

Evaluating the Connections Between Fracking and Earthquakes

Jenelle Hopkins, Shadow Ridge High School
Petya Cronos, 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 fracturing (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/>).

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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

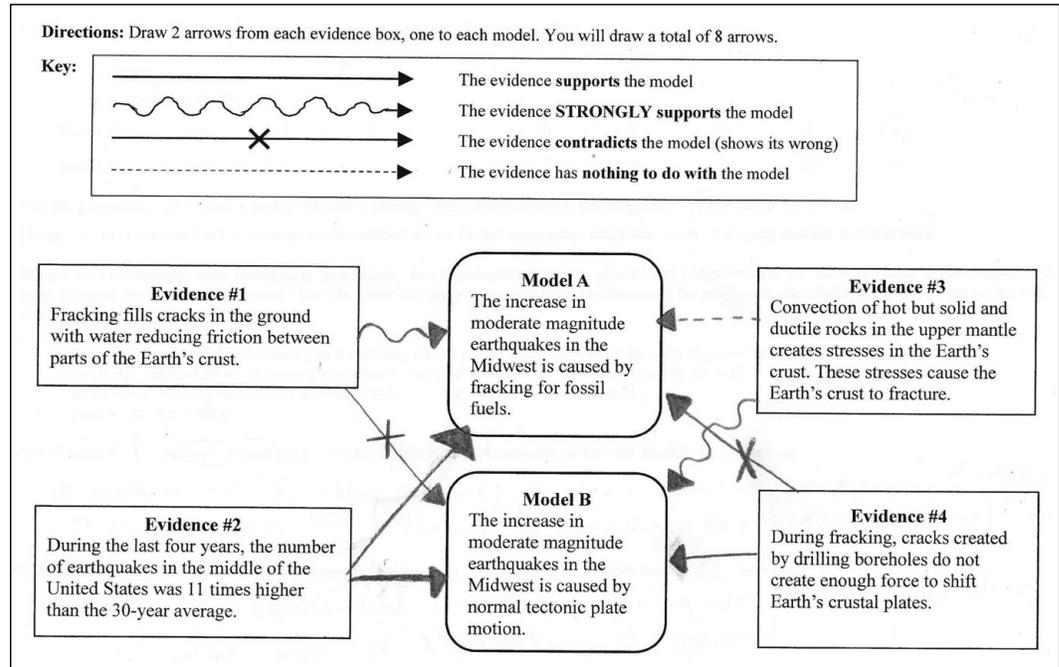


Figure 1. Example of a student-completed Fracking MEL diagram.

Figure 2. Fracking model plausibility ratings.

Plausibility of Models Explaining Increase in Moderate Earthquakes

Name: _____ Date: _____ Teacher: _____ Period: _____

Please work on this individually.

Read the following information carefully.

Humans create *models* to help explain things.

Below are two models. These provide different explanations for the increase in moderate magnitude earthquakes in the Midwest U.S.

Model A: The increase in moderate magnitude earthquakes in the Midwest is caused by fracking for fossil fuels.

A person who supports this model makes the following argument:

Hydraulic fracturing (fracking) is used to drill for fossil fuels. Fracking injects water into the ground at high pressure. This water reduces friction between parts of Earth's crust, resulting in an increased risk for earthquakes near fracking wells.

Model B: The increase in moderate magnitude earthquakes in the Midwest is caused by normal tectonic plate motion.

A person who supports this model makes the following argument:

Earthquakes occur because of motions in Earth's crust. Normal tectonic movement of Earth's crust has caused earthquakes throughout Earth's history and injecting high pressure water into the ground does not provide enough force to move Earth's crust.

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.

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

	1	2	3	4	5	6	7	8	9	10
Model A										
Model B										

Greatly implausible (or even impossible) Highly plausible

Fracking Model Plausibility Ratings (MPR; 08/02/2015) Page 1 of 1

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 this part individually after you complete your diagram. Now that you have completed the diagram, reconsider the plausibility of Models A and B.

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

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

Did the plausibility of Model A and/or Model B change after you completed the diagram? Yes or No [Circle One]

[Note: you may have to look at your previous ratings if you do not remember what they were. Ask your teacher for assistance.]

Which arrows changed your plausibility judgments about the models? If your plausibility judgment did not change, which arrows supported your original plausibility judgments? Use the following steps to provide two explanations for why your plausibility judgments did or did not change.

- Write the number of the evidence you are writing about. [Note: it is okay to include more than one evidence]
- Circle the appropriate word (strongly supports | supports | contradicts | has nothing to do with).
- Write which model you are writing about. [Note it is okay to include both models].
- Then write your reason.

1. Evidence # 1 strongly supports | supports | contradicts | has nothing to do with Model A because:

it explains how fracking reduces friction between parts of Earth's crust, increasing the chance of earthquakes occurring & sinkholes forming

2. Evidence # 2 strongly supports | supports | contradicts | has nothing to do with Model A because:

it shows the exponential increase of earthquakes in the midwest of the US where most of US fracking is operated.

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 student-completed explanation task.

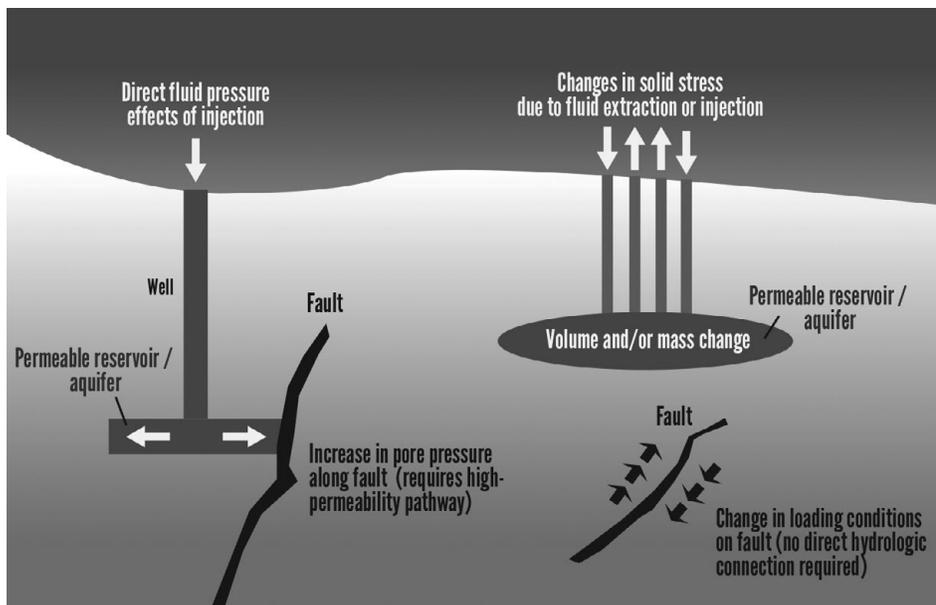


Figure 4. Stresses in Earth's crust potentially caused by wastewater injection.

Credit: Wright Seneres

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

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

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.

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

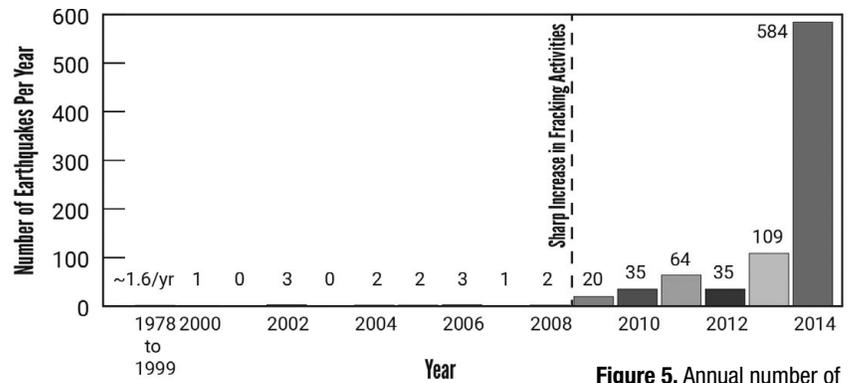


Figure 5. Annual number of earthquakes in Oklahoma from 1978 to 2014.

Credit: Wright Seneres.

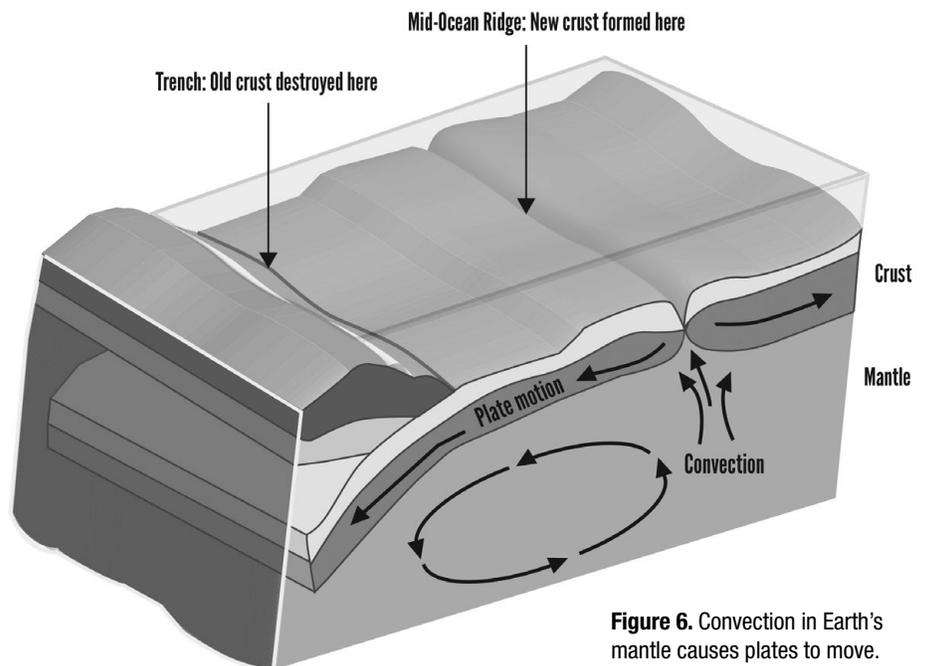


Figure 6. Convection in Earth’s mantle causes plates to move.

Credit: Wright Seneres.

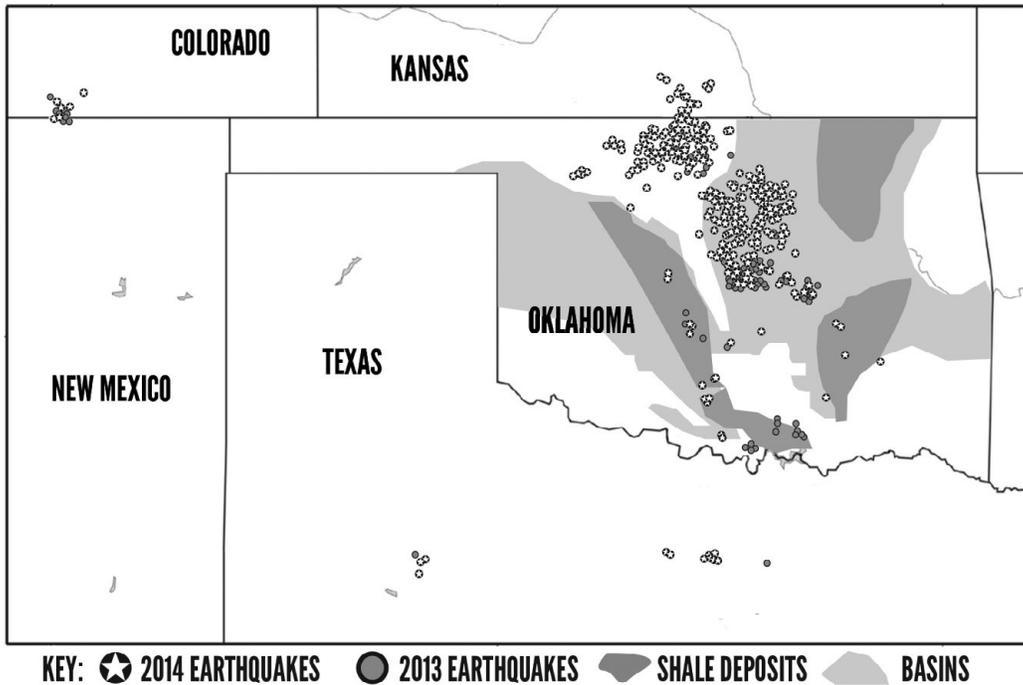


Figure 7. Areas of recent earthquake swarms. The star-shaped symbols show earthquakes in 2014. The shaded dots show earthquakes in 2013. Each symbol represents earthquakes of magnitude 2.7 or greater.

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

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

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 not 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:

³https://www.teachengineering.org/view_lesson.php?url=collection/cub_/lessons/cub_earth/cub_earth_lesson07.xml

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About the Authors

Jenelle Hopkins, M.S., has been a high school science teacher since 1995. She currently teaches Geoscience and AP Environmental Science at Shadow Ridge High School, Las Vegas, Nevada. Jenelle has received numerous honors, including selection as a Albert Einstein Distinguished Educator Fellow (2004-2005), working at the NSF Directorate for Geosciences; recipient of the President's Council on Environmental Quality Teacher Professional Development Award for the State of Nevada (2000); Mandalay Bay Teacher of the Month Award (October, 2001); and Educator of the Year Award, Centennial High School (April, 2002). Jenelle can be reached at jhopkins@interact.ccsd.net.

Jenelle Hopkins; Shadow Ridge High School; 5050 Brent Ln, Las Vegas, NV 89131; home/mobile: 702-281-6174; work: 702-799-6699; jhopkins@interact.ccsd.net

Petya Crones, M.S., is a science teacher at Green Valley High School in Las Vegas, NV. Petya earned her M.S. in Molecular Biology and Biochemistry from the University of Sofia, Bulgaria. She obtained her teaching credentials from Sierra Nevada College and is licensed in Biological Science, Physical Science and General Science. Prior to becoming a teacher, Petya worked at Geneva Laboratories in Elkhorn, WI. Petya has a passion for both teaching and science and is working on different projects aimed at improving science education. She can be reached at prcrones@interact.ccsd.net.

Petya Crones; Green Valley High School; 460 N Arroyo Grande Blvd, Henderson, NV 89014; home/mobile: 702-544-5318; work: 702-799-0950; prcrones@interact.ccsd.net

Shondricka Burrell is a doctoral student and graduate research assistant with the MEL project at Temple University. She has graduate degrees in geology and education, teaching experience in the Earth sciences, and research interests in improving how students mentally access, process and comprehend Earth science concepts. Prior to coming to Temple, Shondricka was a teacher at an alternative high school, worked as instructional faculty at the University of California—Berkeley and San Jose State University, and served as an Education Specialist at NASA Ames Research Center. She can be reached at shondricka.burrell@temple.edu.

Shondricka Burrell; Temple University; 1301 Cecil B. Moore Ave., RH 373, Philadelphia, PA, 19122; home/mobile: 408-398-2812; work: 215-204-8290; shondricka.burrell@temple.edu

Janelle M. Bailey, Ph.D.

Janelle M. Bailey; Temple University; 1301 Cecil B. Moore Ave., RH 456, Philadelphia, PA, 19122; home/mobile: 702-513-8763; work: 215-204-5195; janelle.bailey@temple.edu

Doug Lombardi, Ph.D.

Doug Lombardi; Temple University; 1301 Cecil B. Moore Ave., RH 450, Philadelphia, PA, 19122; home/mobile: 702-513-4415; office: 215-204-6132; doug.lombardi@temple.edu