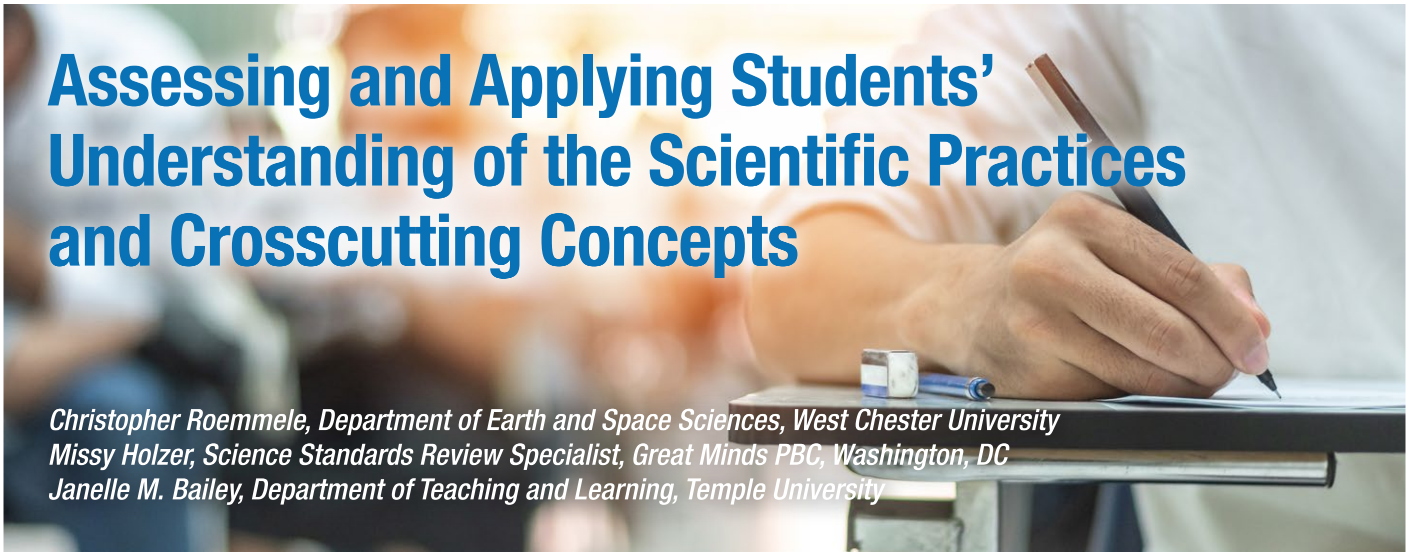

Assessing and Applying Students' Understanding of the Scientific Practices and Crosscutting Concepts

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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; Brewe, 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

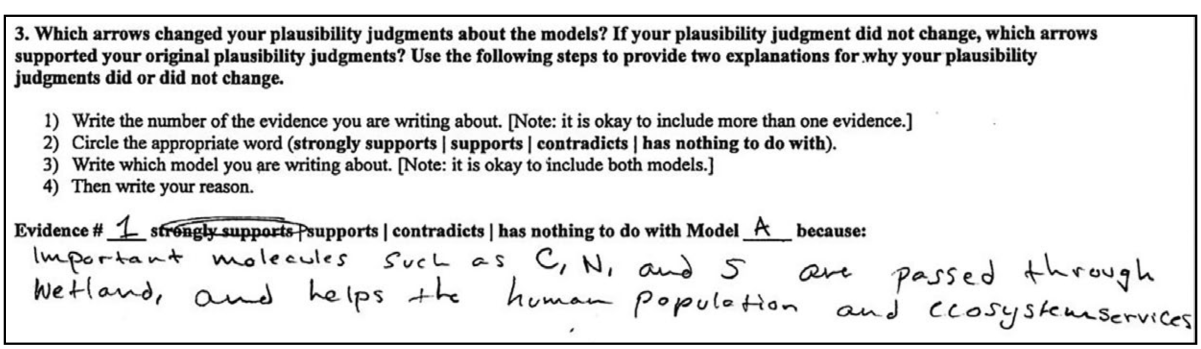
We developed a scoring rubric to assist teachers with assessing students' engagement in and learning about the scientific practices and cross cutting concepts after completing a MEL or baMEL (the full rubric can be found at our website). The criteria used in the rubric are taken from the Science and 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	*Engaging in Argument from Evidence* *Constructing Explanations* *Analyzing and Interpreting Data*	*Cause & Effect*
Moon Formation	*Developing and Using Models* *Engaging in Argument from Evidence* *Constructing Explanations*	*Cause & Effect*
Fracking	*Engaging in Argument from Evidence* *Constructing Explanations* *Analyzing and Interpreting Data*	*Stability & Change*
Wetlands	*Constructing Explanations* *Engaging in Argument from Evidence* *Constructing Explanations*	*Stability & Change*
Freshwater Resources	*Engaging in Argument from Evidence* *Constructing Explanations* *Analyzing and Interpreting Data*	*Cause & Effect*
Extreme Weather	*Engaging in Argument from Evidence* *Constructing Explanations* *Analyzing and Interpreting Data*	*Cause & Effect*
Fossils	*Engaging in Argument from Evidence* *Constructing Explanations*	*Stability & Change*
Origins of the Universe	*Engaging in Argument from Evidence* *Constructing Explanations*	*Stability & Change*

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.



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 ecosystemservices

Figure 1. Sample Explanation Task Item

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

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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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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