**Teacher Guide:** They Really Used to Think That? Evaluating current and historical claims in geology using adapted primary scientific literature

**Grades:** 9-12

**Time:** 2 Weeks / 7 – 8 hours of class time

**Unit Goal:** The overall goal of this three-dimensional unit is to have students use the Next Generation Science Standards’ Science and Engineering Practices, particularly engaging in argument from evidence and using models, to develop foundational knowledge about the evidence of past and current crustal movements of the Earth’s surface and to develop a mechanistic account of plate tectonics.

**NGSS Performance Expectations**

* HS-ESS1-5. Evaluate evidence of the past and current movements of continental and oceanic crust and the theory of plate tectonics to explain the ages of crustal rocks.
* HS-ESS2-3. Develop a model based on evidence of Earth’s interior to describe the cycling of matter by thermal convection.

**Learning Objectives**

Students should be able to:

Science Content

* Explain the relationship between mantle convection and the motions of tectonic plates
* Explain why plate tectonics is a better model than alternative models like continental drift
* Explain why the rocks at the centers of mid-ocean ridges are younger than the rocks that are further from the center

Science and Engineering Practices

* Evaluate the quality of evidence
* Generate valid and sufficient arguments that, by the end of the unit, support plate tectonics as the best model of large-scale earth systems processes for moving continents and oceans
* Distinguish between evidence that is diagnostic and non-diagnostic
* Relate key evidence to predictions or causal mechanisms of models

Cross Cutting Concepts

* Explain energy and matter cycles through mantle convection
* Identify patterns in empirical data
* Explain or generate an argument in favor of a causal (i.e. mechanistic) account of plate tectonics

Nature of Science Content

* Explain how multiple lines of evidence make a more compelling argument for a model
* Understand that scientific communities have norms of practice, like shared understandings of what counts as good scientific evidence
* Explain how models can be accepted based on early evidence and then later reject based on new evidence.

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| **Phase** | **Main Activities** |
| **Pre-Modeling** | **Introduce Unit****Criteria List*** Have students develop individual lists of what counts as good and bad evidence and then share with a partner or group.
* Next have the class contribute to a list of what makes for good and bad evidence that is written on the white board.

**!**  **Teaching Tip:** Don’t be afraid to curate the list. Suggest possible options but only after it seems that students will not come up with them.**Ball and Ring Demonstration*** Conduct a ball and ring demonstration showing that when the ball is heated it expands and cannot pass through the ring.

**Argumentation Activity*** This activity ties into the demonstration.
* This page of the student packet contains four arguments and very simple rubrics to help students think about how evidence connects to claims. Rather than Reasons (from the well-known Claims, Reasons, and Evidence framework) the word “connect” was chosen because it more directly describes the rhetorical and logical moves that students need to make.
* Once students have read the arguments, they evaluate them based on the rubric, share with their peer or group, and then discuss as a class.

**!**  **Teaching Tip:** Prompt students to look at the length of the arguments to see if longer arguments are always better. Make sure to point out that longer arguments are not necessarily better; what really matters is how well the argument is constructed.**Geologic Content Knowledge Formative Assessment*** Have students first explain whether they think the continents and oceans change shape, size, and/ or location over time and then draw and label a model (diagram) of their thinking.

**!**  **Teaching Tip:** This can be used as part of a post-test as well if time permits.**Assessment*** As part of a post-test you may wish to have students respond to the same prompt as the pre-test where they are asked to draw a diagram and explain how continents and oceans move, and change size and shape. Key elements to look for would be the inclusion of a mechanism (convection cells in the mantle) as well as certain predictions (shallow and deep earthquakes at convergent plate boundaries).
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| **Scientific Reasoning Cycle 1** | **Introduce the Two Models*** Have students read the models in their packet and complete the short multiple choice quiz after them (the quiz measures their understanding of the two models).
* Discuss the models to address student misconceptions.

**!**  **Teaching Tip:** Make sure to convey that both models are feasible. Students will use the evidence introduced next to figure out that the shrinking Earth model is incorrect. The vast majority of students will settle on the right model by themselves. The few who don’t can be caught up to speed with a class discussion at the end of this cycle.**Evidence 1, 2, 3, and 4*** Have students read each piece of evidence, respond to the question(s) at the end of the evidence page and then discuss with a partner.
* At the teacher’s discretion you can choose to discuss each piece of evidence or let them go through all four on their own and then discuss them.

**!**  **Teaching Tip:** Encourage students to fill out the MEL Matrix (which is a few pages after the evidence) which will help them keep their thoughts organized. Alternatively, or in addition, you can have them fill out an evidence summary sheet (see supplemental materials).**~**  **Talk Moves:** Make sure to let the students do the thinking at this stage. There is a lot of evidence and plenty of time for them to settle on the right set of conceptions. For now encourage them to give lots of reasons. More importantly, encourage them to respond to each other’s comment. For example “Shamim, what do you think about what Terrance said?” This can be more productive than “popcorn talk” where we call on a different student to hear their idea and then move on, which can be a superficial mode of discussion. Ideally students will learn, with encouragement, that rebuttals and counterarguments are part of the scientific process for verbal argumentation.**MEL Matrix, Select a Model, Write an Argument*** Make sure students have completed their MEL matrix and have circled the model they think is best supported by the evidence.
* Next students should write an evidence-based argument in support of the model they think is correct but also include reasoning that shows why the alternative is not well supported by the evidence.

**Assessment Feedback*** Use the “Rubric for Written Arguments Dealing with Competing Claims.” Rather than just focusing on claims, reasons, and evidence this rubric draws attention to additional elements of a high quality argument, for example, using criteria to evaluate evidence; addressing the primary claim, and why it is supported by the higher quality evidence; and why the alternate claim is less well supported. Encourage students to continue crafting their arguments and ensure them that with quality effort they will improve.
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| **Scientific Reasoning Cycle 2** | **Introduce the Two Models*** Have students read the two models. Then project the “Model Comparison PowerPoint Slides.” Take the time to go through each model carefully. Each model includes the following important information: (a) initial state, (b) mechanism, (c), one or more predictions, and (d) the current state.

**+**  **Nature of Science Teaching Tip:** The mechanism is the causal process that leads from the initial state (in this case when all the continents were joined millions of years ago) to the final state.**+**  **Nature of Science Teaching Tip:** Predictions are phenomena in the world that we should be able to observe if the model is accurate. When evidence contradicts a prediction, that is an indication that one or more parts of the model are not accurate; or that the entire model is not accurate.**+ Nature of Science Teaching Tip:** Focusing students on the predictions and mechanisms of the models is key to promoting: (a) better understanding of the nature of science and (b) seeing deeper connections between the evidence and the models and writing about them in an argument.**Evidence 5, 6, 7, and 8*** Have students read each piece of evidence, respond to the question(s) at the end of the evidence page and then discuss with a partner.
* At the teacher’s discretion you can choose to discuss each piece of evidence or let them go through all four on their own and then discuss them.
* **Evidence 6 Tip:** This is strong evidence against continental drift because it suggests that the “moon’s gravity” mechanism is insufficient.
* **Evidence 7 Tip:** This is strong evidence in favor of plate tectonics because it shows that there are deep earthquakes and shallow earthquakes, whereas drift only makes a prediction that earthquakes would be shallow.

**!**  **Teaching Tip:** Encourage students to fill out their MEL matrix (which is a few pages after the evidence) which will help them keep their thoughts organized. Alternatively, or in addition, you can have them fill out an evidence summary sheet (see supplemental materials).**~**  **Talk Moves:** Keep students talking about mechanisms and predictions. For example the teacher can ask the student(s) “How does this fit with the prediction of continental drift?” Similarly, “Does this evidence actually tell us how the continents move?” as a prompt for thinking about mechanisms.**MEL Matrix, Select a Model, Write an Argument*** Make sure students have completed their MEL matrix and have circled the model they think is best supported by the evidence.
* Next students should write an evidence-based argument in support of the model they think is correct but also include reasoning that shows why the alternative is not well supported by the evidence.

**Assessment Feedback*** Use the “Rubric for Written Arguments Dealing with Competing Claims.” Continue to look for improvements in all areas of the rubric. Since Cycle 2 included information about mechanisms and predictions it is good to look for that in their “relational reasoning” because they can relate that evidence to a particular part of the model. Encourage students to continue crafting their arguments and ensure them that with quality effort they will improve.
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| **Scientific Reasoning Cycle 3** | **Re-Introduce the Two Models*** Refresh students’ thinking about the “Model Comparison PowerPoint Slides” and draw their attention to the: (a) initial state, (b) mechanism, (c), one or more predictions, and (d) the current state.

**Evidence 9, 10, 11, and 12*** Have students read each piece of evidence, respond to the question(s) at the end of the evidence page and then discuss with a partner.
* At the teacher’s discretion you can choose to discuss each piece of evidence or let them go through all four on their own and then discuss them.
* **Evidence 10 Tip:** This is strong evidence in favor of plate tectonics because it shows how seafloor spreading relates to the mechanisms of tectonics and mantle convection.
* **Evidence 12 Tip:** Marie Tharp is a pivotal figure in the early days of geosciences. We have included a short description of the barriers she faced as a woman. Having students learn about the personal stories of geologists is one way for them to understand how evidence is collected, analyzed, and processed in a historical and social context. Another way to enrich this unit is to discuss how a lack of diversity and equity shaped whose voices were included and whose were excluded from geology historically. Teachers can facilitate discussions that enrich students’ understanding of the nature of science by illustrating the historical and current challenges underrepresented groups have faced, and how progress on diversity can improve scientific practice.

**+**  **Nature of Science Teaching Tip:** Diagnosticity refers to evidence that can be used to distinguish between two or more claims or models.**+ Nature of Science Teaching Tip for Evidence 9 and 11:** This kind of evidence is often used in textbooks in support of plate tectonics but this evidence actually can’t distinguish between tectonics and drift as it only deals with the initial and current states without addressing the mechanism or predictions.**!**  **Teaching Tip:** Encourage students to fill out their MEL matrix (which is a few pages after the evidence) which will help them keep their thoughts organized. Alternatively, or in addition, you can have them fill out an evidence summary sheet (see supplemental materials).**~**  **Talk Moves:** Keep students talking about mechanisms, predictions, like the last cycle, but also add in discussions of diagnosticity. For example the teacher can ask the student(s) “Does this evidence show us that one model is more accurate than the other?” If students need a little more prompting ask them “We know that both models start with the continents all connected and they are spread out in modern times. Does this evidence show us how they spread out?”**MEL Matrix, Select a Model, Write an Argument*** Make sure students have completed their MEL matrix and have circled the model they think is best supported by the evidence.
* Next students should write an evidence-based argument in support of the model they think is correct but also include evidence that shows why the alternative is not well supported by the evidence.

**Assessment Feedback*** Use the “Rubric for Written Arguments Dealing with Competing Claims.” Continue to look for improvements in all areas of the rubric and encourage students to write about the diagnosticity of the evidence as it relates to determining if the primary claim, or alternate claim, is more correct or (as is the case with Evidence 9 and 11) it doesn’t really show that one claim is more correct than the other. Encourage students to continue crafting their arguments and ensure them that with quality effort they will improve.
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