The Origins build-a-MEL: Introducing a Scaffold to Explore the Origins of the Universe

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Abstract

The origin of the Universe is something that people have pondered for thousands of years. As evidence has mounted, the Big Bang theory has become the consensus scientific model. Much of this same evidence refutes opposing theories such as the earlier Steady State model. The NGSS for high school includes the nature of and evidence for the Big Bang, providing a rich opportunity to explore—with the help of a scaffold—the connections between evidence and competing models about the origins of the Universe.

One of the most fundamental and existential questions humans have asked is how everything began. The Big Bang theory describes the Universe at the earliest time that we have been able to measure (Coble et al., 2015). At the start of our "clock," the Universe was extremely hot and tremendously dense. The Universe underwent a rapid expansion, in which space itself stretched, and the Universe became larger, cooler, and less dense over time. We see evidence of these early conditions and the expansion in a number of ways. The cosmic microwave background radiation is a leftover "glow" from this time period that is present in every direction we look. Galaxies all around us generally appear to be moving away, with more distant galaxies moving faster than those that are nearer. The composition and abundance of matter is consistent across the galaxy and changes in predictable ways, as predicted by the Big Bang theory.

Origins in the High School Classroom

The Big Bang theory and evidence in support of it is the primary cosmological content included in the *Next Generation Science Standards* (NGSS Lead States, 2013). The relevant performance expectation (Table 1) focuses on students constructing an explanation based on evidence. Students often have difficulty understanding the origin of the Universe, in part because it is very abstract and disconnected from their daily lives. We have created a scaffold, the Origins of the Universe build-a-MEL, to help students better understand this explanatory model.

Table 1. Connections to the *Next Generation Science Standards*

HS-ESS1-2
Construct an explanation of the Big Bang theory based on astronomical evidence of light spectra, motion of distant galaxies, and composition of matter in the universe.

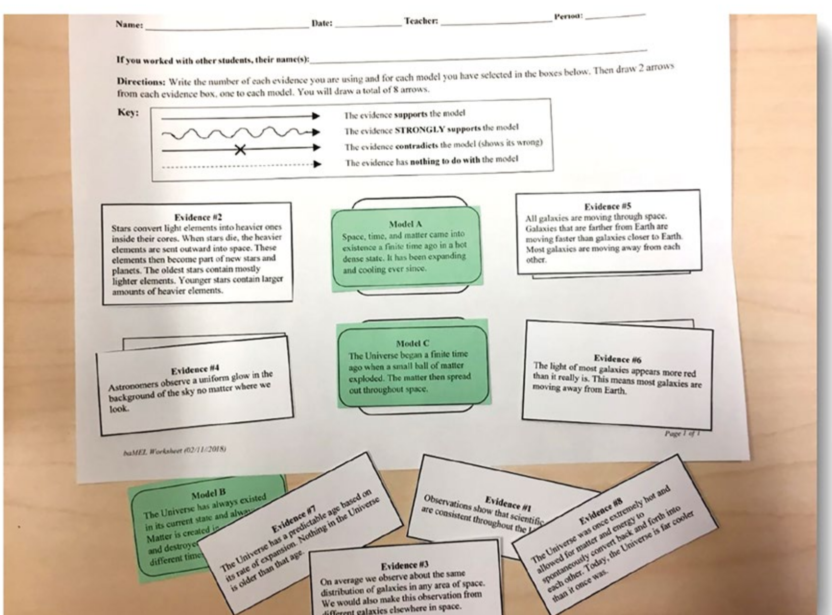
Building a Better MEL

In the Summer 2016 issue of *The Earth Scientist*, available at https://www.nestanet.org/cms/sites/default/files/journal/Summer16.pdf, our team described a suite of scaffolds to help students develop their critical evaluation skills, knowledge, and plausibility judgments about Earth and space science phenomena. The Model-Evidence Link (MEL) diagram activity is designed to help students weigh the connections between evidence and different models—one scientific and one alternative. Students read expository text relating to each piece of evidence and use that to determine how it connects to each of the two models: the evidence might support, strongly support, contradict, or have nothing to do with a given model. Students draw arrows to represent these connections on the MEL diagram, afterward elaborating on a select number of arrows drawn to explain their reasoning. Using the original mode and structure of the MEL activity created by Chinn and Buckland (2012), our team developed and tested four pre-constructed MEL activities in Earth and space science topics—climate change, fracking and earthquakes, wetlands use, and the formation of Earth's Moon.

Our research has shown that the MEL activities help students construct better understanding of the scientific models and evidence for (and against) them as well as demonstrate improved evaluation skills in the topics covered (Lombardi et al., 2013, 2018a,b, this issue; Saribaş et al. 2019). But transfer is challenging, and we've had difficulty in helping students transfer these evaluation skills to other kinds of activities (Burrell et al., 2015; Roemmele et al., this issue). This lack of transfer outside the context of a pre-constructed MEL was the primary motivation for the present project. Recent theoretical and empirical work (as summarized by Nussbaum & Asterhan, 2016) suggests that repeated practice of constructing and using MEL diagrams may help students to internalize the scaffold into a mental representation for application and transfer to authentic situations (e.g., real world controversies pitting scientific versus alternative explanations). With this idea in mind, we created a new, related activity—the build-a-MEL.

The build-a-MEL (or baMEL) provides students with the pieces and parts to construct their own MEL diagram (contrast this with the pre-constructed MELs, where students are given a fully-formed diagram). Rather than the original two models and four lines of evidence, the baMEL activity provides students with three explanatory models (one scientific, two alternative) and eight lines of evidence from which to choose. Students or groups select two models and four lines of evidence, then enter the corresponding letters and numbers onto a blank diagram (Figure 1) and proceed to evaluate the connections between the evidence and models in the same manner as they did with pre-constructed MELs. The models and evidence lines are printed in such a way as to be cut out and manipulated on the blank diagram while students are working on the activity, but writing down the letters and numbers allows the teacher to reuse the cutouts across multiple class periods. Subsequent components of the activity are similar to those used with the pre-constructed MELs and we describe these in more detail in the next section, using the Origins baMEL as an example. Other articles in this issue describe our baMELs on

Figure 1. The Origins Build-a-MEL
Note. This setup shows the selected cut-outs of the two models (green cards) and evidence lines (white cards).



extreme weather (Lombardi et al., this issue), fossils and past climate change (Governor et al., this issue), and freshwater resource availability (Holzer et al., this issue).

It is our hope that this opportunity for students to have agency (i.e., where the student has more autonomy and choice in the learning process) to create, with assistance, their own MEL diagram will support them in their ability to use these evaluation skills in other contexts. Although the efficacy of the Origins baMEL, and the other baMELs described in this issue, has shown to be good, research into the effectiveness of this transfer aspect of the activities is underway.

The Origins of the Universe Build-a-MEL Activity

The first step in the activity is to look at the three explanatory models provided. The Origins baMEL includes the Big Bang theory as the scientific model[1]. The first alternative is what is typically referred to as the Steady State model, in which the Universe has been and always will be essentially the same over time—small changes may occur but the overall structure and patterns do not change. Finally, the second alternative presents a common student misconception, that of an explosion of pre-existing matter into a large but otherwise empty space (Bailey et al., 2012; Trouille et al., 2013). Students will rate the plausibility of each of these models before ultimately selecting two that they want to evaluate further.

The lines of evidence for the Origins baMEL include the three phenomena in the NGSS (i.e., "light spectra, motion of distant galaxies, and composition of matter in the Universe"; Table 1), but also include other lines. Table 2 lists the three models and eight lines of evidence available for students to use in creating their own Origins MEL diagram (Figure 1).

Table 2: Models and Lines of Evidence in the Origins of the Universe baMEL

Model	Statement
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.
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.
Model C	The Universe began a finite time ago when a small ball of matter exploded. The matter then spread out throughout space.
Evidence	**Statement**
Evidence #1	Scientists expect that the scientific principles we use on and around Earth also work elsewhere in the Universe. Observations of phenomena around the Universe show that this is true.
Evidence #2	Models of the Universe predict how much we should see of the lightest elements. Our observations of hydrogen, helium, and other light elements match these predictions.
Evidence #3	On average we observe about the same distribution of galaxies in any area of space. We would also make this observation from different galaxies elsewhere in space.
Evidence #4	Astronomers observe a uniform glow in the background of the sky no matter where we look.
Evidence #5	Observations of the sky's background glow match predictions from models very well. This data tells us that the temperature of the Universe is about 2.7 K.
Evidence #6	All galaxies are moving with space. Galaxies that are farther from Earth are moving faster than galaxies closer to Earth. Most galaxies are moving away from each other.
Evidence #7	The Universe has a predictable age based on its rate of expansion. Nothing in the Universe is older than that age.
Evidence #8	The Universe was once extremely hot and allowed for matter and energy to spontaneously convert back and forth into each other. Today, the Universe is far cooler than it once was.

Each of the eight lines of evidence is a sentence or two long, but is backed by supporting expository text (known as the "evidence text") of about one-half to one page. The evidence texts serve to elaborate on the shorter evidence statements (i.e., those listed in Table 2 and available on the cutouts), and contain figures, graphs, or tables as appropriate for the evidence under discussion. For example, Origins Evidence #5 contains a graph of the blackbody model of the Universe along with observed data from the cosmic microwave background (Figure 2). Students may choose the models and evidence lines by only looking at the cut-out cards first, then using the evidence text in order to make

1 Note that although the scientific model for the Origins baMEL happens to be Model A, this is not always the case. Other baMELs may have the scientific model labeled as Model B or Model C.

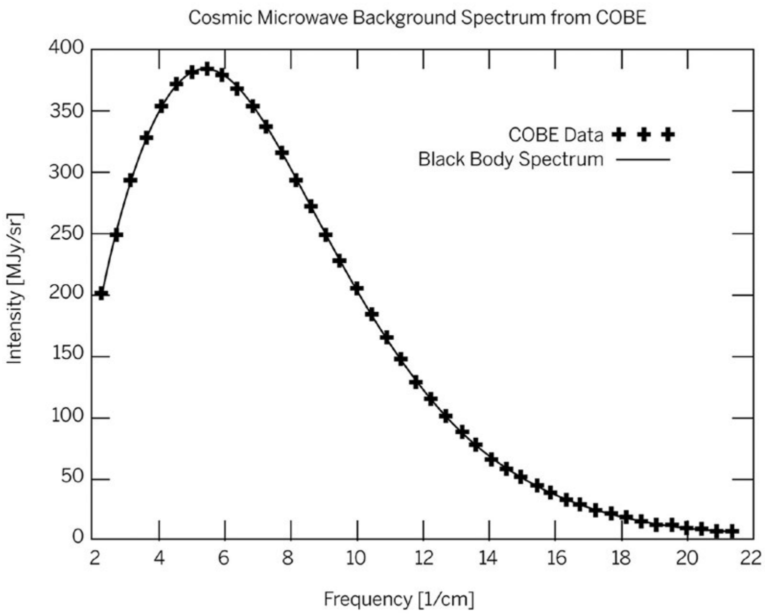


Figure 2. Relationship between the intensity of the cosmic microwave background and its frequency. Note: This graph is included in the Origins build-a-MEL's Evidence #5.

their evaluations of the connections between the four selected lines of evidence and two selected models, or they may use the details provided in the evidence texts to help make the selections of which evidence lines to use in their MEL diagram.

Groups are strongly encouraged to come to agreement about which models and evidence lines to use in order to facilitate meaningful conversations about the connections between them. The discussions should lead students to consensus on the connections between each line of evidence and each model, for which students then draw the appropriate arrows on the MEL diagram. Students next write explanations about their reasoning for a small number of their connections and make a judgement about the plausibility of each model (the "explanation task"). (Note that they will rate the plausibility of each of the three models—even though they may not look at all three in great detail, they often will see connections to the third model as they review the evidence or hear from other groups who might have selected the model they didn't use.)

Implementation of the Origins baMEL

The most challenging aspect of the Origins baMEL is that the difference between Models A (Big Bang, the scientific) and C (explosion, a common misconception) can be subtle. In Model A—the Big Bang theory—space itself is expanding. A common, though imperfect, analogy is that of a rubber band or a piece of stretchy fabric. The Universe is, in effect, growing over time. There is no true center or point of origin of the Universe, as it is steadily expanding in all dimensions. Model C, in contrast, describes an explosion in which an amount of matter starts as a whole but is broken apart then violently spewed away from a central location and redistributed as smaller bits throughout existing space. If this happened, we would see different patterns (on average) of material in different directions; instead we see basically the same thing (Coble et al., 2015). An explosives specialist here on Earth would be able to pinpoint the original location of an explosion of matter on our surface; no such thing is possible for the Universe itself. Some of the lines of evidence might at first seem to support both of these models equally, however this should not be the case upon more careful inspection of the evidence. Helping students understand the differences between the two models and the way the various lines of evidence connect to each will be a critical component of the activity discussion, after students have completed the baMEL diagram and the associated explanation task.

Given that each build-a-MEL contains three models—only one of which is the scientifically accepted model—and that students individually only evaluate two (and therefore may not include the scientific one without knowing it), the teacher may need to intervene. We have found that the best way to do this is to make sure that, in the spirit of a scientific community, all models are being evaluated by someone, even if it isn't by each individual member; this is best done after students make their model and evidence line selections but before they get too far into the discussion about the connections between them. A large group discussion at the end of the activity about the three models and how the evidence connects to each can help expose students to all of the ideas, even those models and evidence lines that a given individual did not evaluate. At the end, be sure to confirm with students that Model A is the scientific model and why.

Conclusions

There is an expectation that students will gain scientific knowledge, improve their evaluation skills, and engage in scientific practices using the Origins build-a-MEL. This scaffolding activity helps students develop scientific thinking and reasoning skills, as well as supports students in using scientific discourse. Finally, the Origins baMEL can be used as a gateway for students to approach understanding astronomy phenomena. Overall, our hope is that this activity, especially when used in conjunction with other MEL and baMEL topics, can help students improve their understanding of scientific issues beyond the field of astronomy using the learned scientific skills.

The Model-Evidence Link (MEL) and build-a-MEL activities can be accessed on our project's website, https://serc.carleton.edu/mel/index.html.

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