Engaging Students in Sensemaking via the Science and Engineering Practices

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ABSTRACT

As educators, we recognize that commercially prepared curricula advertised as “NGSS aligned” do not necessarily emphasize student sensemaking. In this article, we describe our process of modifying such curricula by reflecting on previous instruction and planning for future instruction that centers student sensemaking in a middle school unit on chemical reactions. We highlight the ways that a set of publicly available pedagogical tools (known as the ASET SEP Tools) focused our discourse on a shared vision of sensemaking that is appropriate to expect of middle school students. We encourage our fellow teachers to use the SEP Tools to support these kinds of collaborative, reflective conversations as they strive to center and support their students’ scientific sensemaking.

KEYWORDS: Sensemaking; Science and Engineering Practices; Modeling; Reflective Practice

In our science instruction, we strive to engage our students in scientific sensemaking, or "actively trying to figure out how the world works" within a classroom community of fellow sensemakers (National Science Teaching Association n.d., paragraph 1). NSTA identifies four critical attributes of sensemaking that high-quality lessons exhibit: phenomena, science and engineering practices (SEPs), student ideas, and science ideas. In sensemaking lessons, the science and engineering practices are the *vehicles* that students use "to make sense of the science ideas needed to explain the how or why of a phenomenon" (NSTA n.d., paragraph 1). Unfortunately, the curricula that we use in our classrooms do not always center student sensemaking as the primary goal of instruction. Thus, we find ourselves frequently modifying those curricula to "beef up" students' sensemaking opportunities. To that end, we have found a free, publicly available set of tools (known as the ASET SEP Tools) to be very helpful in supporting this work.

In this article, we (Tiffany, a middle school science teacher, and Amy, a science teacher educator) first describe the ASET SEP Tools, then provide a detailed example of how we used one of them to enhance student sensemaking opportunities in a middle school unit on chemical reactions. We conclude with some general recommendations for getting started using the SEP Tools in your own classroom. Although we focus on sensemaking via modeling (and how we used the SEP 2 Tool for grades 6–8) in this article, our purpose is to demonstrate the usefulness of the SEP Tools more generally, for the purposes of reflecting on past science teaching and/or planning for future science teaching that better engages students in sensemaking. We hope that this information will be useful to teachers who want to try out the tools for similar purposes.

The ASET science and engineering practices tools

The Alliance for Science Educators Toolkit (ASET 2015) includes a set of SEP Tools that were designed to help teachers attend to sensemaking as they plan for and reflect on their own teaching. The SEP Tools can be used by individual teachers, as well as collaboratively among multiple teachers. The SEP Tools subdivide each SEP into discrete and digestible components meant for easy access and application to lesson/unit planning and preparing precise learning objectives (Sinapuelas et al. 2018).

There is a two-page SEP Tool for each practice, and every SEP Tool is downloadable as a fillable PDF (see Figures 1 and 2 for one example, and the reference for ASET with a link to the complete set). The first page of each SEP Tool provides a short description of the practice, a list of the components of that practice, a yes/no column to indicate each component's presence/absence, and columns for describing the teacher and student actions that match the component. The second page includes grade band descriptors that reveal the complexity of each SEP, providing very clear characteristics of the practice as it is used by students in grades K–2, 3–5, 6–8, and high school.

Example: Using the SEP 2 Tool to enhance student sensemaking via modeling

Working together, we used a SEP Tool to analyze, evaluate, and modify a commercially prepared middle school unit focused on chemical reactions that Tiffany taught for the first time the previous school year. Reflecting on the unit, we recognized that its sensemaking is anchored around a concerning, real-world phenomenon (an unknown, reddish-brown substance was produced in the tap water of a neighborhood that gets its water from a well) and consistently works toward specific science ideas—two critical attributes of sensemaking. But we were dissatisfied with its overall opportunities for leveraging students' ideas and engaging in the SEPs (the other two critical attributes of sensemaking). Modeling in the unit was essentially limited to students individually manipulating (via a digital simulation or hands-on activity) a molecular model provided by the curriculum. While using an existing model to explain a phenomenon is one way to engage in sensemaking, the ASET SEP Tool helped us to recognize that students could be doing so much more (and different

FIGURE 1: ASET SEP tool for developing and using models, Page 1.

ASET Science & Engineering Practice (SEP) Tool: Developing & Using Models

Name or ID:
Lesson/Unit Title:
Intended Grade:

Directions for use

Indicate if a component is present using Y (yes) or N (no) and then, if it is present, fill in the right 2 columns.
A single lesson will most likely not address each of the components below.
The numbering of these components is not meant to indicate they should be used in sequence, they are simply for reference.

SEP 2	**Developing and Using Models:** A practice of both science and engineering is to use and construct models as helpful tools for representing ideas and explanations. These tools include diagrams, drawings, physical replicas, mathematical representations, analogies, and computer simulations. Modeling tools are used to develop questions, predictions and explanations; analyze and identify flaws in systems; and communicate ideas. Models are used to build and revise scientific explanations and proposed engineering systems. Measurements and observations are used to revise models and designs.

Components of SEP: In this lesson/unit plan, it is clear that students have a structured opportunity to:	Present? **Y/N**	**What teacher actions were taken to facilitate this component for students?**	**What are the students doing? What sensemaking or intellectual work are students doing?**
1) **Describe** components and characteristics of models			
2) **Develop** models consistent with prior evidence or theories to represent, explain, and/or describe a phenomenon			
3) **Use** models to describe relationships between components, predict outcomes, and/or test ideas to explain a phenomenon			
4) **Compare** and/or **evaluate** features and limitations of (a) model(s)			
5) **Revise** models based on additional evidence*			

* This component is not required in K-2 or 3-5 grade bands

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kinds of) modeling that better reflects the nature of scientists' sensemaking. We found the grade band descriptors to be particularly useful in guiding our expectations for what middle school students can do, which in turn helped us to design classroom practices to facilitate their sensemaking. Next, we describe how we used the ASET SEP Tool to enhance four aspects of Developing and Using Models (SEP 2) that students used to make sense of the unit phenomenon.

Aspect 1: Connecting the observable and unobservable features of phenomena

We first attended to Component 2: *Develop models consistent with prior evidence or theories to represent, explain and/or describe a phenomenon,* and specifically to the grade band descriptor: *Students develop models that reasonably represent, explain, and/or describe both literal and unobservable features of scientific phenomena* (see Figure 2). Reflecting on the previous year's classes, we felt that the students became too quickly focused on the unobservable features of the phenomenon (the chemical reaction at the atomic level) while losing sight of the "big picture" literal features (the macroscopic changes in the water). We wanted the students to understand that the atomic-level interactions that they learn about at school are directly connected to consequential changes that could impact people in the real world (e.g., drinking water contamination) and that scientific modeling can connect one to the

FIGURE 2: ASET SEP tool for developing and using models in grades 6–8, Page 2.

ASET Grade Band Criteria (Grade Band: 6-8) - Science & Engineering Practices

SEP 2: Developing and Using Models: Modeling in 6–8 builds on K–5 experiences and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems.	
By the end of the grade band **students** will have had a structured opportunity to develop an understanding of each of these. Individual lessons or units should include opportunities for **students** to practice one or more of the following components ……	
1) **Describe** components and characteristics of models	Using a model they developed, or an existing model, students: a. **specify/identify** observable and unobservable elements of the model (and their attributes) **needed to explain** the phenomenon or communicate the desired information b. **describe** the key relationships or interactions among model elements as they relate to the phenomenon or aspect of the phenomenon being addressed c. **describe** the correspondence between specific model elements and relationships, and the relevant components of the real world object or phenomenon that they represent
2) **Develop** models consistent with prior evidence or theories to represent, explain, and/or describe a phenomenon	Students develop models that: a. are **consistent with prior evidence and scientific theories** about the phenomenon b. reasonably represent, explain, and/or describe both literal and unobservable features of scientific phenomena c. include only components and relationships that are relevant to the purpose of the model Using these models students: a. define and clearly **label all of the essential variables** or factors (components) within the system being modeled, including uncertain and less-predictable variables b. describe/demonstrate the **relationships** among the components of the model, including relationships that are not directly observable, but predict observable phenomena
3) **Use** models to describe relationships between components, predict outcomes, and/or test ideas to explain a phenomenon	Using a model they developed, or an existing model, students: a. Correctly and completely **describe the components** and mechanisms of a scientific phenomenon providing a causal account including mechanisms that are not directly observable b. Generate new knowledge including: i. Construct a correct and complete **prediction** about a phenomenon ii. Generate data to **test ideas** about phenomena iii. Generate **testable** questions about phenomena iv. Make meaningful **comparisons** between phenomena v. Support their **own thinking** about and understanding of a phenomenon vi. **Apply** models to related phenomena
4) **Compare** and/or **evaluate** features and limitations of (a) model(s)	Using a model they developed, or an existing model, students: a. **Identify, describe, and evaluate** the appropriate boundaries and limitations of a model with respect to explaining the phenomenon or communicating the desired information b. **compare** and **evaluate** the ability of different models to accurately represent and account for patterns in phenomena, and to **predict** related phenomena.
5) **Revise** models based on additional evidence*	Using a model they developed, or an existing model, students: a. **Modify** a model – based on evidence – to match what happens if a variable or component of a system is changed b. **Revise** a model **to increase its explanatory and predictive power**, taking into account additional evidence or aspects of a phenomenon.

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other. We designed a model scaffold (Windschitl and Thompson 2013) that included spaces for both a "zoomed in" perspective (at the atomic level) as well as a "zoomed out" macroscopic view of what was happening in the well water.

Aspect 2: Representing the mechanism of change

Next, we attended to Component 3: *Use models to describe relationships between components, predict outcomes and/or test ideas to explain a phenomenon*, and specifically, the descriptor: *Using a model they developed, or an existing model, students correctly and completely describe the components and mechanisms of a scientific phenomenon, providing a causal account, including mechanisms that are not directly observable*. In the previous year, the students' models tended to include the reactants and products of the chemical reaction happening in the water (sort of like before and after "snapshots" of the reaction) but did not represent the mechanism that transformed those reactants into products. In the model scaffold, we included a "before, during, after" structure, with the goal of helping students explicitly attend to the mechanism of the atoms in the molecules breaking apart and rearranging in new combinations in the "during" part of the scaffold, while also showing the molecules of the reactants and products in the "before" and "after" spaces.

Aspect 3: Reflectively and iteratively revising their models

With the model scaffold in place, we then focused on Component 5: *Revise models based on additional evidence*, and the descriptor: *Students revise a model to increase its explanatory and predictive power, taking into account additional evidence or aspects of a phenomenon*. Previously, the students had generated just one, "final" model of the phenomenon (at the end of the unit). To achieve the vision of the grade band descriptor, we strategically identified two additional places in the unit where students could develop models: (1) immediately after being introduced to the anchoring phenomenon, but before generating any evidence about what the unknown substance might be or how it got in the water (initial model), and (2) after students had generated sufficient evidence (through classroom investigations) that the reddish-brown substance was rust and was formed via a chemical reaction between the town's iron pipes and some fertilizer from a nearby farm that was found in the town well ("midway" model). Toward the end of the unit (as they learn about conservation of matter), students are expected to recognize that based on the chemical makeup of the reactants (the fertilizer and the iron pipes), there must be another product (in addition to the rust) in the water. Thus, their final model could account for this change in their thinking, and they could use scientific reasoning to deduce the chemical makeup of that additional product (sodium nitrite). As part of the revision process (for the midway and final models), students would first view their previous model(s) and, after creating a revised version, reflect on what they changed and why, ideally citing evidence from in-class investigations. We hoped that this modification would help students understand how and why scientists revise models—reflectively and iteratively as their thinking changes—as they make sense of phenomena (see Figures 3–5 for examples of students' initial, midway, and final models).

Aspect 4: Publicly evaluating their models

For our last modification, we focused on Component 4: *Compare and/or evaluate features and limitations of (a) of model(s)*, and the descriptor: *Using a model they developed, or an existing model, students compare and evaluate the ability of different models to accurately represent and*

FIGURE 3: Student initial model of the changes in the tap water.

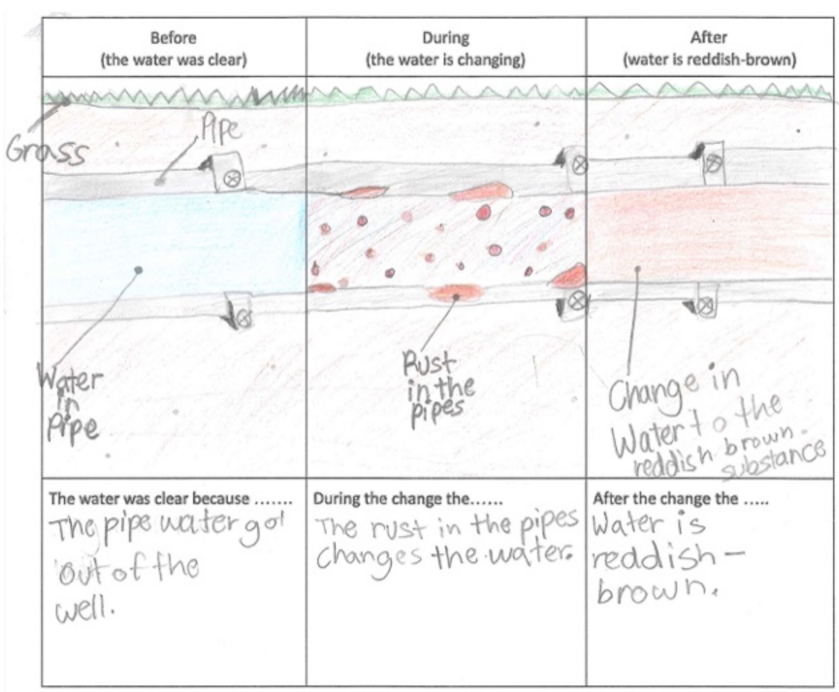


FIGURE 4: Student midway model of the changes in the tap water.

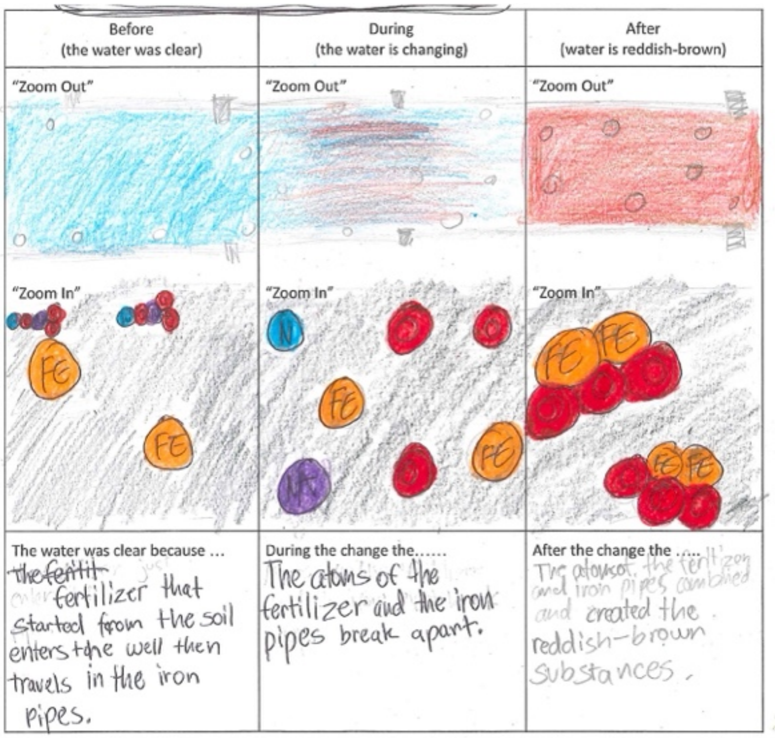
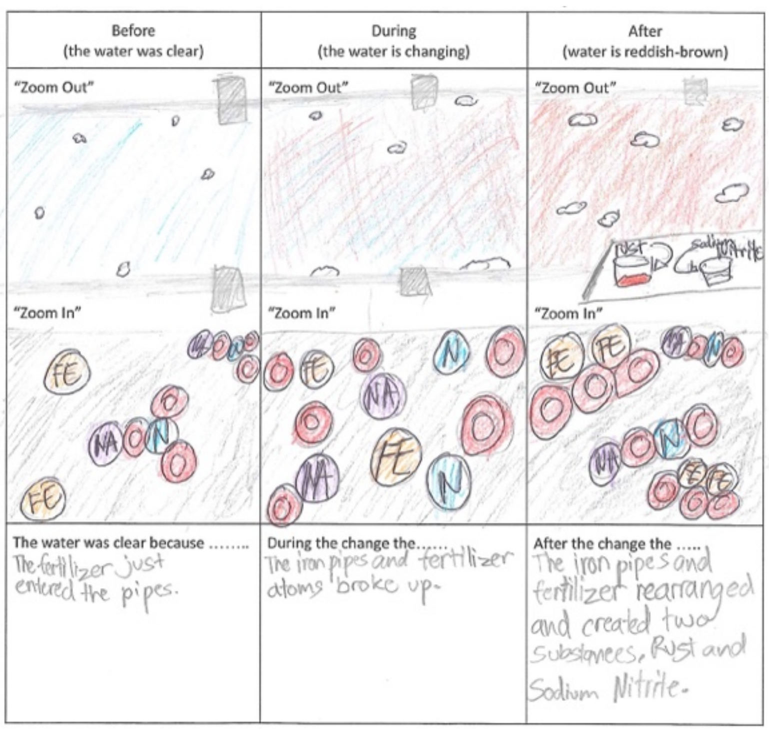


FIGURE 5: Student final model of the changes in the tap water.



account for patterns in phenomenon. Previously, students generated their models of the phenomenon without evaluating those models or comparing them to any other students' models. Thus, we designed a three-part activity to support students in comparing, evaluating, and giving each other feedback about the various models they produced. For each iteration of the model, students would first work together in small groups to generate a model that they could all agree on, using a large (whiteboard) version of the model scaffold. Second, they would do an interactive "gallery walk" to view other groups' models and provide those groups with written feedback using color-coded sticky notes (to suggest additional ideas, point out areas needing revisions, and pose questions for the group to consider; Windschitl and Thompson 2013). Third, they would come together to make comparisons across the models and discuss which aspects of the models were most "productive" for explaining the phenomenon. In this way, modeling in the classroom could better reflect the nature of scientists' work as a social endeavor.

Using the SEP tools in your classroom

We know that teachers want their students to have plentiful opportunities for scientific sensemaking. Based on our experience, we believe that other teachers will find the SEP Tools very useful for helping them work toward that goal. The SEP Tools are useful whether working solo or in collaboration with other teachers, but we do encourage you to engage in this work with other teachers whenever possible. We found that using the language from the tool in our collaborative conversations really helped us to clarify and align our thinking about what it looks like for middle school students to be fully engaging in the practices, as defined by the *NGSS*. If you are the sole science teacher in your school or district who wants to use the SEP Tools with a thinking partner, you might consider reaching out to other teachers via your local or state science teacher association, your county office of education, or a professor of science education at a nearby university. Whether you use the SEP Tools individually or collaboratively, we provide a few recommendations to help you get started.

First, start small. Choose a single lesson where you feel that there could be more, better, or different opportunities for student sensemaking than presently exist. Likewise, choose a specific SEP that is most appropriate for that lesson's sensemaking work. Next, use the grade band descriptors (on the second page of the tool) to identify components of sensemaking that your students are already doing in that lesson. As you consider these components, double check who is doing the "heavy lifting" of the intellectual work of this kind of sensemaking. If you realize that you are doing the heaviest lifting, then you might consider ways to shift some agency for that work to your students and how you could facilitate that sensemaking. For example, when your students plan an investigation, you might use the SEP 3 Tool to create opportunities for them to take multiple parameters into account, rather than determining those parameters yourself (see link to "Planning and Carrying out Investigations: Component 3" in Online Resources). Likewise, you might identify a component (or components) of the SEP that would be appropriate for students to use for sensemaking in a lesson but is currently lacking. For example, perhaps your students construct scientific arguments in class, but you also want them to learn to compare and critique those arguments (and the arguments of others). You could use the SEP 7 Tool to define criteria for that critique (see link to "Engaging in Argumentation from Evidence: Component 1" in Online Resources). Lean on the SEP Tool's grade band descriptors to provide a vision of what that work might look like in the lesson and think carefully about how you can facilitate that sensemaking. Keep in mind that a single lesson will most likely not address each of the components of a SEP. Rather, students should have opportunities to practice each component by the end of the grade band. As you gain more experience using the SEP Tools to reflect on and plan for sensemaking in your classroom, you can use multiple SEP Tools, "zooming out" to look across a unit, a school year, or even a grade band. We hope that you find the SEP Tools as useful as we do for providing students with meaningful sensemaking opportunities. ●

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ONLINE RESOURCES

Planning and Carrying out Investigations: Component 3—*https://tinyurl.com/3vwn63jx*

Engaging in Argumentation from Evidence: Component 1—*https://tinyurl.com/nmkb78hz*

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