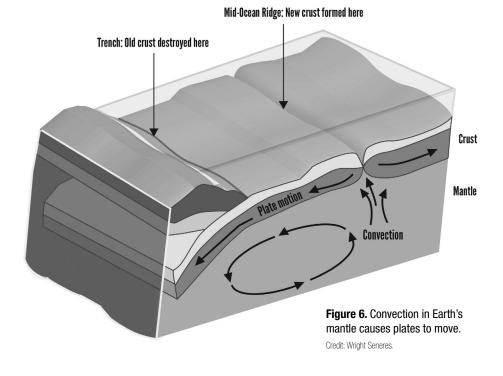
Evidence Text #3

With this evidence text, students were shown the basic stresses that are associated with plate tectonics and specifically consider how convection of hot but solid and ductile rocks in the upper mantle creates stresses in Earth's crust. We included an illustration of convection associated with plate movement (Figure 6), which is a relatively standard image of the type used in many high school geology textbooks and curricula. The connection between stress and earthquakes is a main component of the Theory of Plate Tectonics, and the Fracking

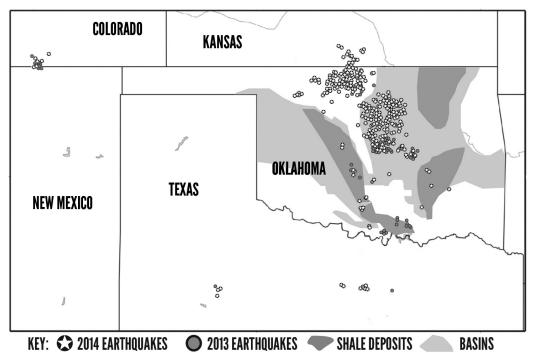
MEL has students make connections between evidence associated with this fundamental theory and two alternative models. In this way, the Fracking MEL facilitates students' application of their fundamental geoscience understanding to a current socio-scientific issue.

Evidence Text #4

This evidence text includes a diagram showing US Geological Survey data of earthquake epicenters in Oklahoma in 2013 and 2014 (Figure 7), showing that many earthquakes are currently occurring in regions surrounding fracking sites. Students should be aware that fracking occurs in the shale deposits located on the edges of basins that contained the reservoirs of oil and gas that are more easily removed by more traditional drilling techniques. When



considering this evidence text in the classroom, some students were unfamiliar as to how to read a geologic map. Therefore, we devoted some whole class discussion to reading these types of maps. The location of the non-fracking oil drilling rigs is in response to the geologic conditions that allowed the hydrocarbons to accumulate in the basins. In Oklahoma, fracking is recovering hydrocarbons locked in shale deposits that are bordering the basins. This evidence text shows that the earthquakes are occurring in the basins and not in the shale. Excellent



resources that you can refer to if you feel you need some background on oil drilling and recovery when discussing this text are those found at the US Department of Energy website.² The Teach Engineering website³ is also an excellent resource that takes students through the steps of fossil fuel development and methods of recovery.

Connecting the Fracking MEL with NGSS

Although fracking is not specifically discussed in

Figure 7. Areas of recent earthquake swarms. The star-shaped symbols show earthquakes in 2014. The shaded dots show earthquakes in 2013. Each symbol represents earthquakes of magnitude 2.7 or greater.

Credit: Wright Seneres.

the Next Generation Science Standards (NGSS Lead States, 2013), the topics covered in the Fracking MEL can support students' understanding of several performance expectations, such as those relating to the water cycle, fossil fuel recovery, and human sustainability (Table 1).

The fracking MEL also can be an effective way to introduce students to engineering practices within the context of geoscience. The Science and Engineering practices outlined in the NGSS are one of the three dimensions of learning and some teachers struggle to offer engineering principles in a way that is relevant and understandable to students. Although the Fracking

Table 1. NGSS performance expectations related to the fracking MEL
(NGSS Lead States, 2013)

· · ·
MS-ESS2-5: Earth's Systems
Develop a model describing the cycling of water through Earth's systems driven by energy from the sun and the force of gravity.
HS-ESS2-5: Earth's Systems
Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes.
MS-ETS1-1: Engineering Design
Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
HS-ETS1-3: Engineering Design
Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.
HS-ESS3-2: Earth and Human Activity
Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.
HS-ESS3-4: Earth and Human Activity
Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.

MEL does necessarily require students to engage in the engineering design process, the activity presents students with potential consequences of the engineering techniques used with fracking. As with all MELs the key instructional component is asking the students to construct and evaluate connections between lines of evidence and two alternative models about a phenomenon in order to gain deeper understanding.

Concluding Thoughts

We did this MEL activity after the students had engaged in the Climate Change MEL, the Wetlands MEL, and the Moon MEL (see related articles this issue). Although we made some adjustments in the composition of student teams, we kept most teams intact if students worked well together. The teams developed a sense of comradery when completing the MELs, which increased their engagement in the activity. Other teachers may see the MEL activity as a way to show students how to work together with different personalities and may want to change the structure of the student teams with each MEL. There are many ways to group the students but our most successful groupings had one high, one low (or ELL), and two average ability students. Teachers should select teams where the individual students feel comfortable expressing themselves and not just following the lead of one student. It is also important to constantly move among the student teams to ensure that productive discussion is taking place.

We noticed that by the fourth MEL, students had become comfortable with the process of selecting a connection that they felt 'linked' with the evidence text. The visual differences among the different types of arrows indicating connection strength (e.g., strongly supports, supports, contradicts, and has nothing to do with the model) allowed to students to immediately discover who was thinking what and students were encouraged to 'speak up' if their links did not match what others were drawing. This promoted collaborative argumentation in the classroom.

With the Fracking MEL, set-up of the science concepts before starting was necessary because the students had little or no experience with the fracking process. Because the MEL evidence texts are not designed to be a lesson in and of themselves, we found it necessary to have a full class discussion about oil exploration and extraction in general, as well as how the fracking process is different than traditional drilling. Even basic porosity concepts needed additional explanation in our classes. Without this fundamental understanding, using the MEL diagram may involve no more than guessing.

While the increase in earthquakes around fracking operations in the Midwest has been in the news, scientists are still active in trying to understand the possible link between the two. This means that this particular MEL does not have an overwhelming scientific consensus that favors one model over another. By having the students critically analyze both models with respect to the evidence presented to them, students are engaging in a current scientific debate.

Web Resources

Department of Energy:

²http://www.fe.doe.gov/education/energylessons/coal/gen_howformed.html

Teach Engineering:

³<u>https://www.teachengineering.org/view_lesson.php?url=collection/cub_/lessons/cub_earth/cub_earth</u> <u>lesson07.xml</u>

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Assessing Students' Evaluation on the Model-Evidence Link Diagram

Elliot S. Bickel and Doug Lombardi, Temple University

Abstract

Assessing both knowledge of Earth science concepts and students' scientific evaluations in making sense of these concepts is important to gauge understanding. In the Model-Evidence Link (MEL) diagram activities, students engage with Earth science content knowledge and evaluate the connections between evidence and alternative explanations. We have developed a rubric for assessing the quality of student evaluations when engaging in the MEL activity, specifically in the written explanations about the connections between evidence and explanations. This rubric features four distinct categories of evaluation: (a) erroneous, (b) descriptive, (c) relational, and (d) critical. For each category, the rubric identifies specific criteria addressing a student's accuracy, certainty, and use of elaborative language when explaining the connections made during the MEL activity. These categories may serve as individual levels of evaluation, and allow teachers to recognize and follow the development of students' critical evaluation skills when using MEL diagrams over time.

Students' knowledge of scientific topics and their ability to be scientifically evaluative are both important parts of understanding the connections between evidence and explanations. Therefore, both students' knowledge and their critical evaluation skills should be specifically addressed, encouraged, and assessed in the science classroom. Developing critical evaluation skills is an essential part of a student's ability to understand complex scientific phenomena (NRC, 2012) because it helps develop a more grounded understanding of the nature of science and teaches students to approach new scientific ideas in a logical way. These skills emerge from opportunities to make scientific judgments on the implications of material and the use of conclusive reasoning when presented with competing explanations (Erduran & Msimanga, 2014; Stanovich & West, 1997). Therefore, Earth science lessons should aim to not only engage students in the material of a given topic, but also allow reflection on their own evaluations of the meaning and plausibility of more general scientific models.

The Model-Evidence-Link (MEL) diagram is a classroom activity that integrates critical thinking into Earth science lessons (Chinn & Buckland, 2012; Lombardi, Sibley, & Carroll, 2013). When using the MEL, students use scientific evidence to evaluate competing models based on their

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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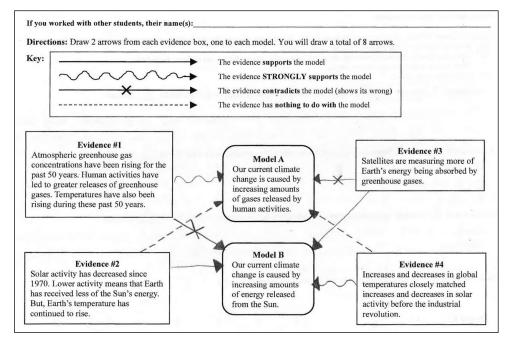
Figure 1. Example of a student completed MEL diagram

relative connections to each provided line of evidence. These models present alternative explanations for various phenomena (i.e., cause of current climate change, ecological services of wetlands, increased incidence of moderate earthquakes in the Midwest, and formation of Earth's Moon). This format also allows teachers to assess students' understandings of the examined scientific concept and also students' applications of the scientific practice of critical evaluation (Lombardi, Sinatra, & Nussbaum, 2013).

The purpose of this article is to outline ways in which teachers may assess students' understanding and scientific reasoning after engaging in the MEL activities. In this article, we briefly discuss the qualitative research applied in developing a rubric that teachers may find useful for assessment purposes. More details about our research regarding students' reasoning during MEL instruction are found in Lombardi, Brandt, Bickel, and Burg (2016).

Brief Overview of the MEL Diagram and Explanation Task

The format of the MEL diagram and explanation task were originally developed by researchers at Rutgers University who were developing instructional scaffolds for middle school life science (Chinn & Buckland, 2012). Lombardi, Sinatra, and Nussbaum (2013) adapted the MEL activity for instruction on the topic of current climate change. This Climate Change MEL was revised, and three other Earth science-related MELs were designed and developed, for a National Science Foundation-funded project titled "Developing Critical Evaluation as a Scientific Habit of Mind: Instructional Scaffolds for Secondary Earth and Space Science" (for more details about each of the four MEL diagrams, please see the other articles in this special issue).¹ Each MEL focuses on a phenomenon that can be explained by two plausible alternative models (e.g., current climate change is a result of human activities vs. current climate change is a result of increased amounts of energy released from the Sun), with one of the models being the scientifically accepted explanation (e.g., human-induced climate change). Students complete a MEL diagram by drawing different types of arrows from each of four evidence statements to each alternative model. The type of arrow drawn by the student represents a judgment about how well a line of evidence supports a model: strongly supports (squiggly solid arrow), supports (straight solid arrow), contradicts (straight solid arrow)



with a large X marked through the middle), or has nothing to do with the model (dashed straight arrow) (see Figure 1).

Our position is that students should NOT be assessed on the specific types of arrows they draw on the MEL diagram, but rather on the subsequent explanation task. We take this stance firmly because the MEL diagram is a scaffold designed to fully engage students in the act of weighing the connections between lines of evidence and alternative explanations, which is an essential practice of the scientific community embedded within the Next Generation Science Standards (NGSS Lead States, 2013).

Please work on	this indivi	dually.							1 an agus anns	
Provide a reason A. Write the B. Circle the C. Write white D. Then write	number of t appropriate ch model yo	he evidence word (stron ou are writin	you are wr Igly suppo	iting about.					g or impor	tant arrows.
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yoing u	P For	the Po	ist Se) Yeur	5. Mode	A I	s abou	+ Our C	limate	s have been chansing because
0F 999 2. Evidence #	2_strongl	y supports	supports	contradict	ts has noth	ing to do w	vith Model	<u>B</u> beca	ause:	
It Evid	ence :	#2,1+	Savs	SOLAr	activit	1 495	decrea	ised s	ince 1	970' in Moder
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Model B	1	\bigcirc	3	4	5	6	7	8	\bigvee_{0}	10

Assessing students on which arrow they draw may actually disengage students from practicing critical evaluation. Although we do acknowledge that students should complete the MEL diagram fully, the Explanation Task (Figure 2) should be the focus when assessing students' performances.

Students perform the Explanation Task after completing the MEL diagram. This task asks students to explain their reasoning behind the types of arrows they drew connecting lines of evidence to the explanatory models. Students are asked to write three explanations for the connections that most compelled them or on which they feel strongest. The explanation tasks facilitates students' reflections on their decisions about the meaning of the evidence texts, and also reveals the types and levels of evaluation that students are applying to the activity.

Assessment of the Explanation Task

Our qualitative research analysis revealed multiple distinct categories of responses, reflecting students' applied evaluative skills and levels of understanding. These categories resembled those presented by Driver, Leach, Millar, and Scott (1996) to describe levels of scientific reasoning. We adapted these, and added an additional category, based on the results of a thorough iterative analysis on the types of evaluations students made in their explanation tasks. The four evaluation categories that emerged from our analysis include: (a) erroneous, (b) descriptive, (c) relational, and (d) critical (Table 1). Using these four levels (discussed in more detail below), teachers can rank explanations based on both students' understanding of the material and their application of evaluative skills toward making sense of the material.

Erroneous Evaluation refers to student explanations that show a fundamental lack in scientific understanding, which are often apparent from a student's indication of a model-evidence link

Figure 2. Example of a student-completed explanation task.

Table 1. Types of Evaluation Scoring Rubric for Explanation Tasks

Erroneous Evaluation	Explanation contains incorrect relationships between evidence and model, excluding misinterpreting a "Nothing To Do With" relationship by elimination-based logic. The explanation may also be mostly inconsistent with scientific understanding and/or include nonsensical statements.
Descriptive Evaluation	Explanation contains a correct relationship without elaboration, or correctly interprets evidence without stating a relationship. For example, 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. Explanations could also demonstrate "elimination- based logic" to come to a positive or negative weight, when evidence-to-model link weight states that the evidence has nothing to do with the model. For example, an explanation states that an evidence supports one model, but uses reasoning that the evidence contradicts the other model.
Relational Evaluation	The explanation addresses text similarities, and includes both specific evidence and an associated model or reference to a model. For example, 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 that is often based on text similarity.
Critical Evaluation	Explanation describes a causal relationships and/ or meaning of a specific relationship between evidence and model. For example, explanation is correct, with an evidence-to-model link weight of strongly supports, supports, or contradicts as appropriate and 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/or concurrently examines alternative models.

that is illogical and incorrect. These errors in judgment prevent effective application of critical reasoning due to the student's difficulty with initially making meaning of the evidence text. For example, one student who completed the Climate Change MEL wrote that Evidence Statement #2 supported Model B because, "Both state about the energy of the Sun" (note: the examples provided are unedited quotations from student work). This student is clearly mistaken because this evidence statement actually contradicts the model's claim. Erroneous explanations may also include nonsensical statements, in which a student's response is not a coherent enough answer to be assessed for understanding.

One particular type of response worth noting, which we determined not to be erroneous, are those that reflect elimination-based logic. In these cases, a student incorrectly indicates what would otherwise be a "nothing to do with" relationship to one model, but uses reasoning that reflects an accurate interpretation of the evidence's link to the other model. For example, Fracking MEL Evidence Statement #4 has nothing to do with Model B, but some students claim that it supports this model. Many do this by accurately explaining how the evidence contradicts Model A but not actually talking about Model B. This type of answer, though possibly incomplete in its evaluation of the evidence, reflects a level of reasoning beyond misinterpretation. Most commonly, we considered answers of this form to be one type of "Descriptive Evaluation," as discussed in detail below.

Descriptive Evaluation refers to student responses that are scientifically accurate, but are based merely on similarity of wording between a line of evidence and the explanatory model. This type of student explanation often lacks any expressed reasoning or provides an answer that reflects or requires minimal amounts of evaluation. Most of

the responses that fall into this category are correct assessments of a "nothing to do with" link. The choice to make this type of evaluation, which only requires a student to realize a lack of connection between evidence texts and models, impedes vigorous scientific reasoning because this link can be generalized via superficial understanding. We categorized these cases, and similarly undeveloped connections, as descriptive evaluations. Sometimes students correctly identified a connection but only wrote a trivial explanation about the connection (such as, "They [the model and evidence

statement] are talking about different subjects"). In cases where even a correctly identified nonneutral link is expressed on the explanation task, answers are considered descriptive when they lack meaningful explanations or have only basic assessments of word-by-word similarity between the evidence and model.

Relational Evaluation reflects a more advanced level of evaluation, but these student explanations still lack a fully critical quality. Explanations that demonstrate relational evaluation are scientifically accurate and discuss either a supportive or contradictory link. When students accurately evaluate such a link, they have identified a useful connection based on a line of evidence, which indicates some understanding of the material and an ability to use scientific reasoning. However, in the case of relational evaluation, these explanations are mostly insubstantial in that they do not discuss the more complex scientific implications of the evidence or the cause-and-effect relationships between lines of evidence and explanatory models. In general, these responses do not reflect an understanding of the way a line of evidence would impact a particular model, perhaps by incorrectly describing the model as having influence over the evidence or by identifying a correlation without considering causation. Thus, these students clearly used scientific reasoning to make sense of the material, but may still need help with understanding how these pieces work together within a larger scientific theory. When completing the Moon MEL, one student wrote that Evidence Statement #2 strongly supports Model B because, "They both talk about smaller particles being broken off to come together and form a more massive object." This is an accurate evaluation and does express an understanding of the scientific discussion, but the student interprets the evidence and model as separate ideas rather than discussing the evidence's specific role in confirming plausibility of the model.

Critical Evaluation refers to student explanations that are scientifically accurate judgments of the lines of evidence and explanatory models, and also use sound reasoning for more thorough evaluations of the model-evidence links. These explanations reflect an understanding of the relationship between evidence and models through descriptions of cause-and-effect relationships, applications of counter-examples, or other full demonstrations of well-grounded logic. They make sense of the evidence based not only on correct interpretations of meaning, but also by describing relevant implications of the evidence. A simple but critical explanation by one student, after accurately indicating that wetlands MEL Evidence Statement #1 supports Model A, simply says, "Wetlands provide nutrients and essential gases, which proves that they are beneficial to human welfare." Despite being brief, this answer identifies the student's understanding of the evidence while also addressing the role that it plays in the evidence-model relationship. Other responses that are categorized as critical evaluation may discuss the student's more complex analysis of the evidence text, such as another student's explanation of the same link, which states, "This piece of evidence discusses all of the ways that wetlands contribute to the biochemical cycles. For example, carbon will be stored in the wetlands as long as they remain wet." Here, the student does not explain as thoroughly how the evidence text directly affects the plausibility of the model, but does elaborate on her understanding of the evidence text to clearly show her reasoning for the indicated model-evidence relationship.

Conclusions

These evaluation categories (erroneous, descriptive, relational, and critical) serve as four distinct levels of scoring for individual explanations (see Table 1). We consider this scoring system to carefully reflect both students' understandings of the material and their ability to use critical thought and reasoning when making sense of the implications of scientific data. Progress in understanding and reasoning skills, then, could be closely followed as students learn to be critically evaluative during repeated use of the MELs for various Earth science topics, and the explanation task serves as an explicit record of the types of thought processes that each student uses in working through new scientific ideas and information. Students and teachers can then gauge explanations to assess whether students are viewing the larger ideas differently (e.g., more scientifically) after completing the MEL diagrams and explanation tasks. When teachers and students specifically observe, and assess, the use of these abilities, it will help acclimate students to the scientific practices of critical evaluation and reasoning as means to construct understanding of Earth science phenomena.

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