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Astronomy activities for promoting scientific evaluation

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We have developed activities to engage students in evaluating competing scientific models. Ford[1] identified evaluation as a critical aspect of doing science, and it sits at the crux of the *K-12 Framework* and *NGSS's Science and Engineering Practices*.[2] Scientific evaluation often involves both the evaluation of the connections between evidence and the explanation and the evaluation of competing explanations. But how do we get students to engage with this process?

Our approach is the Model-Evidence Link (MEL) diagram in both preconstructed and build-a-MEL forms. The MELs are a series of activities addressing a scientific topic and take ~90 minutes to complete. The lesson activities provide a structured opportunity for students to evaluate the connections between evidence and competing scientific explanations. We have created three MEL activities focusing on astronomy: the Moon Formation preconstructed MEL[3] and the Origins of the Universe preconstructed MEL and build-a-MEL.[4]

In a preconstructed MEL, we provide students with four lines of evidence and two competing models (i.e., explanations; Fig. 1) around a given phenomenon. One of the models is the currently accepted scientific explanation; the other is a plausible but nonscientific alternative (e.g., a common misconception or historical explanation that scientists have since discounted),[5] although the models are not identified as such in advance. Students first read brief descriptions of the two models and rate the plausibility of each on a scale of 1-10. *Plausibility* is a rough judgment of the relative truthfulness of a statement and is different from the *probability* of said statement being true.[6] Table I displays the models for the astronomy MELs.

Next, students read one-page texts that elaborate on each line of evidence and then use this information to evaluate whether a given line supports, strongly supports, has nothing to do with, or contradicts each model. We encourage students to read and discuss these texts in groups and move toward consensus about each evidence-model connection.[7] Students indicate connections by drawing different types of arrows on the diagram (a total of eight are drawn). We developed the evidence texts by examining current scientific research (citations provided on our website, below), and all have been reviewed by experts external to the development team. We have also updated them as needed to address scientific advances or student difficulties.

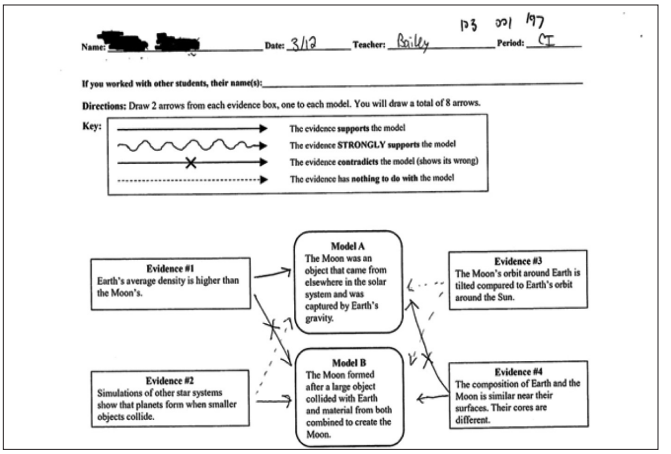

Fig. 1. The preconstructed Moon Formation MEL diagram.

Table I. Models used in the astronomy MEL and build-a-MEL activities.

Moon Formation	**Model A**	The Moon was an object that came from elsewhere in the solar system and was captured by Earth's gravity. [*nonscientific model*]
	Model B	The Moon formed after a large object collided with Earth and material from both combined to create the Moon. [*scientific model*]
Origins of the Universe	**Model A**	Space, time, and matter came into existence a finite time ago in a hot dense state. It has been expanding and cooling ever since. [*scientific model*]
	Model B	The Universe has always existed in its current state and always will. Matter is created in some places and destroyed in other places at different times. [*nonscientific model]*
	Model C	The Universe began a finite time ago when a small ball of matter exploded. The matter then spread out throughout space. [*nonscientific model*]

Finally, students complete the Explanation Task (Fig. 2). Here they write about two of their connections, with emphasis on those connections that helped them evaluate the competing models. Students also re-rate the plausibility of each model in light of their evaluations. This reflective process of plausibility reappraisal can strengthen students' evaluations to be more scientific.[8] Explanation Tasks are completed individually and are typically the portion of the activity that can be used for assessment. (We encourage teachers to focus not on specific evidence-to-model connections but rather on the reasoning behind the connections.[9])

The build-a-MEL (Fig. 3) works similarly, but we designed it to increase students' agency. Students now select two out of three provided models and four out of eight lines of evidence. After selecting, they build their own MEL diagrams by placing cut-out cards on a template and proceed in the same way as a preconstructed MEL activity. It is possible that a

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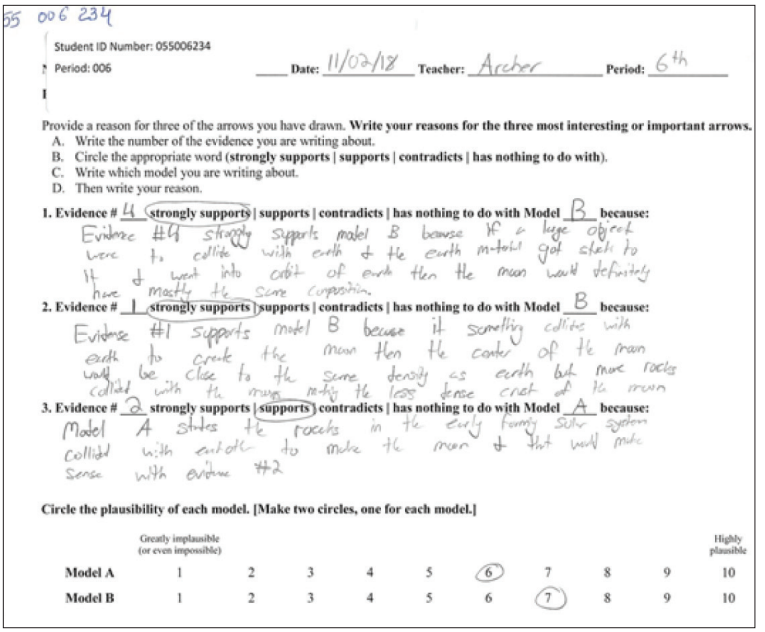

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Student ID Number: 055006234

Period: 006 Date: 11/02/18 Teacher: Archer Period: 6th

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 # 4 **strongly supports | supports | contradicts | has nothing to do with Model** B **because:**
Evidence #4 strongly supports model B because if a large object were to collide with earth & the earth material got stuck to it & went into orbit of earth then the moon would definitely have mostly the same composition.

2. Evidence # 1 **strongly supports | supports | contradicts | has nothing to do with Model** B **because:**
Evidence #1 supports model B because if something collide with earth to create the moon then the center of the moon would be close to the same density as earth but more rocks collided with the moon making the less dense crust of the moon

3. Evidence # 2 **strongly supports | supports | contradicts | has nothing to do with Model** A **because:**
Model A states the rocks in the early forming Solar system collided with eachother to make the moon & that would make sense with evidence #2

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

Fig. 2. The Explanation Task for the Moon Formation MEL. Students completed three explanations in this earlier version; the most recent version asks for only two.

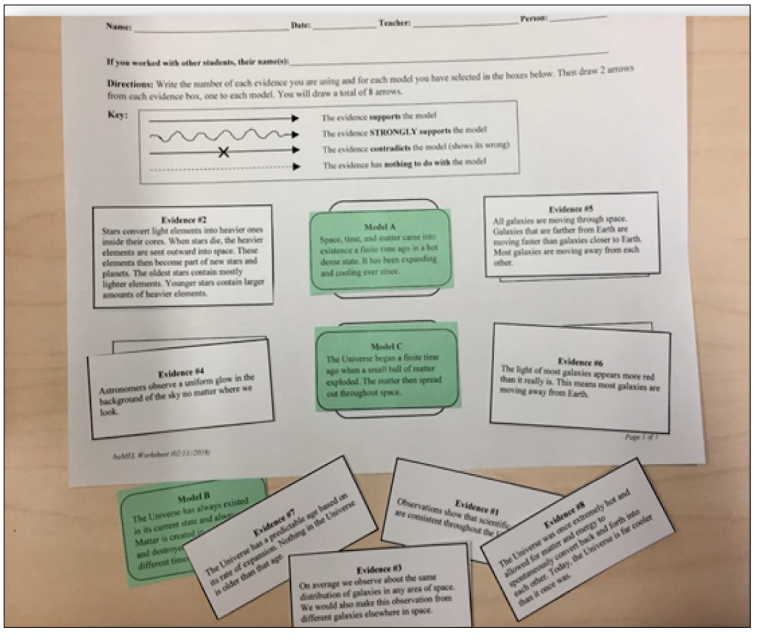

Fig. 3. The Origins of the Universe build-a-MEL showing selected models and evidence laid on the template.

given group might not select the scientific model; the teacher should make sure that each model is being evaluated by at least one group in the class.

A large-group discussion at activity's end allows the teacher to elicit students' ideas about which model offers the better explanation for the phenomenon and their reasoning for their ideas. This discussion also helps expose students to all of the models and lines of evidence within the build-a-MEL. It is helpful, after the activity is complete, to be explicit about which is the currently accepted scientific model and why.

Our full suite of MEL activities for Earth and space science can be found at https://serc.carleton.edu/mel/index.html. Today's society is challenged by complex and controversial socio-scientific issues, and students need to engage in scientifically evaluating how well evidence supports a particular explanation in light of competing alternatives. The MEL activities are instructional scaffolds that provide students the opportunity to easily engage in more scientific evaluations for these important challenges and issues in a collaborative and meaningful way.

References

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3. J. M. Bailey, C. Girtain, and D. Lombardi, "Understanding the formation of Earth's Moon," *Earth Sci.* **32** (2), 11–16 (2016).
4. J. M. Bailey, T. G. Klavon, and A. Dobaria, "The Origins build-a-MEL: Introducing a scaffold to explore the origins of the universe," *Earth Sci.* **36** (3), 7–12 (2020).
5. Note that although we use the term "nonscientific" here, we acknowledge that some models may have been accepted explanations in the past (e.g., steady state model of the universe) or for other situations (e.g., gravitational capture of moons around other planets). In other MEL topics, the nonscientific models may not have ever been considered accurate; for example, the nonscientific model in the Climate Change MEL is a commonly proposed skeptic model of increasing solar radiation causing increased global temperatures.
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