

THE EARTH SCIENTIST



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FREE INSIDE
Earth Science Week Poster
“Earth Materials in Our Lives”
*compliments of the American Geoscience
Institute (AGI)*

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From the President

Earth System Science a Changing and Dynamic Era

Aloha NESTA,

2020 has been a challenging time for everyone with the emergence of the Novel Corona Virus (COVID-19) and the global pandemic forcing schools and teachers to transition overnight to distance learning modalities with little time to prepare and develop solid learning experiences for students. Organizations like NESTA have risen to the need, providing digital resources (<https://serc.carleton.edu/nesta/resources/index.html>) to help teachers provide rigorous, relevant, and real learning. In addition to NESTA's Teaching Resources you will find this issue of The Earth Scientist focused on the Model-Evidence Link (MEL) Diagrams Project and the student driven build-a-MEL (baMEL) project.

The MEL Project uses an instruction scaffold model to promote students' scientific thinking when confronted with controversial and/or complex Earth and space science topics (SLRG, 2020), that I think you will find useful as you continue to seek materials to enhance your instruction regardless of the modality you find yourself immersed in.

As you read through the articles in this edition of TES you will notice that **MELs and baMELs were designed with both the student and the teacher in mind. For students there are multiple** opportunities to practice arguing from evidence, by assessing evidence and their relationship to claims assisting students in weighing strengths in competing models. All the MELs and baMELs focus on the Nature of Science as students grapple with scientific models. From my perspective, that of a teacher, the MELs and baMELs address topics that can be somewhat "charged" so they are designed to assist teachers design effective pedagogies that will support students as they learn about these "charged" topics. As an added bonus, all MELs and baMELs are designed to exemplify what is expected from three dimensional (3D) teaching and learning and will help teachers fully embrace the NGSS or other curricula that focuses on the three dimensions.

In the coming academic year, the authors and designers plan to modify the MELs and baMELs so they can be more easily used in virtual settings, something critical as we all deal with changes to teaching in a COVID-19 world. While we all wait for these modifications, both MEL and baMELs can be used via distance learning, but they depend on online platforms that allow breakout rooms, like Zoom, and access to shared documents, like Google Docs, to record the connections students observe on PDFs of the various diagrams.

As the year progresses and you discover how to use MELs and baMELs in your teaching NESTA will provide updates via our members E-News that focus on specific MELs and baMELs and how to use them in any classroom modality.

Enjoy this issue of The Earth Scientist.

Richard Jones, President, 2020 - 2022

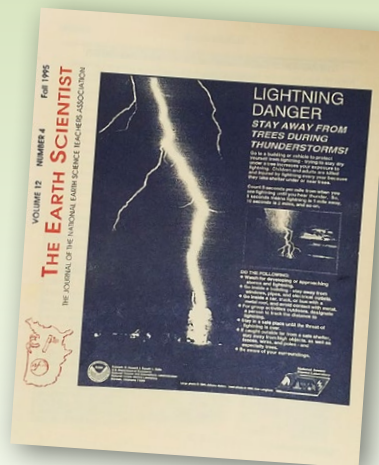
Editor's Corner

It is a pleasure to present the second special issue of *The Earth Scientist* sponsored by the MEL Project team (<https://serc.carleton.edu/mel/index.html>)! The Model-Evidence Link (MEL) and MEL2 projects have been sponsored by the National Science Foundation (Grant Nos. 1316057, 1721041, and 2027376) to Temple University and the University of Maryland, in partnership with the University of North Georgia, TERC, and the Planetary Science Institute. In 2016 we shared with you the four MEL diagram activities, covering the topics of climate change, the formation of the Moon, fracking and earthquakes, and wetlands use, as well as a rubric for assessment. This issue brings to you our four new build-a-MEL activities on the origins of the Universe, fossils and Earth's past, freshwater resources, and extreme weather. Additionally, there are articles about a new NGSS-aligned rubric and transfer task to help students apply their new skills in other situations and about teaching with MEL and build-a-MEL activities. Our goals with all of these activities are to help students learn Earth science content by engaging in scientific practices, notably the evaluation of alternative explanatory models (by looking at the connections between lines of evidence and the competing models) and argumentation. The team has tested these activities in multiple middle and high school classrooms. Our research has shown the activities to be effective in learning both content and skills, and our partner teachers report that students enjoy the activities. These activities are freely available for teachers to use. We hope that you and your students will also find them to be effective and enjoyable approaches to learning about complex and sometimes controversial socio-scientific issues within Earth Science.

MEL2 Co-PI and Guest Writer of this *Editor's Corner*,
Janelle M. Bailey

Twenty-Five Years Ago in TES

Twenty-Five years ago, in 1995, TES was in its twelfth year of publication. This cover photo features an image of a lightning poster produced by NOAA and available (at the time) at the National Severe Storms Laboratory in Norman, OK. The cover photo was very appropriate for this TES issue, as it was devoted to "Meteorology". The lead-off article was about Super Cells – nature's most violent storms. The next article explained how hurricanes were named. This was followed by a computer media review of "Sim City 2000". Next came a 7-page article dealing with how to understand the weather forecast. There was a 5-page article regarding lightning hazard education. The final inclusion was a 3-page survey to assess teachers' technological needs, including: "Do you use computers at school?", "Does your School have Internet?", and "Do you have a computer at home?" So many changes in just 25 years.



By Tom Ervin

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Earth Materials in the Spotlight

EARTH SCIENCE WEEK 2020

By Geoff Camphire

Earth Materials are essential to manufacturing, industry, transportation, food production, energy generation, and product recycling. Earth Science Week 2020 (www.earthsciweek.org) is celebrating the theme “Earth Materials in Our Lives” on Oct. 11-17 to focus on the many ways that Earth materials impact human beings and human activity. This theme offers a fascinating window into the interactions of the Earth systems of the geosphere, hydrosphere, atmosphere, and biosphere. Earth Science Week 2020 education resources include a host of new offerings, as well as opportunities and items that teachers have found engaging for students for decades.

The week-long celebration organized by the American Geosciences Institute (AGI) provides educational materials, activities, and opportunities for school audiences, including some new resources as well as many that program participants find useful year after year.



Latest Offerings

Earth Science Week’s Focus Days can help you find the ideal time to pursue your geoscience passion. Minerals Day is Oct. 12, 2020. AGI and the Mineralogical Society of America have collaborated to develop materials, organize outreach, and work with geoscience partners in government agencies, professional associations, private corporations, and other groups to promote public awareness and appreciation of minerals. See the Earth Science Week website for links to resources, events, and information (www.earthsciweek.org). On Tuesday, Oct. 13, Earth Observation Day allows students

and teachers to learn about remote sensing as a powerful educational tool. National Fossil Day promotes understanding of paleontology, mainly in schools, parks, and other sites across the country, on Wednesday, Oct. 14. Geologic Map Day boosts awareness of the importance of geologic mapping for education, science, business, and policy on Friday, Oct. 16.

The winning submission by Tonya Boone from the 2019 Earth Science Week Photography Contest. Participants were invited to capture how people in their communities are “Exploring Earth Science.”



Science teachers and students are invited to check out the “Earth Materials Frontiers” webinar series by experts and scholars will cover topics such as raw materials, new technologies, social responsibility, and economic ramifications. Find details online close to Earth Science Week.

AGI, Lyda Hill

Philanthropies (LHP), and *Nautilus* magazine are inspiring girls and women in STEM (science, technology, engineering, and math) with the IF/THEN® initiative. The new Geoscience Women in STEM website supports geoscience education through exploration of the stories of four pioneering women scientists and engineers. AGI debuted the website with an NGSS-ESS Working Group webinar, “Promoting Diversity in the Geosciences: Meet the Geoscience Women in STEM.” The webinar is available online.

Global Sponsorship has been introduced this year to support the development, collaboration, and public projection of awareness of the role of Earth materials in society. Global Sponsors – the International Raw Materials Observatory, Newmont Corporation, ExxonMobil, and the American Association of Petroleum Geologists Foundation – join the ranks of longtime supporters such as NASA, the U.S. Geological Survey, the Geological Society of America, and the American Geophysical Union.

Copies of the Earth Science Week 2020 Toolkit are free and available for the cost of shipping and handling. This year’s toolkit includes dozens of items, such as the Earth Science Activity Calendar, a wall calendar that features a variety of educational activities throughout the academic year and beyond. The calendar provides a great way explore the celebration of “Earth Materials in Our Lives” all year long. (To receive the toolkit, order at www.earthsciweek.org.)

Compete for Earth Science Week Prizes

Who can participate? Any person of any age. Join in the fun by entering – or helping a young person to enter – one of the program’s contests in visual arts, essay writing, video production, and photography.

- “Earth Materials in My Community” photo contest entries must be composed of original, unpublished material, and show someone in the entrant’s own community exploring geoscience.
- “Earth Materials and Me,” visual arts contest is open to students in kindergarten through grade five. Essays by older students must address the idea of “How We Process Earth Materials.”



Photo credit: Jim Di Loreto from a National Fossil Day event during Earth Science Week in partnership with the National Park Service.

The Earth Scientist

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- People of all ages can enter the “Earth Materials Around the World” video contest by submitting a brief video that shows how Earth materials play various roles for people from a wide range of places.

Each contest winner receives a prize of \$300 and a copy of an AGI publication. Each winning entry will be featured on the Earth Science Week website. For all contests, entries may be submitted up to the Friday of Earth Science Week, October 16, 2020.

Make an Impact

Teachers can connect students with many fascinating facets of geoscience — including Earth materials — through activities detailed online. The Earth Science Week website (www.earthsciweek.org) offers curriculum connections that concentrate on the Next Generation Science Standards in Earth and Space Science (NGSS-ESS) and illustrate ways that STEM topics can be investigated across traditional disciplinary boundaries and in the context of students’ experiences. The collection of more than 120 learning activities can be searched by grade level, science education standard, and topic and many activities can be conducted safely by students at home.

Educators can also explore resources inspired by previous years’ themes. “Geoscience Is for Everyone,” the 2019 theme, has Diversity, Equity, and Inclusion Strategies. 2016’s “Our Shared Geoh heritage” theme has downloadable reports, articles, blogs, location profiles, and learning activities relating to geoh heritage. The “Visualizing Earth Systems” theme of 2015 offers dozens of visualizations on topics such as energy, climate, minerals, water, and hazards.

Millions of people learn about geoscience each year thanks to the information, materials, activities, and online coverage of Earth Science Week. As an Earth science teacher, you have a vital role to play!



*Every Week is
Earth Science Week!*

In this issue you will find a copy of the poster celebrating AGI's 2020 Earth Science Week which will be held October 11-17 in 2020. The theme is “Earth Materials in Our Lives” exploring the relationship between Earth materials and people. The theme promotes public understanding of geoscience and stewardship of the planet, especially in terms of these raw materials.

NESTA supports and promotes Earth Science Week. Each year we create a Teaching Resources collection around the theme and hold our annual members meeting at the end of the week (https://serc.carleton.edu/nesta/resources/earth_science_week_2019.html).

The 2020 theme for Earth Science is “Earth Materials in Our Lives”. You can order this year’s Earth Science Week Toolkit for just the cost of shipping. (<https://store.americangeosciences.org/catalog/product/view/id/207/s/2019-earth-science-week-toolkit-geoscience-is-for-everyone-1/>).

Join us this fall as we celebrate Earth Science Week, but remember, at NESTA every week is Earth Science Week!



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

Janelle M. Bailey, Timothy G. Klavon, Archana Dobaria
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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.

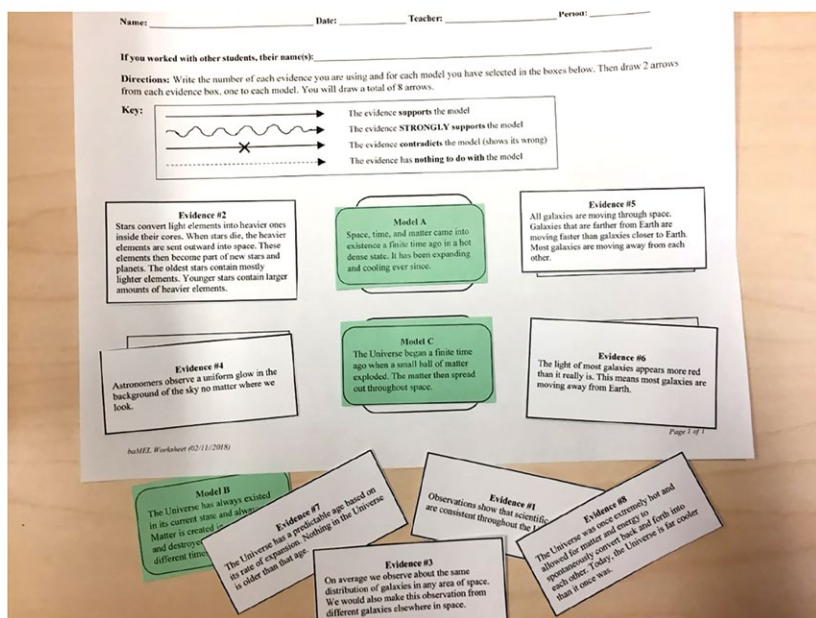
Our research has shown that the MEL activities help students construct better understanding of the scientific models and evidence for (and against) them as well as demonstrate improved evaluation skills in the topics covered (Lombardi et al., 2013, 2018a,b, this issue; Saribaş et al. 2019). But transfer 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.

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).

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



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 model¹. 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).

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

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.

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.

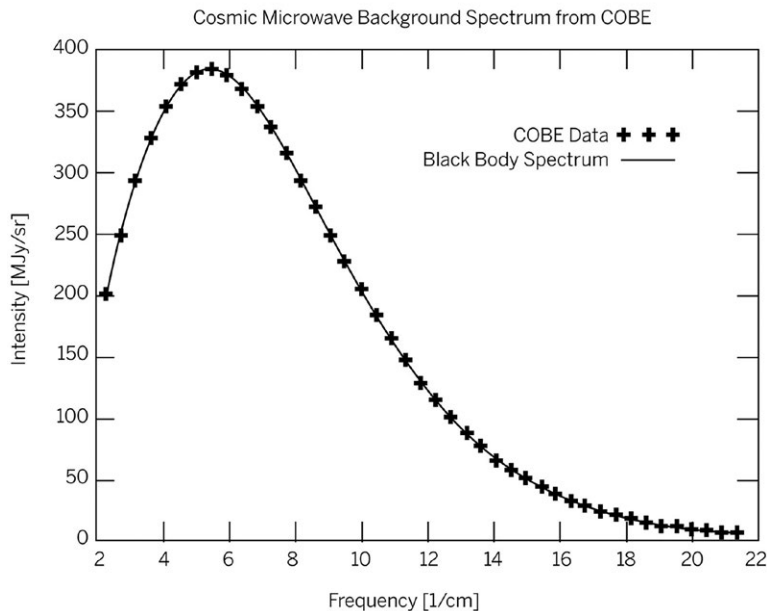


Figure 2. Relationship between the intensity of the cosmic microwave background and its frequency. Note: This graph is included in the Origins build-a-MEL's Evidence #5.

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.

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

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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Climate Changes of the Past: Engaging in Evidence-Based Argumentation

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Abstract

Our Earth's climate is dynamic and ever changing. The fossil record provides evidence of early organisms and information about climate changes of the past. By exploring evidence of variations in the fossil record, students can better understand the issues related to climate change today. In the build-a-MEL activity described here, students are asked to evaluate different lines of evidence and make a judgement about how they connect to alternative explanatory models. Critical thinking skills are enhanced while students engage in a process of negotiation about the evidence, and students are hopefully better prepared to address the complexity of issues related to our current climate change situation from studying fossil evidence.

One of the most controversial topics today in science education is that of climate change. While the evidence is overwhelming that Earth's climate is changing as a result of human activities, there are still some who deny that climate change exists. If we want students to understand current issues associated with climate change, it is easiest to introduce the topic by exploring paleoclimatology—past changes in climate—and more importantly the lines of evidence that help us understand Earth's dynamic past and how its systems change and interact. By exploring fossil evidence, we can gain insight not only into Earth's past, but provide a foundation for understanding current shifts in Earth's climate and the evidence that supports the science.

We have created the Fossils build-a-MEL to scaffold students' understanding of how fossils can provide evidence for the past and to support their development in argumentation skills. The activity follows a similar approach as the Model-Evidence Link (MEL) diagram scaffold (Lombardi, 2016) and other build-a-MELs (baMELs; see other articles in this issue).

Support the Standards with the Fossils build-a-MEL

Exploring paleoclimate with fossil evidence crosses disciplinary boundaries in science. Understanding past life forms and what they tell us about the climates they lived in can be studied through different disciplines. In life science, adaptations that help organisms thrive in specific ecosystems provide explanatory evidence to understanding the connections between life and climate. The relationship between past life forms and their environments can be approached through exploring the cross-cutting concept of structure and function. For example, the process of leaf-margin analysis provides information about past climates from leaf fossils because in cooler environments leaves often have more toothed edges, allowing an increased surface area for photosynthesis. In warmer climates, there is no need for such an adaptation as there is ample yearly

Table 1. High School NGSS Standards in Life Science for Fossils build-a-MEL

LS4-6: Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity.

Science and Engineering Practices	Disciplinary Core Idea	Cross-Cutting Concepts
<ul style="list-style-type: none"> Analyzing & Interpreting Data Engaging in Argument from Evidence 	LS4.c: Adaptation <ul style="list-style-type: none"> Changes in the physical environment, whether naturally occurring or human induced, have thus contributed to the expansion of some species, the emergence of new distinct species as populations diverge under different conditions, and the decline and sometimes the extinction of some species. 	<ul style="list-style-type: none"> Cause & Effect Stability & Change

Table 2. High School NGSS Standards in Earth Science for Fossils build-a-MEL

ESS2-7: Construct an argument based on evidence about the simultaneous coevolution of Earth's system and life on Earth.

Science and Engineering Practices	Disciplinary Core Idea	Cross-Cutting Concepts
<ul style="list-style-type: none"> Analyzing & Interpreting Data Engaging in Argument from Evidence 	ESS2.e: Biogeology <ul style="list-style-type: none"> The many dynamic and delicate feedbacks between the biosphere and other Earth systems cause a continual co-evolution of Earth's surface and the life that exists on it. 	<ul style="list-style-type: none"> Cause & Effect Stability & Change

tell us about climate change in the past (see Table 2).

The activity described below is well grounded in three-dimensional instruction; each content standard is matched with the appropriate cross-cutting concepts and science practices that should be emphasized. The two cross-cutting concepts of *cause and effect* and *stability and change* are critical components of the activity as students consider the evidence that fossils provide for past climate change. Additionally, specific science practices are interwoven. These include *analyzing and interpreting data*, which is an important component of all MEL activities, and *engaging in argument from evidence*, a critical practice for students as they negotiate the connections between evidence and alternative explanatory models.

The main activity in this, or any, build-a-MEL (baMEL) is for students to engage in the scientific practice of constructing arguments from evidence. The MEL and baMEL activities, such as the

Fossils baMEL, provide both the scaffold and the opportunity for negotiation that can be instrumental in building these skills as students work in small groups throughout the activity.

Table 3. Models for the Fossils build-a-MEL

Model	Statement
Model A	When people interpret fossils, they often make mistakes. It is misleading to make conclusions about how Earth's surface has changed from fossils.
Model B	Many organisms' fossils are missing from the fossil record. We cannot make any conclusions about Earth's past environments from fossils.
Model C	Fossils provide evidence for Earth's changing surface. Understanding past life forms tells us about past environments.

Selecting the Models and Evidence

In the Fossils baMEL activity, students start by reviewing three potential scientific explanations that connect fossils to their environment. These are shown in Table 3. Individually, students first rate the plausibility of each model, then must agree on which two models to choose for the activity. Sometimes students choose the

sunlight. By studying changes in the ratio of toothed to smooth edges in leaf fossils, scientists can understand how environments have changed over time, depending on the strata in which leaf fossils have been found. NGSS standards for high school life science related to adaptations can be explored by discussing fossils as evidence of past climates, and how changes in the environment result in populations of different organisms, each uniquely adapted to survive in specific ecosystems (see Table 1; NGSS Lead States, 2013).

Paleoclimatology is also an important concept in the NGSS standards for Earth science as students explore system interactions. The fossil record provides us with a treasure trove of evidence for continental drift, as well as how environments in which fossils are found have changed. For example, fossils of tropical plants are often found in taiga biomes, indicating a warmer past environment. NGSS high school standards in Earth Systems can be explored when examining the types of fossils found in layers of sedimentary rock and inferring what they

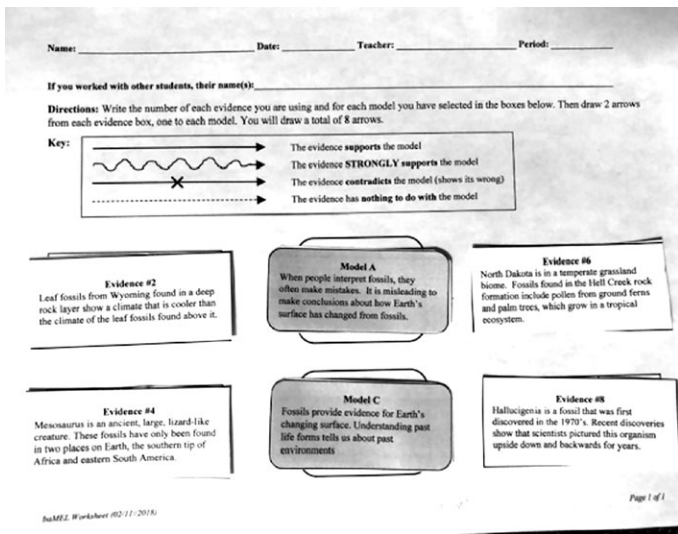


Figure 1. Fossil baMEL Diagram with Model and Evidence Cards

models based on which ones they think are most plausible, other times on those they think are most interesting. Once a decision is made, students select cards based on their choice of models and place them in the center of their MEL diagram handout for reference throughout the activity (Figure 1).

After choosing models to compare, students are presented with eight evidence texts, four of which will be used for the MEL diagram in the activity. These lines of evidence include several examples of fossils found in different locations, and provide information about past environments that are different from current conditions where the fossils were found. Depending on the models selected, different lines of evidence may or may not be relevant. The eight different lines of evidence are summarized in Table 4.

With so many lines of evidence to consider, students occasionally get overwhelmed. Therefore, it may be helpful to present the evidence pieces one at a time so that students can become familiar with each text. It is important that all students can evaluate and discuss the relationship of each line of evidence to each of the two chosen competing explanatory models. Start by presenting each piece separately, projecting a visual for each evidence text and have a conversation, either in small or large groups, to discuss what each means. One strategy for making it easy for students to work with these texts is to slip each into a plastic sheet protector so that students can mark important phrases or make notes with a Vis-à-vis pen (see Figure 2). Make sure students understand the terms used and have a chance to engage with the graphics provided. Many students report that they find the lines of evidence with data tables and graphs to be the most important, because they feel this type of support “quantifies” the information and is the most valid for supporting claims. For example, students have reported that maps used in several of the explanation texts provide a visual representation that can help support their claims with greater certainty and will often find those evidence texts the most compelling.

Table 4. Lines of Evidence for Fossils build-a-MEL

Evidence	Statement
Evidence #1	Trilobites were small animals that lived at the bottom of the ocean. They fed on organic matter in sediment on the ocean floor. Because trilobite fossils are so abundant and well preserved in the limestone and shale rock of Ohio, they were officially named the state fossil.
Evidence #2	Leaf fossils from Wyoming found in a deep rock layer show a climate that is cooler than that of the fossils found above it.
Evidence #3	The Svalbard forest in Arctic Norway is filled with fossils of tropical trees, called Lycopsid. These trees lived hundreds of millions of years ago.
Evidence #4	Mesosaurus is an ancient, large, lizard-like creature. These fossils have only been found in two places on Earth, the southern tip of Africa and eastern South America.
Evidence #5	Fossils of coral reefs have been found in deep water off the coast of Texas. Coral reefs require sunlight to form. Sunlight cannot reach deep water. These coral reefs are about 19,000 years old.
Evidence #6	North Dakota is in a temperate grassland biome. Fossils found in the Hell Creek rock formation include pollen from ground ferns and palm trees, which grow in a tropical ecosystem.
Evidence #7	Many large geographic areas, like the Blue Ridge and Piedmont regions in Georgia, are made up of metamorphic and igneous rock. Fossils are not usually found in these types of rock.
Evidence #8	Hallucigenia is a fossil that was first discovered in the 1970's. Recent discoveries show that scientists pictured this organism upside down and backwards for years.

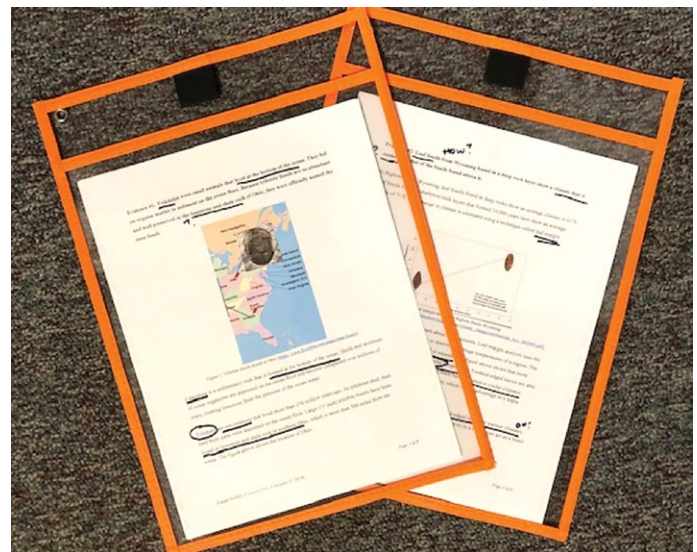


Figure 2. Marking up the Evidence Text

Negotiation and Argumentation

After students have reviewed all eight evidence texts, they are now in a position to decide which four to use for the MEL task. This is where argumentation and negotiation begin. Allow students time to debate the lines of evidence in their groups to decide which are most interesting, relevant, or important for evaluating the models they have chosen. It is important that they come to a consensus about all four pieces of evidence to use, rather than each choosing a different text, to stimulate discussion. Once the decision is made, students should select the corresponding cards for those four lines of evidence and add them to their MEL diagram handout (Figure 1).

Now that the stage is set, students are ready to do the real work of the activity: negotiating the relationship between the four lines of evidence they have selected and the two competing models. Students must decide if each line of evidence supports, strongly supports, contradicts, or has nothing to do with each of the two models. This decision should be a group one, requiring students to negotiate and debate their decisions. For example, in one class students had the following conversation when discussing the relationship between Evidence 2 and Model C:

Student 1: What do you think?

Student 2: I think it strongly supports it.

Student 1: Why?

Student 2: Because of the strong quantitative evidence that things have changed.

Student 1: I agree with your statement.

In this exchange it is clear to see that a negotiation is occurring while one student makes a claim, and the other challenges it. Not all negotiations are this quick and easy. These same two students also had the following exchange while discussing another line of evidence:

Student 1: So, do you feel like evidence 2 supports or strongly supports Model C?

Student 2: I don't feel like any of them, well, this has nothing to do with what you just said but, I don't feel like it has anything to do with Model A.

In this exchange one student feels that the evidence supports the model but is unsure whether it “supports” or “strongly supports.” The second student provides a different perspective and provides a different choice. As this negotiation plays out, each student presents their claim, cites the evidence, and eventually agrees on a resolution. These types of negotiations not only help students develop the skills necessary for critical discourse, but also better understand the scientific claims and evidence presented in the activity.

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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Revisiting and Explaining the Models

The final part of any MEL or baMEL activity is to re-evaluate each of the scientific models, based on the evidence presented. Before students complete the task on the handout for the Explanation Task, you'll want to have a conversation with your students. Probe how each of the eight lines of evidence relates to each model and why. Regardless of which models and lines of evidence they selected, discuss all of the connections. While these conversations can be lengthy, it is important for students to hear about both the evidence texts they did and did not select, because other students may provide a compelling argument about an evidence-model connection. For example, students who evaluated Evidence 8 (Table 4) but not Model A (Table 3) might not see how these are connected; or for those who did evaluate this relationship, might mistake the nature of the evidence. It is worth

having an in-depth, whole class conversation about how science changes but that even when we get something wrong, it doesn't automatically mean that the explanation no longer works. Hearing from other students about the models and lines of evidence that they have not examined may influence their final plausibility rating for any of the three models, which is one of the last tasks of the activity. Of course, the nature of science tells us that no single scientist knows the full story, so stress the importance of collaboration and consensus in the scientific community.

Once students have considered the entire scope of the evidence presented, it is time for them to re-evaluate the plausibility of each model. In our experience, shifts in plausibility for the scientific model are usually largest and toward higher values, demonstrating that students are willing to accept that Earth's surface and climate are dynamic and ever-changing. Finally, ask students to explain one of the connections they made between models and evidence. Look to see if they are able to present a claim, support it with evidence, and explain the relationship. Encourage your students to hone their argumentation skills as they complete the Explanation Task.

Conclusion

There is no doubt that students must practice argumentation skills throughout this baMEL activity. Students are asked to make claims and justify the connections between fossil evidence of past climates and current scientific models that present Earth's climate as dynamic and ever-changing. As they review the fossil evidence that helps us understand past shifts in climate, they begin to build an understanding of how scientists know what they know and how they build support for explanatory models using evidence. Through making evidence-based claims, students participate in the scientific practice of argumentation and begin to see how scientists co-construct evidence-based explanations of scientific phenomena. If students can accept the premise that Earth's climate is constantly changing and understand how we know about past changes, then they are ready to discuss our current climate change situation and, hopefully, the reasons to be alarmed about the evidence and implications related to it.

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Freshwater Resources: The Challenges of Quantity and Quality

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Abstract

Freshwater resources are limited due to issues related to water quality and/or quantity. This article introduces a build-a-MEL that challenges students to address this socioscientific issue by considering the plausibility of three models: A) Earth has a shortage of freshwater, which will worsen as our world's population increases; B) Earth has a shortage of freshwater that can be met by engineering solutions; and C) Earth's freshwater is abundant and will remain so even in the face of global climate change. The eight lines of evidence in this build-a-MEL are data-rich and challenge students to think critically as they connect the evidence to the models. As a result of this activity, students develop an understanding of the spatial complexity of access to freshwater resources.

Since the publication of *A Framework for K-12 Science Education* (National Research Council, 2012, pp. 14 and 212), socioscientific topics have been brought up more often in science classes in general, and in Earth, environmental, and space science more specifically. When considering Earth and human interactions with the environment, human needs cannot be divorced from the science of natural resource management, climate change, and sustainability. However, when it comes to decision making around how we use our natural resources, scientific evidence plays the most important role in the decisions on how we, as humans, should interact with our Earth. An excellent example of a socioscientific issue worthy of consideration is that of freshwater resource management. This article describes an instructional model that challenges students as they grapple with competing viewpoints on this important issue.

Concerning Freshwater Resources

Water is essential for life; indeed, all ecosystems and organisms rely on water to function. Earth has a finite amount of freshwater to quench the needs of our growing population. Although we live on a water planet covered by more than 70% water, we find that nearly 97% of that water is in our oceans, rendering it close to unusable. Availability of freshwater is heavily dependent on the water cycle, which is influenced by global climate patterns.

Anthropogenic climate change is already impacting both the quantity and quality of Earth's water resources. Precipitation patterns are changing, and if there is no curtailing of greenhouse gas

emissions, then the intensity and frequency of these patterns will continue to change in ways that we cannot yet predict. The inevitable outcome will be a reallocation of water resources away from some locations leading to droughts, and into other locations, which could result in persistent flooding.

Another limitation on the availability of Earth's freshwater is an ever-increasing human population on our planet, especially in areas that are already stressed from the lack of easy access to potable water. As populations in urban areas increase, the need for water in those areas also increases. To get water to places with the greatest need, a costly infrastructure system is required to divert or extract water from one place and transport it to another. In addition, agriculture requires the greatest use of potable water for food production, which is expected to increase nearly 70% over the next 15-20 years as our world population increases.

A great deal of our water currently comes from aquifers. Although these aquifers can often extend great distances and depths, the water available in them is finite and the continuous use of this water can lead to issues such as ground subsidence or soil salinization. Therefore, access to groundwater should not serve as an invitation to populate regions where climates are typically very dry. The great quantity of water stored in aquifers can be easily depleted without proper management. Places where groundwater is extracted for agriculture have experienced ground subsidence caused by the loss of stability from over-extraction of water. This is another issue that will only get worse as our population increases across the planet.

Snow cover and glacier meltwater contribute to the supply of potable water for nearby communities, as well as those downstream from the flow of the meltwater. Despite climate change accelerating the loss of glacial mass and volume, this meltwater may only provide a short-term increase to the water supply. Even this supply of freshwater will eventually diminish as the glaciers continue to shrink and their meltwater becomes but a trickle. Snow cover in mountainous regions such as the Rockies has been unstable lately, as our climate has become more variable; this lack of snow cover translates into a decrease in freshwater supplies for the region and downstream the following year.

All the above challenges to water quantity and quality provide the basis for the Freshwater Resources build-a-MEL (baMEL), where students consider connections between eight lines of evidence and three models related to these challenges. The three competing models are: A) Earth has a shortage of freshwater, which will worsen as our world's population increases; B) Earth has a shortage of freshwater that can be met by engineering solutions; and C) Earth's freshwater is abundant and will remain so even in the face of global climate change. During this activity, students evaluate how eight lines of evidence connect to the three models to determine which model aligns with current scientific consensus. Three evidence statements (#1, 2, and 3) and associated texts lead students to consider the effects of land use changes brought about by global population increases. With surging numbers of people living in already stressed regions on our planet, the amount of freshwater (both groundwater and surface water) is severely compromised and being used at a rate faster than local or regional recharge allows. Two lines of evidence (#4 and 5) are related to engineering solutions for water quantity and quality, and the final lines of evidence (#6, 7, and 8) reflect the issues climate change is having on our regional and global water supply.

Build-a-MEL Implementation

The content of this baMEL connects with *Next Generation Science Standards* (NGSS) performance expectations from ESS2 - Earth's Systems and ESS3 - Earth and Human Activity in middle school and high school (see Table 1; NGSS Lead States, 2013). Moreover, the content is a natural fit for AP Environmental Science (Unit 5, Land and Water Use), physical geography, and introductory college level science and socioscientific courses.

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>.

The National Science Foundation (NSF), under Grant Nos. 1721041 and 2027376, supported some of the research and development described herein. Any opinions, findings, conclusions, or recommendations expressed are those of the author(s) and do not necessarily reflect the NSF's views.

Table 1. Next Generation Science Standards (NGSS) Performance Expectations (PE) Related to the Freshwater Resources Build-a-MEL

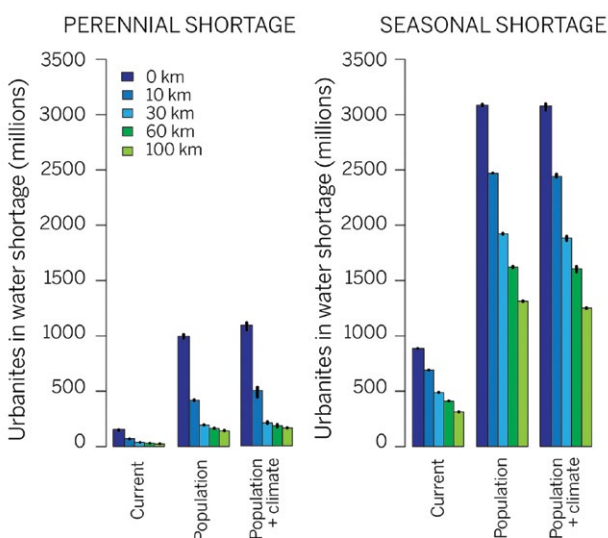
PE Code	PE Description
MS-ESS2-4	Develop a model to describe the cycling of water through Earth's systems driven by energy from the sun and the force of gravity.
MS-ESS3-1	Construct a scientific explanation based on evidence for how the uneven distributions of Earth's mineral, energy, and groundwater resources are the result of past and current geoscience processes.
MS-ESS3-3	Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.
HS-ESS2-2	Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems.
HS-ESS3-1	Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.

As with the previously developed MELs (see Bailey et al., this issue, and the Spring 2016 issue of *The Earth Scientist*), implementation of baMELs can vary from one class to another depending on the goals of instruction. There is quite a bit of flexibility in how baMELs are embedded in a course and how they are orchestrated within a class. They may be incorporated into the introduction of a new unit, challenge students in the middle of an instructional sequence with new ideas for a topic they are learning, or used as part of a summative assessment activity to check for understanding.

When implementing a baMEL in class, ideally students should have the ability to select two of the three models and four of the eight lines of evidence after surveying the evidence text for each line of evidence. Arguments for the selections students make may be based on a variety of reasons, such as the comparability between two of the models or how data is presented or interpreted in the evidence text. Another instructional option that is not recommended is for the teacher to preselect the scientific model, and allow students the freedom to select the

second model from the remaining two. Modifying the activity in this manner would ensure there is a student voice in the selection process and that the scientific consensus model is included. However, the results of the activity may not provide the formative assessment information a teacher needs to check for understanding of the topic. Finally, to simplify the activity another suggestion for implementation is to have the teacher select the two models and narrow the options for the lines of evidence to fewer than the eight provided. By limiting the activity to four lines of evidence instead of the eight, the baMEL is converted to a MEL activity. However, with this implementation model, the opportunity for rich student discourse around the choice of models and lines of evidence is limited.

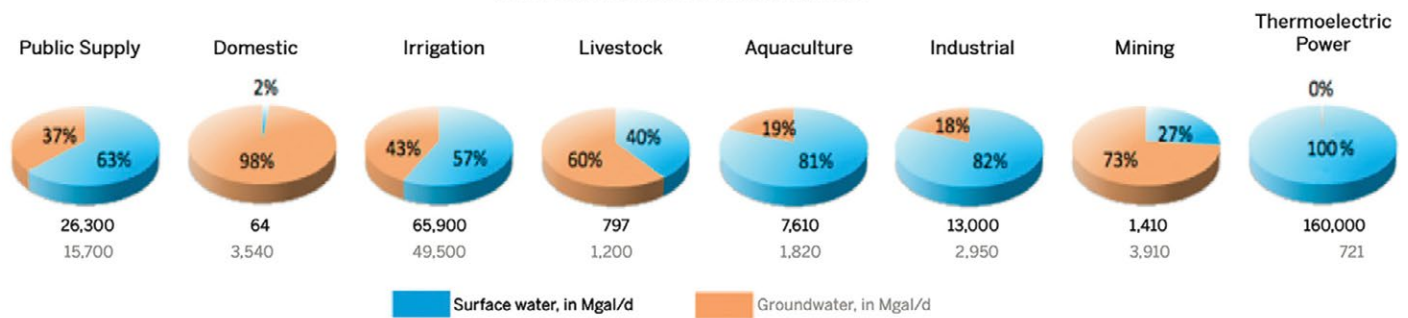
Figure 1. This figure from the text for Evidence #2 shows urban populations with either yearly on the left, or seasonal water shortages on the right. The bars show different distances from urban areas, and take into account current conditions, with an increase in population, and an increase in population coupled with climate change.



Scientists in the fields of Earth and space science employ a variety of data representations and figures in their work, and this baMEL includes a variety as well. The types of data and figures presented in the evidence texts of the Freshwater Resources baMEL may be new to students who are typically used to analyzing data in graphical forms only. Therefore, we suggest that you take time to

discuss and interpret the data and figures in each evidence text. For example, the bar charts in Evidence #2 (Figure 1), or the coupling of the data in the pie charts with the multi-line graph in Evidence #3 (Figure 2), may not be as straightforward as they appear, and taking time to assist students may result in an improved instructional experience when engaging in a baMEL activity. One way to support students in their interpretation of the data and figures is to use the pedagogical tool called *Identify and Interpret (I²) Strategy* (BSCS, 2012). In it, students first identify three “what I see” components of the figure, then determine “what it means” for each graphic, and finally craft a caption about the figure. Since there are eight lines of evidence, using a “jigsaw” approach may reduce the need to have all students perform this strategy for each figure. Learning how to interpret the charts and graphs embedded into the MEL or baMEL evidence texts is a necessary skill that will carry over to other science activities.

TOTAL WATER WITHDRAWALS, 2010



Closing

Access to freshwater resources has been in the public eye quite a bit lately as communities wrestle with contaminated water and droughts. When students feel connected to the content either personally or peripherally, they enjoy working through socioscientific issues such as this one. By considering various models and data-rich lines of evidence, students develop an awareness of the vast reach of this issue, and therefore are empowered to consider viable solutions for better use of Earth's natural resources (Medrano et al., 2020).

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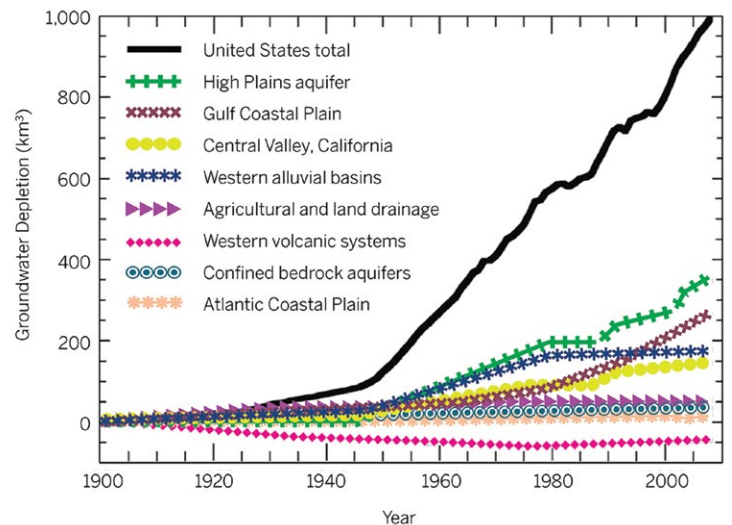


Figure 2. These figures from the text of Evidence #3 are combined to connect groundwater uses and rate of usage.

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Extreme Weather Events and the Climate Crisis: What is the Connection?

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Abstract

Students face many challenges that are connected to the scientific enterprise, such as the increasing frequency of extreme weather events (e.g., prolonged periods of drought, record temperatures, severe precipitation episodes). Recent scientific consensus has attributed increases in such events to the current climate crisis caused by human activities. The potential relation between extreme weather and current climate change characterizes why these phenomena may be complex, and understanding both the distinctions and relations between weather and climate is essential for reasoning about such phenomena. To help students in this regard, we have designed the Extreme Weather build-a-MEL, where they evaluate the connections between lines of evidence and alternative explanations. The build-a-MEL helps increase students' agency (i.e., to intentionally make things happen through actions). And with increased agency, students are able to construct knowledge about weather and climate through engagement in scientific practices, with alignment to the *Next Generation Science Standards*.

Students are often confused about the difference between weather and climate. For example, students may think that short-term weather trends indicate long-term climate patterns (Lombardi & Sinatra, 2012). Adults may also share this confusion about weather and climate differences. During a 2010 blizzard in the Washington D.C. area, some politicians used this extreme snowfall event as evidence supporting the nonscientific notion that climate change is a hoax. However, a single weather event, such as this blizzard, is not an indicator—in and of itself—of current climate change. Students' and adults' confusion about the distinctions between weather and climate may point toward the need for increased climate science literacy. A report by the U.S. Global Change Research Program (USGCRP) said, among other things, that “a climate-literate person (a) understands the essential principles of Earth's climate system and (b) knows how to assess scientifically credible information about climate” (USGCRP, 2009, p. 4). The report specifically points out that “Climate is not the same thing as weather. Weather is the minute-by-minute variable condition of the atmosphere on a local scale. Climate is a conceptual description of an area's average weather conditions and the extent to which those conditions vary over long time intervals” (USGCRP, 2009, p. 13). And yet, the idea of climate as simple “average weather conditions” may also contribute to misunderstanding between weather and climate.

Climate conditions are more precisely established by statistical trends in weather conditions and other factors (e.g., extremes such as record maxima and minima temperatures and precipitation in addition to averages). Climate is also characterized by considering these statistical trends over relatively long periods of time in a given region. The U.S. National Oceanic and Atmospheric Administration (NOAA) says that “climate normals” reflect averages of precipitation, temperature, humidity, sunshine, wind, and other measures of weather that occur over a 30-year period (NOAA, 2018). Scientists also use extreme temperature and precipitation events, as well as droughts and frequency of very severe events (e.g., tornadoes, hurricanes), to characterize an area’s climate. Thus, climate represents a wide variety of weather-related statistics that involve different phenomena over relatively long time scales, whereas weather involves short duration (minutes, hours, days, and months) atmospheric events at a particular location (Lombardi & Sinatra, 2012).

Because of both statistical and scientific complexities, learning about the differences between weather and climate may be difficult for students. Instructional scaffolds that help students with these various complexities, however, may facilitate their learning. This article discusses the use of a Model-Evidence Link (MEL) scaffold, which we developed around the concept of extreme weather events and potential relations to the current climate crisis. We have specifically designed this MEL scaffold to help students evaluate the connections between lines of scientific evidence and alternative explanations about the extreme weather phenomena. Table 1 shows how this extreme weather instructional scaffold is well-aligned with some Performance Expectations (PEs) found in the *Next Generation Science Standards* (NGSS Lead States, 2013).

Table 1. Next Generation Science Standards (NGSS) Performance Expectations (PE) Related to the Extreme Weather Build-a-MEL

PE Code	PE Description
MS-ESS3-2	Analyze and interpret data on natural hazards to forecast future catastrophic events and inform the development of technologies to mitigate their effects.
HS-ESS2-4	Use a model to describe how variations in the flow of energy into and out of Earth systems result in changes in climate.

The Design Behind the Scaffold

The MEL scaffold incorporates a series of activities focused around a central socio-scientific topic, such as extreme weather events. The MEL helps students evaluate connections between lines of scientific evidence with alternative and competing explanations (Bailey et al., this issue; Lombardi, 2016). In a series of classroom-based experiments, we have seen meaningful shifts in students’ judgments toward a more scientific stance, as well as increased understanding about complex socio-scientific topics (e.g., causes of current climate change and value of wetlands to ecosystem services) when high school students use the MEL scaffolds (Lombardi et al., 2018a,b). The current project, supported by the U.S. National Science Foundation, is trying to optimize the instructional effectiveness of the MEL by promoting increased student agency (i.e., where the student has more autonomy and choice in the learning process). To promote greater agency, we have developed enhanced MEL scaffolds in the current project, which we call the build-a-MEL. Students construct their own diagrammatic scaffolds in the build-a-MEL by selecting four evidence lines from eight choices and two alternative explanatory models from three choices. Students then evaluate the connections between their selected lines of evidence and alternative explanatory models after constructing the diagrams. Finally, they reflect on their reasoning and judgments about these connections in written tasks (see Bailey et al., this issue, for more details).

Extreme Weather Phenomena

The Extreme Weather build-a-MEL presents eight major lines of scientific evidence about various weather-related events, including but not limited to occurrences of record rainfall in the U.S. during the 20th century, increases in North Atlantic tropical storm power intensity since 1970, and record European snowfall over the past decade. Some lines of evidence include multiple weather

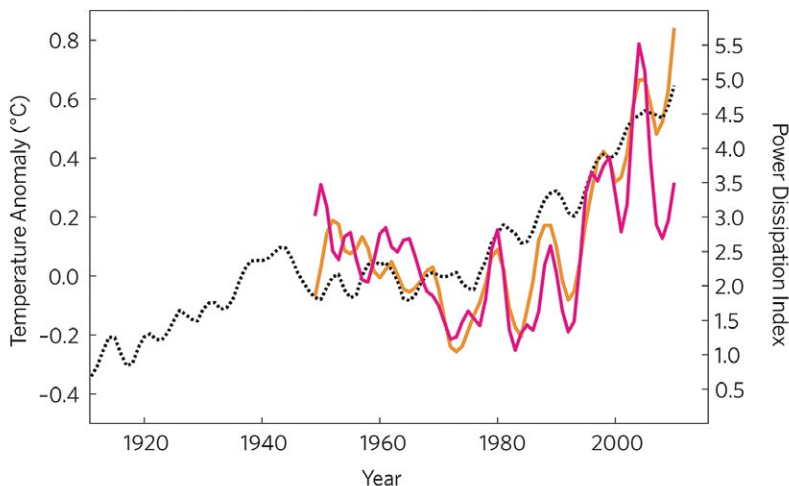


Figure 1. Relations Between Atlantic Tropical Storm Cumulative Annual Intensity (as Power Dissipation Index) and Atlantic Sea-Surface Temperatures

Note. The solid orange line shows ocean temperature anomalies in the Atlantic. Anomalies are things that differ from the “normal” or average conditions. “0” on the left axis represents that average. It is the long-term, global, average, ocean temperature between 1910 and 2010 in the Atlantic. The solid red line shows the power dissipation index (PDI) for tropical cyclones in the Atlantic. The PDI measures the amount of energy a storm releases. The PDI of a storm depends on its strength, how long it lasts, and how often it occurs and reflects the total destructive power in all tropical cyclones for a year. The dotted line represents global average (land and sea) temperatures.

Table 2. Models and Lines of Evidence in the Extreme Weather Build-a-MEL

Model	Statement
Model A [non-scientific consensus]	The number and strength of extreme weather events vary naturally. Human activities release carbon in the atmosphere. Yet, plants and oceans absorb any carbon increases.
Model B [scientific consensus]	Increases in extreme weather events are linked to climate change. Current climate change is mainly caused by human activities, such as fossil fuel use.
Model C [non-scientific consensus]	Over time, increases and decreases in extreme weather events are mainly caused by changes in Earth’s orbit around the Sun.
Evidence	Statement
Evidence #1	Since 1950, Earth’s atmosphere and oceans have changed. The amount of carbon released to the atmosphere has risen. Dissolved carbon in the ocean has also risen. More carbon has increased ocean acidity and coral bleaching.
Evidence #2	From 1910 to 1995, record rainfall events increased across the United States. Over the same time period, there was a sharp increase in the amount of carbon released to the air. Much of this carbon comes from fossil fuel use.
Evidence #3	Ocean sea surface temperatures have increased since about 1970. In the North Atlantic, tropical storm power has also increased over this same time period. A storm’s power depends on its strength and how long it lasts.
Evidence #4	Since 2000, there have been more intense, extreme, weather events around the world. Record rainfall fell in Europe. The southeastern United States had the most active month of tornadoes. The decade from 2000 to 2010 was the warmest ever during the past 1000 years.
Evidence #5	Frequency and size of large wildfires have increased in the Western U.S. since 1970. Average spring and summer temperatures have also risen in the Western U.S. during this time.
Evidence #6	In the last 100 years, global temperatures have increased. In that same time period, heavy precipitation events have also increased.
Evidence #7	Arctic Ocean sea ice extent has declined, with the Arctic warming at a pace two to three times the planet’s average. Over the last decade, record cold temperatures and snowfall have occurred in Europe and Asia.
Evidence #8	Earth’s orbit is elliptical. But, the shape of the ellipse is almost a perfect circle. In the Northern Hemisphere, Earth is slightly closer to the Sun in winter than in summer.

conditions that relate to one specific phenomenon, such as the increase in frequency and size of Western U.S. wildfires since 1970 (see Table 2 for the evidence statements). Such wildfire events are associated with drought, high wind, and/or high temperature events. We synthesized these and other lines of evidence based on results from well-regarded scientific journals (e.g., *The Bulletin of the American Meteorological Society* and *Nature*). For each line of evidence, we developed one-page evidence texts at the high school reading level. These texts often present data in graphical or tabular format (see Figure 1, taken from Evidence #3). We designed the evidence texts to have clear, declarative, and focused statements to facilitate students’ comprehension.

Alternative Explanations about the Extreme Weather Phenomenon

The Extreme Weather build-a-MEL also presents students with three alternative explanatory models that relate to these lines of evidence (see Table 2 for the three models). Each explanatory model provides an alternative and conflicting explanation for increases in extreme weather events over the last 50 years. These events include intense hurricanes, heavier rainfall and flooding, dangerous wildfires, and heat waves. One of the three models that students consider is the scientific consensus explanation (i.e., increased occurrences of extreme weather events are caused by human-induced climate change, i.e., the climate crisis; Schiermeier, 2018). The other two models are compelling, but non-scientific explanations, with one saying that (a) the frequency of extreme weather events cannot be linked to human activities because plants and oceans are absorbing

carbon emissions, and the other saying that (b) the intensity of extreme weather events ebbs and flows naturally due to long-term changes in Earth's orbit around the Sun.

We encourage teachers not to tell the students which is the scientific consensus when introducing these three alternative explanatory models at the beginning of the instructional activity. Some students may have prior knowledge about one of the alternatives. The purpose of the build-a-MEL activity is to activate this prior knowledge in a way that promotes meaningful knowledge construction. Therefore, telling students at the beginning of the activity what the scientific consensus model is could reduce their willingness to be active agents of their learning. Conversely, we also suggest that at the end of the activities, teachers are very clear about which explanatory model is the scientific consensus. We do caution that, although the scaffold is designed to facilitate students' shifting toward the scientific consensus explanation, other individual factors may prevent students from full acceptance. Therefore, we do not consider the build-a-MEL to be a "silver bullet" lesson, but rather one in a series of activities that teachers could use in a unit covering weather and climate.

Results from Initial Pilot Testing

Our multi-year project has been developing the build-a-MELs using a process of design-based research. Teachers are heavily involved in this process, both in the research design and in the testing of the build-a-MEL materials. During the project's second year, we conducted pilot tests of the freshly developed build-a-MEL materials, including the Extreme Weather build-a-MEL, in several middle and high school classrooms. The pilot tests have yielded some interesting results when comparing the build-a-MEL scaffold (in general) to our previous scaffold version that is pre-constructed for the students. In comparison to this pre-constructed version, the build-a-MEL scaffolds resulted in students being more evaluative with greater shifts in judgments toward thinking that the scientific explanation was more plausible than the alternative. Further, students learned even more about the topic. When specifically comparing the Extreme Weather build-a-MEL to the pre-constructed Climate Change MEL, the pilot tests showed a marked shift in plausibility toward the scientific explanation (~20% greater shift than the pre-constructed Climate Change MEL) and comparable shifts in understanding (~8% increase in knowledge for both the Extreme Weather build-a-MEL and Climate Change MEL). We consider this knowledge increase to be meaningful for classroom instruction because both the MEL and build-a-MEL are relatively short duration activities, taking about 90 minutes of total class time each.

Teachers involved in our pilot test of the Extreme Weather build-a-MEL commented that students enjoyed this activity because they felt it was relevant and they enjoyed debating about the current climate crisis as they worked in collaborative groups. The teachers suggested presenting lines of evidence one piece at a time, and to specifically show evidence text figures (e.g., graphs, charts, pictures) on the projector. The teachers also suggested to remind students to consider the lines of evidence fully as they reflect on the evaluations of the connections between evidence and explanation in the final written task.

Even though we are encouraged by our initial pilot test results, we are revising and further testing the Extreme Weather build-a-MEL, as well as the other three build-a-MELs (see the other articles in this issue). In our continued development process, we consult our project's advisory board, which includes well-respected geoscientists. We also include master teachers who ensure that our materials are classroom-ready. All of the project materials, including assessment rubrics, teachers' guides, and professional development handouts, are freely available on the MEL project website (see Sidebar).

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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Concluding Thoughts

Challenges facing today's society require citizens to be scientifically literate, which includes knowing the big ideas of science and knowing how scientists construct these big ideas. Extreme weather events are one of the many challenges that our society faces, with such events affecting our local and regional communities. Additionally, the connection between increased occurrence of extreme weather and the human-induced climate crisis has now been well-established via rigorous scientific investigation and research. Thus, to be fully equipped to face future challenges, students need to deepen their climate science literacy by understanding situations where weather and climate events are distinct and directly related. The Extreme Weather build-a-MEL is an instructional scaffold that aims to help students develop scientific literacy in this area by more critically connecting how well lines of evidence support alternative explanations about these phenomena (e.g., increased frequency of severe storms, stronger rainfall episodes, and prolonged periods of drought). In gauging connections between evidence and explanations, and also promoting shifts in judgments toward a more scientific stance, the Extreme Weather build-a-MEL engages students in the process of reasoned evaluation that underpins many scientific practices (Ford, 2015). And by promoting agency to be more scientific in the process of knowledge construction, we hope that the Extreme Weather build-a-MEL will help students, in part, to be better problem solvers in their communities.

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Assessing and Applying Students' Understanding of the Scientific Practices and Crosscutting Concepts

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Abstract

The Model-Evidence-Link (MEL) and build-a MEL (baMEL) tasks are designed to engage students in scientific practices, including argumentation and critical thinking. We designed a rubric for teachers to assess the various practices and skills students use while completing a MEL or baMEL, based on several NGSS Science and Engineering Practices (SEPs) and Cross Cutting Concepts (CCCs). When applying this rubric, we suggest that teachers only focus on student performance with respect to one SEP or CCC each time they implement a MEL or baMEL. We also developed a transfer task to ascertain how well students are able to perform MEL-related thinking skills, such as identifying a scientific model and alternative (but non-scientific) models, lines of evidence, and plausibility of knowledge claims, in a grade-appropriate scientific journal article. The near-transfer activity can help teachers gauge how well students apply their MEL/baMEL skills and can improve students' scientific literacy.

Scientists routinely debate and critique data, evidence, hypotheses, and theories. Argumentation is a vital process of reasoned debate and critique, reflecting many of the scientific practices (e.g., analyzing and interpreting data). This regular and ongoing process of evaluation of evidence, models, and theories, as well as the use of data collected during investigations, is a practice that science teachers can incorporate into their pedagogy and curriculum. Teachers can provide opportunities for students to develop critiquing skills and the ability to use evidence from various data sources and engage in true scientific inquiry (Faize, Husain, & Nisar, 2017; Richmond, 2018). This offers students a chance to evaluate different, and perhaps competing, explanations or models about a particular phenomenon. The Model-Evidence-Link (MEL) and build-a-MEL (baMEL) activities facilitate students' reasoning about the connections between lines of evidence and alternative explanations, and help students make judgments about which explanation is more scientific (i.e., more plausible). The MEL model also allows students to explain why an individual model may be implausible. When this occurs, there is a great chance that true learning has happened, and that students have a more secure understanding of a scientific concept (Larrain, Howe, & Freire, 2018; Lombardi et al., 2016). Such positive affect may increase self-efficacy, motivation, and productive attitudes toward learning (Arthurs & Templeton, 2009; Berg, 2014; Brewster, Kramer, & O'Brien, 2009; Roemmele, 2017). By simulating the practice of real scientists, students may develop a richer, deeper understanding of scientific practices and develop critical and analytical thinking and reasoning skills along the way (Bickel & Lombardi, 2016).

Scoring Rubric

We developed a scoring rubric to assist teachers with assessing students’ engagement in and learning about the scientific practices and cross cutting concepts after completing a MEL or baMEL (the full rubric can be found at our website). The criteria used in the rubric are taken from the Science and Engineering Practices (SEPs) as well as the Cross Cutting Concepts (CCCs) found in the *Next Generation Science Standards* (NGSS Lead States, 2013). We determined that there are four SEPs (*Developing and Using Models, Engaging in Argument from Evidence, Constructing Explanations, and Analyzing and Interpreting Data*) and two CCCs (*Cause and Effect* and *Stability and Change*) that apply to completing the MEL/baMEL instructional activities.

Table 1. Scientific and Engineering Practices and Cross Cutting Concepts Found in MELs and baMELs

MEL/baMEL	SEPs	CCCs
Climate Change	<i>Engaging in Argument from Evidence Constructing Explanations Analyzing and Interpreting Data</i>	<i>Cause & Effect</i>
Moon Formation	<i>Developing and Using Models Engaging in Argument from Evidence Constructing Explanations</i>	<i>Cause & Effect</i>
Fracking	<i>Engaging in Argument from Evidence Constructing Explanations Analyzing and Interpreting Data</i>	<i>Stability & Change</i>
Wetlands	<i>Constructing Explanations Engaging in Argument from Evidence Constructing Explanations</i>	<i>Stability & Change</i>
Freshwater Resources	<i>Engaging in Argument from Evidence Constructing Explanations Analyzing and Interpreting Data</i>	<i>Cause & Effect</i>
Extreme Weather	<i>Engaging in Argument from Evidence Constructing Explanations Analyzing and Interpreting Data</i>	<i>Cause & Effect</i>
Fossils	<i>Engaging in Argument from Evidence Constructing Explanations</i>	<i>Stability & Change</i>
Origins of the Universe	<i>Engaging in Argument from Evidence Constructing Explanations</i>	<i>Stability & Change</i>

Each row in the rubric is a different SEP or CCC that is applied to the MEL, however not all SEPs or CCCs apply equally to each MEL/baMEL (see Table 1). For example, not all MELs or baMELs include tables/graphs/charts of data to analyze and interpret. Similarly a particular MEL or baMEL may focus on the Stability and Change CCC. Thus, it is the task of the teacher to select which SEP(s) and/or CCC(s) is/are most germane to the MEL or baMEL the students are performing and assess students only on those. Table 1 unpacks the SEPs and CCCs that are present in the MELs and baMELs. For some, multiple SEPs apply and we suggest only selecting one SEP to assess, in order to manage the assessment process and scaffold students’ learning (i.e., selecting only one reduces teacher workload and allows the teacher and the student to focus on a single practice at a time). We also recommend that the rubric be shared with students in advance so that they know how they will be assessed. If a student or several students score on the lower end of the rubric, this can provide teachers with valuable information as to how to adjust their teaching, and to assist their students with understanding the function of the SEPs and CCCs in their learning process.

Figure 1 shows a sample of explanation task responses from the Freshwater Resources baMEL, where a student achieved “Approaching” for the SEP Developing and Using Models

(“The explanation evaluates the merits and limitations of one of the two different models of the phenomenon in order to select the most plausible model based on the evidence.”). This sample was collected from a high school student in AP Environmental Science. A middle grades student’s response may be quite different in language and terminology, so knowing their audience, teachers should assess according to grade level ability.

Figure 1. Sample Explanation Task Item

3. 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.

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

Evidence # 1 ~~strongly supports~~ supports | contradicts | has nothing to do with Model A because:
 important molecules such as C, N, and S are passed through wetland, and helps the human population and ecosystems services

Transfer Task

Transfer of learning can happen when students learn and teachers assess how that learning can be applied in different situations. Learning transfer is reduced when teaching of factual information and key terms may lead to students viewing their learning as requiring memorization of a list of disconnected facts, because students will rarely cue themselves or recognize that the new situation is reflective of or related directly to prior learning. Conversely, when students learn for understanding and do understand, then their knowledge becomes usable, and transfer is more likely to occur. Transfer requires practice, and so performing tasks of proximal or near transfer (a related context to what was learned or experienced in class), or distal or far transfer (unrelated context, possibly outside of the classroom), successfully can inform a teacher that true learning has occurred (Calais, 2006; Pai, Sears, & Maeda, 2015).

Learning through the MEL activities may help students to transfer their learning to other applications. When completing MEL and baMEL tasks, students should be reflective of the learning process and we have developed a transfer task to help both students and teachers see how their MEL learning may be applied.

Transfer from previous learning is necessary for all new and future learning (Barnett & Ceci, 2002). Because we don't want students to repeat learning or a learning activity over and over again with no chance for intellectual growth or improvement of scientific reasoning and critical thinking skills, a transfer task enables this opportunity by bridging the experience students have with the MEL into a new, related scenario that emphasizes scientific literacy. Students may be more motivated to learn, accommodating and assimilating new information and experiences, when they see how useful and meaningful the new information is.

The transfer task involves reading about studies published in scientific journals. Because many academic journal articles in the sciences are complex, long, and above typical adolescent reading levels, we use online resources that report about these studies, where text is more readable and less complex. To offer teachers support for this task, we provide links to a number of articles from <https://www.sciencenewsforstudents.org/>. The articles suggested from this site all have reading levels from grades 7 through 9, and thus are easier to read for both middle and secondary students. We also chose articles that are not exact content matches of the MELs or baMELs, in order to offer teachers and their students a wider variety of topics with which to gauge transfer and application. The articles from this site are not encyclopedic in nature; rather, they present investigation methods, ideas, and results from scientists who authored the original article (i.e., from the longer, more advanced science journal).

Students read the chosen article. This can be done independently out of class or within class, either silently or in either small or whole group reading. The accompanying worksheet asks students to identify the author's claim or model, which is a new task compared to the MELs and baMELs in which the models were provided to them. Students are directed to find evidence in the article that supports the claim or model (we offer space for up to three possible lines of evidence, although each article may vary, so it is strongly recommended that teachers have read and can identify the claims and evidence themselves). We also ask students to explain how each line of evidence they locate in the article connects to the model, which is related to what the students are asked to do in the MELs and baMELs. Students are also asked to identify any alternative models presented by the author and how evidence supports or refutes it.

To maintain proximal transfer and familiarity with previous work (the MEL and baMEL activities), we ask students to assess the plausibility of the model or claim presented in the article. But new to this task is students providing evidence for their plausibility rating and asking questions of the

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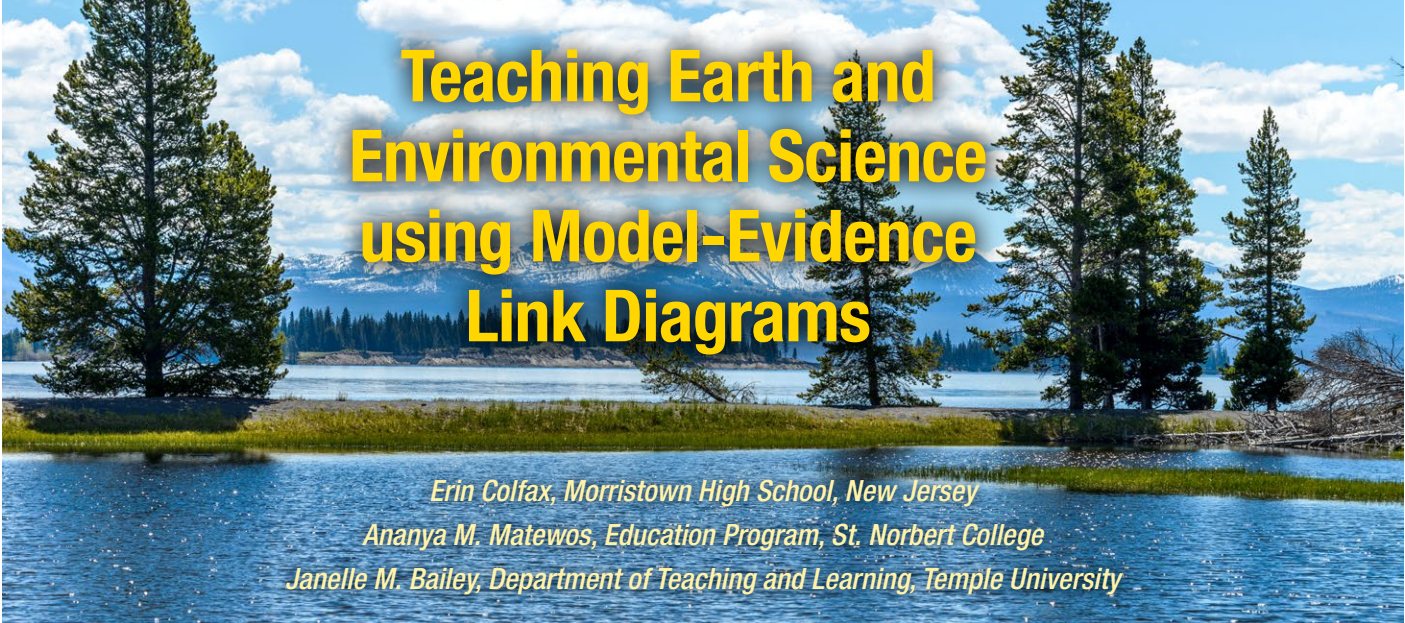
author about their model and evidence. This metacognitive reflective process is meant to enhance and fortify student learning, facilitating their make meaning of the potentially new concepts and models that are being accommodated and assimilated as new knowledge.

Closing Remarks

We designed a rubric to assist teachers in assessing the four SEPs and two CCCs that their students develop while completing a MEL or baMEL. We strongly recommend that teachers assess only one of these at a time, in order to make teacher workload more manageable and for better scaffolding the experience for students. Additionally, the transfer task assists students in developing scientific literacy and reinforces their skills gained in performing a MEL and baMEL. The transfer task can be used as a pre-MEL activity in order for the classroom teacher to assess student ability and to focus teaching during MEL delivery to those specific deficiencies, and again at a later time (after all MEL and baMEL activities of the year are complete) to gauge changes in students' performance. The use of the task should improve the transfer of learning and skills. There is also the expectation that students will acquire scientific content knowledge, and may shift gears or perspective in overcoming prior assumptions or misconceptions about curricular topics and socio-scientific issues.

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Teaching Earth and Environmental Science using Model-Evidence Link Diagrams

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Abstract

High-quality science education is essential for students to become scientifically literate. Model-Evidence Link (MEL) diagrams and build-a-MEL (baMEL) diagrams are instructional scaffolds that create an opportunity for students to build scientific understanding through the evaluation of the connections between evidence and alternative explanations of a scientific phenomenon. The MELs and baMELs allow for a natural incorporation of three-dimensional learning that has been recommended by the *Next Generation Science Standards* to enhance students' comprehension. Through this science teaching methodology, students are able to see that by diagramming and then writing about one's thoughts about the connections between evidence and explanations, one can deepen their understanding of scientific concepts.

As attendees of the summer 2019 Earth and Environmental Science (EES) Educators Institute, middle and high school EES teachers were introduced to a methodology that explored two instructional scaffolding techniques: Model-Evidence Link (MEL) diagrams and build-a-MEL (baMEL) diagrams. The MEL and baMEL diagrams promote students' scientific thinking when confronted with controversial and/or complex Earth and space science topics. These instructional scaffolds facilitate critical thinking, evidence-based reasoning, construction of scientific explanations, and collaborative argumentation (Lombardi, 2016; Science Learning Research Group, 2020; see also the other articles in this issue).

The MEL and baMEL diagrams facilitate student learning by presenting material in three science learning dimensions (i.e., scientific practices, disciplinary core ideas, and crosscutting concepts; NGSS Lead States, 2013), and capitalizing on the intrinsic interest and natural curiosity of students. Students examine the underlying crosscutting concepts, depict disciplinary core ideas, and make use of science and engineering practices in an intertwined means in order to make sense of phenomena that are explained by alternative models (Science Learning Research Group, 2020).

Instructional Context: The Instructor and Classroom Environment

I (Colfax) am a high school environmental science teacher who applied to the summer 2019 Earth and Environmental Science Educators Institute because I was interested in exploring a new NGSS

teaching methodology. As a former research science teacher and science poet, I am often attracted to professional learning opportunities that have students analyzing and interpreting real world data and evidence. (The second and third authors are part of the Institute teams.)

The students in my year-long college preparatory class are part of a comprehensive, four-year suburban NJ high school that serves an ethnically, racially, and socially diverse student population of more than 2000 students. Some students come from families who have attended the school district for four-plus generations while others have immigrated to the United States within the past few months. The course has no prerequisites, is not a requirement, and can be taken at any point in a student's sequence of high school science classes. Each heterogeneous class section has students of varying past achievement and motivational levels and two of the four class sections are co-taught by life science teachers, one of whom has special education certification.

Instructional Process: Teaching with MEL and baMEL Diagrams

After attending the summer Institute and being trained on MEL and baMEL diagrams, I evaluated the scope and sequence of my curriculum and selected which MEL and baMEL activities I would integrate. In order to ensure that these activities were in alignment with the NGSS and taught in 3-dimensions, I made sure each activity provided a sound body of scientific knowledge and was based in evidence. This would allow students to realize that science continually seeks to extend, refine, and revise knowledge. I came to understand that the MEL and baMEL diagrams are not taught as stand-alone activities; rather they should be a part of a bigger conceptual unit and can serve to build / introduce information, ascertain knowledge, or provide closure to a sequence of lessons. I selected four instructional scaffolds to roll out throughout the year: Fracking MEL, Climate Change MEL, Extreme Weather baMEL, and Freshwater Resources baMEL. The Fracking MEL was used as a closure activity in a sequence of lessons where renewable / nonrenewable energy was taught. The Climate Change MEL was used for students to ascertain knowledge in the middle of an Earth's systems unit (Cervetti et al., 2012). The Extreme Weather baMEL was used to clarify and put closure to a sequence of lessons that examined weather and climate patterns, and the Freshwater Resources baMEL was used to have students ascertain knowledge about freshwater in a biomes unit.

In order to develop student confidence prior to rolling out the instructional scaffolds, I opted to introduce components of the modeling diagram to students in a first quarter unit on birding. I placed 3-4 students each in a different pre-assigned group and had them evaluate and classify pieces of evidence on how they connected to bird migration obstacles. Each piece of evidence needed to be classified as: (a) strongly supportive, (b) supportive, (c) has nothing to do with, or (d) contradicts what is being studied (e.g., an explanation of a phenomenon). This simple activity helped students to better organize their thoughts when completing Claim, Evidence, and Reasoning (CER) tasks and laid the framework for communication and facilitating discussions in a small group setting prior to using the MEL and baMEL diagrams.

I decided to use the preconstructed MEL diagram activity first (i.e., prior to a baMEL) because it gave students a chance to evaluate fewer pieces of evidence at a time. This also allowed students to get used to the format without having to make as many decisions themselves. The outcome of this decision allowed me to see students build communication momentum not only as a group, but as individual learners as well.

Students stayed in the same group each time that we worked through a MEL or baMEL activity so that they could develop a communication and model analysis strategy (Horizon Research, 2013). I was able to see growth in the depth of the conversations between students. In some groups one student would emerge as a leader, directing the conversation around the lines of evidence, whereas

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in other groups students used pointed language to engage one another by asking for another student's opinion when their own confidence level on a particular topic was weaker.

The first MEL I rolled out was on hydraulic fracturing (aka, fracking). Prior to the MEL, students had been introduced to related disciplinary core ideas via interactive lecture; they then participated in an environmental design challenge where students worked in pre-selected teams to design a "protest sign" that represented their position and support for an energy resource. They found a peer-reviewed journal article of a *current* research study (2010-2020) that either "strongly supported" or "opposed" their selected energy resource to support their position. After the design challenge, students took to the streets outside of the school and protested, documenting their participation as an environmentalist. Students then completed a photovoice on the environmental protest actions their group considered important. (A photovoice is an assessment technique where the learner showcases a scientific concept or phenomenon that they consider important by taking a picture and composing an explanatory semi-structured narrative; Stroud, 2014.) Next, students uploaded the image, wrote a semi-structured narrative, and answered questions that delved into their perception of the best renewable/nonrenewable energy resource (Stroud, 2014). The fracking MEL followed these lessons and was used as a closure activity in this sequence exploring renewable/nonrenewable energy.

When students attended the 80-minute Fracking MEL class, they sat in their pre-selected teams whom they had been working with for the past several class periods (Horizon Research, 2013). We warmed up with a quick review of related disciplinary core ideas. After discussing and completing the model plausibility ratings, student teams were assigned to one of six identical stations that were spread throughout the room. Every station had in the middle of the table two clear acetate sleeves containing the two models printed on colored paper in large font; white board markers; and clear acetate sleeves containing each of the different evidence texts (Figure 1). Students arrived at the table with a pencil and were given the MEL diagram.

I began by going over how to read and use a MEL diagram, focusing particularly on the use of the arrows and the direction in which they point and then discussing the models on the table and how to use the evidence documents. After providing some additional guidance and documenting examples from the previous interactive lecture on the board, students were then given work time. They initiated the process by discussing the models and making sense of the evidence provided. Students were encouraged to use the white board markers to write on the clear acetate sleeves of the evidence documents as they brainstormed and classified the pieces of evidence (Figure 2). They arranged the evidence physically around the models, drawing arrows to represent whether each evidence (a) strongly supports the model, (b) supports the model, (c) has nothing to do with the model, or (d) contradicts the model. I walked around the room facilitating and engaging in dialogue to help students through this process.

After about 15-20 minutes of brainstorming and discussion, the energy in the room shifted and the analytical writing process was well underway. Students were asked to fill out an explanation task and use the completed MEL diagrams to clarify their model-and-evidence connections, construct

Figure 1. Lab Station Setup for the MEL.

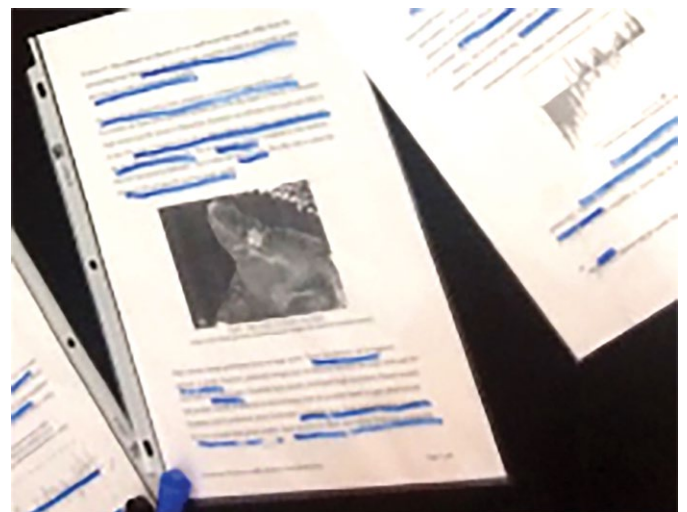
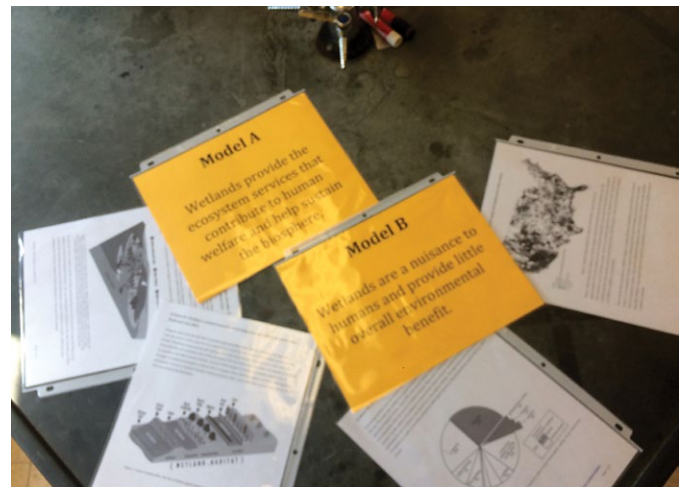


Figure 2. Students Used White Board Markers to Identify Key Aspects of the Evidence.

Note. The white board markers allowed students to underline, circle, and draw connections to information to help them better determine and draw connections to a line of evidence that (a) strongly supports the model, (b) supports the model, (c) has nothing to do with the model, or (d) contradicts the model.

understanding, make sense of their reasoning, and provide justification for the strength of their selected evidence (Katz, 2010). I had students hold onto their explanation tasks until the last ten minutes of class to share out to the larger group as part of the lesson closure (Horizon Research, 2013). There were times when the students' scientific explanation was highly developed and other times it was not; in some cases a student struggled just to come up with one solid explanation of an evidence-to-model connection. The level of explanation was highly dependent upon the background of the student and their confidence level with evidence classification. I found that students who had familiarity with FRQs (free response questions) from Advanced Placement courses, particularly in history, were the strongest with this process. Students who had many informal science learning experiences outside of the traditional classroom setting were also more at ease and confident in their evaluation of the evidence presented (NSTA, 2012). Ultimately, I hope that the students walked away from the MEL lesson knowing that scientific evidence and analytical writing “cross fertilize” one another and that by diagramming one's thoughts about evidence one can deepen their understanding of scientific concepts (Lederman, 2014).

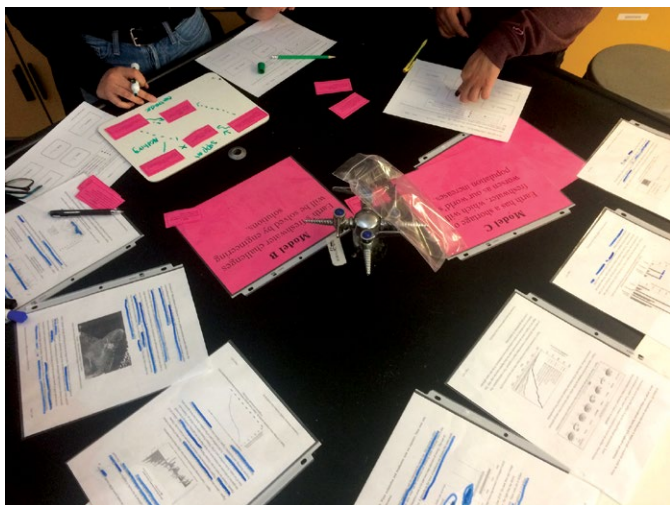


Figure 3. Students Used Small White Boards for Processing and Elimination.

While each MEL or baMEL activity had a different topic, the approach that I undertook to structure the activities were similar. The only difference between the structure and delivery of MEL and baMEL activities were the tools that the student groups were given at each lab table. When we conducted a baMEL activity, each station had three clear acetate sleeves, each containing a different model printed on colored paper in large font in the middle of the table; white board markers; clear acetate sleeves containing each of the different evidence documents; and a stack of four small white boards (Figure 3). Several student groups requested the white boards before the baMELs were conducted to help them process and eliminate evidence that they were not going to use.

After using multiple MEL and baMEL activities throughout our year-long course, we found it beneficial to assess students through

a CER task. The goal for this type of assessment was not to determine the student's acquired conceptual knowledge; rather it was in their skill of justification. We provided students with an article and a singular question to reflect upon. In return, they developed a scientific claim, selected pieces of evidence from the provided source and justified the use of their evidence through a reasoning explanation.

Conclusions

The MEL and baMEL tasks use alternative and contradictory models that explain a particular phenomenon (e.g., causes of current climate change). They allow for students to strengthen their scientific reasoning skills by examining evidence and how it connects to (i.e., supports, strongly supports, contradicts, or has nothing to do with) the models in order to promote scientific thinking. They also ensure that students are learning in three dimensions; the knowledge and evidence examined provide ample opportunity for students to extend, refine, and revise their scientific knowledge. My colleagues and I intend on using MEL and baMEL instructional scaffolds to have students explore controversial and/or complex Earth and space science topics for many years to come. It is through science teaching methodologies such as these that students can dialogue and communicate using scientific evidence to deepen their understanding of scientific concepts.

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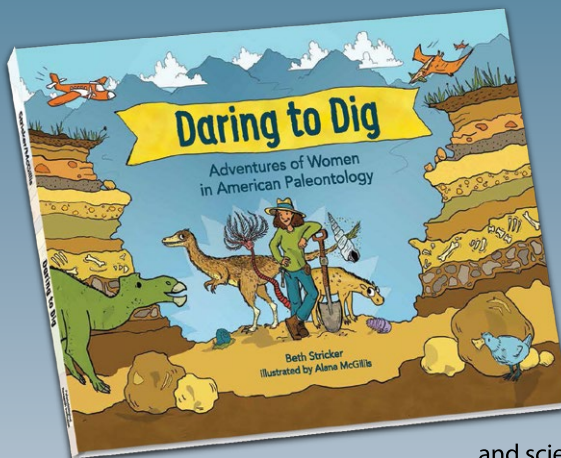
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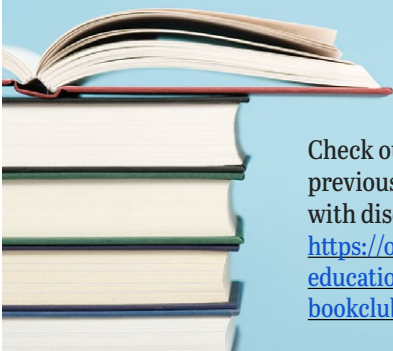
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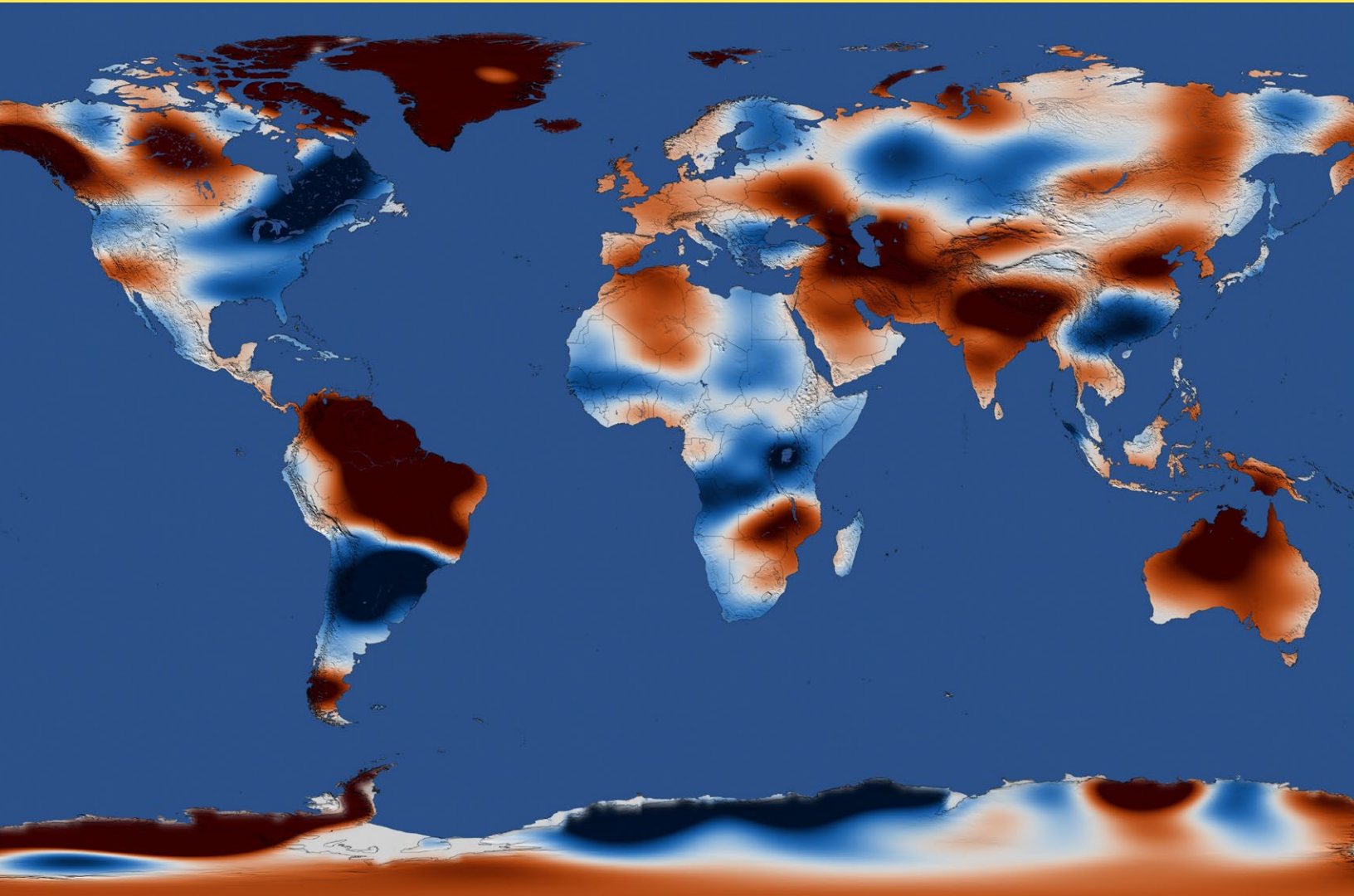
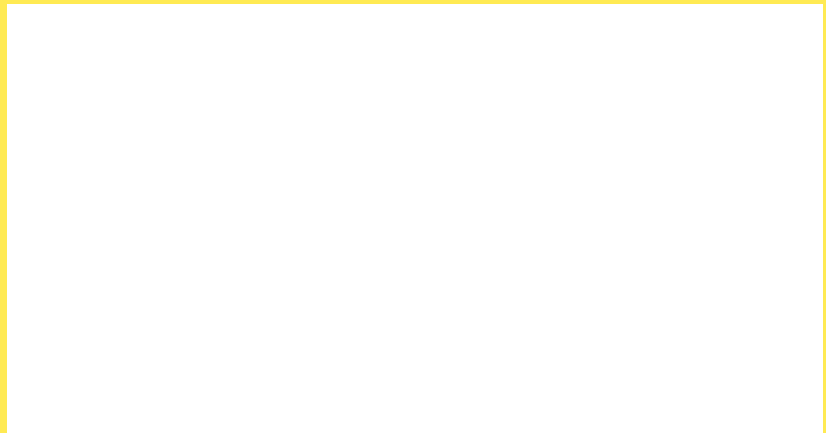
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*Map depicts data collected by NASA's Gravity Recovery and Climate Experiment (GRACE) mission from 2002 to 2016, showing where freshwater storage was higher (blue) or lower (red) than the average for the 14-year study period.
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