

Abstract

Assessing both knowledge of Earth science concepts and students' scientific evaluations in making sense of these concepts is important to gauge understanding. In the Model-Evidence Link (MEL) diagram activities, students engage with Earth science content knowledge and evaluate the connections between evidence and alternative explanations. We have developed a rubric for assessing the quality of student evaluations when engaging in the MEL activity, specifically in the written explanations about the connections between evidence and explanations. This rubric features four distinct categories of evaluation: (a) erroneous, (b) descriptive, (c) relational, and (d) critical. For each category, the rubric identifies specific criteria addressing a student's accuracy, certainty, and use of elaborative language when explaining the connections made during the MEL activity. These categories may serve as individual levels of evaluation, and allow teachers to recognize and follow the development of students' critical evaluation skills when using MEL diagrams over time.

Students' knowledge of scientific topics and their ability to be scientifically evaluative are both important parts of understanding the connections between evidence and explanations. Therefore, both students' knowledge and their critical evaluation skills should be specifically addressed, encouraged, and assessed in the science classroom. Developing critical evaluation skills is an essential part of a student's ability to understand complex scientific phenomena (NRC, 2012) because it helps develop a more grounded understanding of the nature of science and teaches students to approach new scientific ideas in a logical way. These skills emerge from opportunities to make scientific judgments on the implications of material and the use of conclusive reasoning when presented with competing explanations (Erduran & Msimanga, 2014; Stanovich & West, 1997). Therefore, Earth science lessons should aim to not only engage students in the material of a given topic, but also allow reflection on their own evaluations of the meaning and plausibility of more general scientific models.

The Model-Evidence-Link (MEL) diagram is a classroom activity that integrates critical thinking into Earth science lessons (Chinn & Buckland, 2012; Lombardi, Sibley, & Carroll, 2013). When using the MEL, students use scientific evidence to evaluate competing models based on their

¹ All MEL activities and associated materials may be downloaded for free at our project website: (<https://sites.temple.edu/meldiagrams/materials/>).

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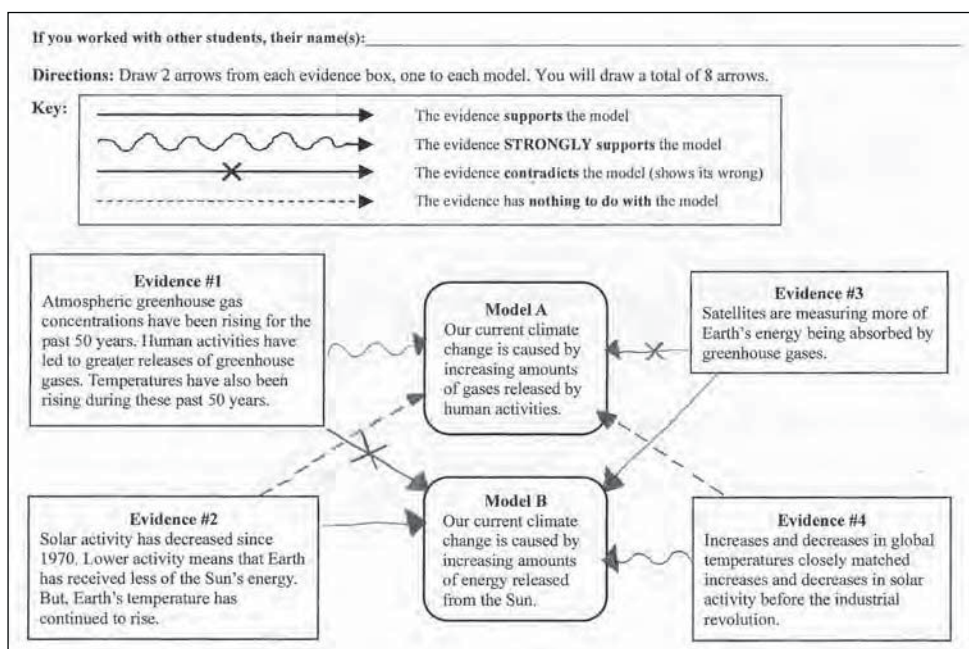
relative connections to each provided line of evidence. These models present alternative explanations for various phenomena (i.e., cause of current climate change, ecological services of wetlands, increased incidence of moderate earthquakes in the Midwest, and formation of Earth's Moon). This format also allows teachers to assess students' understandings of the examined scientific concept and also students' applications of the scientific practice of critical evaluation (Lombardi, Sinatra, & Nussbaum, 2013).

The purpose of this article is to outline ways in which teachers may assess students' understanding and scientific reasoning after engaging in the MEL activities. In this article, we briefly discuss the qualitative research applied in developing a rubric that teachers may find useful for assessment purposes. More details about our research regarding students' reasoning during MEL instruction are found in Lombardi, Brandt, Bickel, and Burg (2016).

Brief Overview of the MEL Diagram and Explanation Task

The format of the MEL diagram and explanation task were originally developed by researchers at Rutgers University who were developing instructional scaffolds for middle school life science (Chinn & Buckland, 2012). Lombardi, Sinatra, and Nussbaum (2013) adapted the MEL activity for instruction on the topic of current climate change. This Climate Change MEL was revised, and three other Earth science-related MELs were designed and developed, for a National Science Foundation-funded project titled "Developing Critical Evaluation as a Scientific Habit of Mind: Instructional Scaffolds for Secondary Earth and Space Science" (for more details about each of the four MEL diagrams, please see the other articles in this special issue).¹ Each MEL focuses on a phenomenon that can be explained by two plausible alternative models (e.g., current climate change is a result of human activities vs. current climate change is a result of increased amounts of energy released from the Sun), with one of the models being the scientifically accepted explanation (e.g., human-induced climate change). Students complete a MEL diagram by drawing different types of arrows from each of four evidence statements to each alternative model. The type of arrow drawn by the student represents a judgment about how well a line of evidence supports a model: strongly supports (squiggly solid arrow), supports (straight solid arrow), contradicts (straight solid arrow with a large X marked through the middle), or has nothing to do with the model (dashed straight arrow) (see Figure 1).

Figure 1. Example of a student completed MEL diagram



with a large X marked through the middle), or has nothing to do with the model (dashed straight arrow) (see Figure 1).

Our position is that students should NOT be assessed on the specific types of arrows they draw on the MEL diagram, but rather on the subsequent explanation task. We take this stance firmly because the MEL diagram is a scaffold designed to fully engage students in the act of weighing the connections between lines of evidence and alternative explanations, which is an essential practice of the scientific community embedded within the Next Generation Science Standards (NGSS Lead States, 2013).

Please work on this individually.

Provide a reason for three of the arrows you have drawn. Write your reasons for the three most interesting or important arrows.

- Write the number of the evidence you are writing about.
- Circle the appropriate word (**strongly supports** | **supports** | **contradicts** | **has nothing to do with**).
- Write which model you are writing about.
- Then write your reason.

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

It mentions how atmospheric greenhouse gas concentrations have been going up for the past 50 years. Model A is about our climate changing because of gases released.

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

It Evidence #2, It says 'solar activity has decreased since 1970'. In Model B, It states that our climate changed because of the amounts of energy received from the sun. Both state about the energy of the sun.

3. Evidence # 3 **strongly supports** | **supports** | **contradicts** | **has nothing to do with** Model A because:

Evidence #3 talks about satellites measuring the earth's energy being absorbed by G.H gases. The opposite of what Model A states. Model A talks about our climate changing because of gases released.

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

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

Assessing students on which arrow they draw may actually disengage students from practicing critical evaluation. Although we do acknowledge that students should complete the MEL diagram fully, the Explanation Task (Figure 2) should be the focus when assessing students' performances.

Figure 2. Example of a student-completed explanation task.

Students perform the Explanation Task after completing the MEL diagram. This task asks students to explain their reasoning behind the types of arrows they drew connecting lines of evidence to the explanatory models. Students are asked to write three explanations for the connections that most compelled them or on which they feel strongest. The explanation tasks facilitates students' reflections on their decisions about the meaning of the evidence texts, and also reveals the types and levels of evaluation that students are applying to the activity.

Assessment of the Explanation Task

Our qualitative research analysis revealed multiple distinct categories of responses, reflecting students' applied evaluative skills and levels of understanding. These categories resembled those presented by Driver, Leach, Millar, and Scott (1996) to describe levels of scientific reasoning. We adapted these, and added an additional category, based on the results of a thorough iterative analysis on the types of evaluations students made in their explanation tasks. The four evaluation categories that emerged from our analysis include: (a) erroneous, (b) descriptive, (c) relational, and (d) critical (Table 1). Using these four levels (discussed in more detail below), teachers can rank explanations based on both students' understanding of the material and their application of evaluative skills toward making sense of the material.

Erroneous Evaluation refers to student explanations that show a fundamental lack in scientific understanding, which are often apparent from a student's indication of a model-evidence link

Table 1. Types of Evaluation Scoring Rubric for Explanation Tasks

<p>Erroneous Evaluation</p>	<p>Explanation contains incorrect relationships between evidence and model, excluding misinterpreting a “Nothing To Do With” relationship by elimination-based logic. The explanation may also be mostly inconsistent with scientific understanding and/or include nonsensical statements.</p>
<p>Descriptive Evaluation</p>	<p>Explanation contains a correct relationship without elaboration, or correctly interprets evidence without stating a relationship. For example, the evidence-to-model link weight states that the evidence has nothing to do with the model. Explanation does not clearly distinguish between lines of evidence and explanatory models. Explanations could also demonstrate “elimination-based logic” to come to a positive or negative weight, when evidence-to-model link weight states that the evidence has nothing to do with the model. For example, an explanation states that an evidence supports one model, but uses reasoning that the evidence contradicts the other model.</p>
<p>Relational Evaluation</p>	<p>The explanation addresses text similarities, and includes both specific evidence and an associated model or reference to a model. For example, explanation is correct, with an evidence-to-model link weight of strongly supports, supports, or contradicts as appropriate. Explanation distinguishes between lines of evidence and explanatory models, but does so in a merely associative or correlation manner that is often based on text similarity.</p>
<p>Critical Evaluation</p>	<p>Explanation describes a causal relationships and/or meaning of a specific relationship between evidence and model. For example, explanation is correct, with an evidence-to-model link weight of strongly supports, supports, or contradicts as appropriate and reflects deeper cognitive processing that elaborates on an evaluation of evidence and model. Explanation distinguishes between lines of evidence and explanatory models, allows for more sophisticated connections, and/or concurrently examines alternative models.</p>

that is illogical and incorrect. These errors in judgment prevent effective application of critical reasoning due to the student’s difficulty with initially making meaning of the evidence text. For example, one student who completed the Climate Change MEL wrote that Evidence Statement #2 supported Model B because, “Both state about the energy of the Sun” (note: the examples provided are unedited quotations from student work). This student is clearly mistaken because this evidence statement actually contradicts the model’s claim. Erroneous explanations may also include nonsensical statements, in which a student’s response is not a coherent enough answer to be assessed for understanding.

One particular type of response worth noting, which we determined not to be erroneous, are those that reflect elimination-based logic. In these cases, a student incorrectly indicates what would otherwise be a “nothing to do with” relationship to one model, but uses reasoning that reflects an accurate interpretation of the evidence’s link to the other model. For example, Fracking MEL Evidence Statement #4 has nothing to do with Model B, but some students claim that it supports this model. Many do this by accurately explaining how the evidence contradicts Model A but not actually talking about Model B. This type of answer, though possibly incomplete in its evaluation of the evidence, reflects a level of reasoning beyond misinterpretation. Most commonly, we considered answers of this form to be one type of “Descriptive Evaluation,” as discussed in detail below.

Descriptive Evaluation refers to student responses that are scientifically accurate, but are based merely on similarity of wording between a line of evidence and the explanatory model. This type of student explanation often lacks any expressed reasoning or provides an answer that reflects or requires minimal amounts of evaluation. Most of

the responses that fall into this category are correct assessments of a “nothing to do with” link. The choice to make this type of evaluation, which only requires a student to realize a lack of connection between evidence texts and models, impedes vigorous scientific reasoning because this link can be generalized via superficial understanding. We categorized these cases, and similarly undeveloped connections, as descriptive evaluations. Sometimes students correctly identified a connection but only wrote a trivial explanation about the connection (such as, “They [the model and evidence

statement] are talking about different subjects”). In cases where even a correctly identified non-neutral link is expressed on the explanation task, answers are considered descriptive when they lack meaningful explanations or have only basic assessments of word-by-word similarity between the evidence and model.

Relational Evaluation reflects a more advanced level of evaluation, but these student explanations still lack a fully critical quality. Explanations that demonstrate relational evaluation are scientifically accurate and discuss either a supportive or contradictory link. When students accurately evaluate such a link, they have identified a useful connection based on a line of evidence, which indicates some understanding of the material and an ability to use scientific reasoning. However, in the case of relational evaluation, these explanations are mostly insubstantial in that they do not discuss the more complex scientific implications of the evidence or the cause-and-effect relationships between lines of evidence and explanatory models. In general, these responses do not reflect an understanding of the way a line of evidence would impact a particular model, perhaps by incorrectly describing the model as having influence over the evidence or by identifying a correlation without considering causation. Thus, these students clearly used scientific reasoning to make sense of the material, but may still need help with understanding how these pieces work together within a larger scientific theory. When completing the Moon MEL, one student wrote that Evidence Statement #2 strongly supports Model B because, “They both talk about smaller particles being broken off to come together and form a more massive object.” This is an accurate evaluation and does express an understanding of the scientific discussion, but the student interprets the evidence and model as separate ideas rather than discussing the evidence’s specific role in confirming plausibility of the model.

Critical Evaluation refers to student explanations that are scientifically accurate judgments of the lines of evidence and explanatory models, and also use sound reasoning for more thorough evaluations of the model-evidence links. These explanations reflect an understanding of the relationship between evidence and models through descriptions of cause-and-effect relationships, applications of counter-examples, or other full demonstrations of well-grounded logic. They make sense of the evidence based not only on correct interpretations of meaning, but also by describing relevant implications of the evidence. A simple but critical explanation by one student, after accurately indicating that wetlands MEL Evidence Statement #1 supports Model A, simply says, “Wetlands provide nutrients and essential gases, which proves that they are beneficial to human welfare.” Despite being brief, this answer identifies the student’s understanding of the evidence while also addressing the role that it plays in the evidence-model relationship. Other responses that are categorized as critical evaluation may discuss the student’s more complex analysis of the evidence text, such as another student’s explanation of the same link, which states, “This piece of evidence discusses all of the ways that wetlands contribute to the biochemical cycles. For example, carbon will be stored in the wetlands as long as they remain wet.” Here, the student does not explain as thoroughly how the evidence text directly affects the plausibility of the model, but does elaborate on her understanding of the evidence text to clearly show her reasoning for the indicated model-evidence relationship.

Conclusions

These evaluation categories (erroneous, descriptive, relational, and critical) serve as four distinct levels of scoring for individual explanations (see Table 1). We consider this scoring system to carefully reflect both students’ understandings of the material and their ability to use critical thought and reasoning when making sense of the implications of scientific data. Progress in understanding and reasoning skills, then, could be closely followed as students learn to be critically evaluative during repeated use of the MELs for various Earth science topics, and the explanation task serves

as an explicit record of the types of thought processes that each student uses in working through new scientific ideas and information. Students and teachers can then gauge explanations to assess whether students are viewing the larger ideas differently (e.g., more scientifically) after completing the MEL diagrams and explanation tasks. When teachers and students specifically observe, and assess, the use of these abilities, it will help acclimate students to the scientific practices of critical evaluation and reasoning as means to construct understanding of Earth science phenomena.

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