Molecular Processes in Earth Systems

DEVELOPER: OpenSciEd

GRADE: High School **|** **DATE OF REVIEW:** January 2024

Molecular Processes in Earth Systems

EQuIP RUBRIC FOR SCIENCE EVALUATION

OVERALL RATING: 8
TOTAL SCORE: E

CATEGORY I: NGSS 3D Design Score	CATEGORY II: NGSS Instructional Supports Score	CATEGORY III: Monitoring NGSS Student Progress Score
2	3	3

Click here to see the scoring guidelines.

This review was conducted by the Science Peer Review Panel using the EQuIP Rubric for Science.

CATEGORY I CRITERIA RATINGS			CATEGORY II CRITERIA RATINGS			CATEGORY III CRITERIA RATINGS		
A.	Explaining Phenomena/ Designing Solutions	Extensive	**A.**	Relevance and Authenticity	Extensive	**A.**	Monitoring 3D Student Performances	Extensive
B.	Three Dimensions	Adequate	**B.**	Student Ideas	Extensive	**B.**	Formative	Extensive
C.	Integrating the Three Dimensions	Extensive	**C.**	Building Progressions	Extensive	**C.**	Scoring Guidance	Extensive
D.	Unit Coherence	Extensive	**D.**	Scientific Accuracy	Extensive	**D.**	Unbiased Tasks/Items	Extensive
E.	Multiple Science Domains	Adequate	**E.**	Differentiated Instruction	Extensive	**E.**	Coherence Assessment System	Extensive
F.	Math and ELA	Extensive	**F.**	Teacher Support for Unit Coherence	Extensive	**F.**	Opportunity to Learn	Extensive
			G.	Scaffolded Differentiation Over Time	Adequate			

Summary Comments

Thank you for your commitment to students and their science education. NextGenScience is glad to partner with you in this continuous improvement process. The unit is strong in several areas, including:

- Use of a high-interest, well-developed phenomenon that is widely discussed and relevant to current events.
- The strong use of developing, revising, and using modeling when considering atomic models and chemical reactions. Students consider the merits and limitations of these different types of models.
- Development of a coherent and extensive assessment system integrated throughout this unit. Each summative assessment and many formative assessments include sample student responses, suggested remediation steps for varying levels of student proficiencies, and clear alignment to each of the claimed elements of Science and Engineering Practices (SEPs), Disciplinary Core Ideas (DCIs), and Crosscutting Concepts (CCCs).
- Provision of a clear system of supports for teachers to meet the needs of emerging multilingual learners, struggling readers, and students interested in extending their learning.

During revisions, the reviewers recommend paying close attention to the following areas:

- **Connections to sustainable development.** At several points students discuss or evaluate sustainable material design and development, but do not extend that learning to connect the benefits from planning for space exploration to a more immediate benefit for Earth.
- **Patterns at varying scales**. There are several lessons that cite CCC: 1.1 as an element being developed, but often does not require students to flexibly move between scales when attempting to discern patterns. Consider including prompts or suggestions for students to more explicitly examine both macroscopic and microscopic scales simultaneously throughout their learning.
- **Elements used once in a unit.** Many elements are claimed or used only once in a unit, including two learning goals. This makes it difficult for students to gain proficiency and develop independence in the element during the unit.

Note that in the feedback below, black text is used for either neutral comments or evidence the criterion was met, and purple text is used as evidence that doesn't support a claim that the criterion was met. The purple text in these review reports is written directly related to criteria and is meant to point out details that could be possible areas where there is room for improvement. Not all purple text lowers a score; much of it is too minor to affect the score. For example, even criteria rated as Extensive could have purple text that is meant to be helpful for continuous improvement processes. In these cases, the criterion WAS met; the purple text is simply not part of the argument for that Extensive rating.

CATEGORY I

NGSS 3D DESIGN

I.A. EXPLAINING PHENOMENA/DESIGNING SOLUTIONS

I.B. THREE DIMENSIONS

I.C. INTEGRATING THE THREE DIMENSIONS

I.D. UNIT COHERENCE

I.E. MULTIPLE SCIENCE DOMAINS

I.F. MATH AND ELA

I.A. EXPLAINING PHENOMENA/DESIGNING SOLUTIONS

Making sense of phenomena and/or designing solutions to a problem drive student learning.

i. Student questions and prior experiences related to the phenomenon or problem motivate sense-making and/or problem solving.

ii. The focus of the lesson is to support students in making sense of phenomena and/or designing solutions to problems.

iii. When engineering is a learning focus, it is integrated with developing disciplinary core ideas from physical, life, and/or earth and space sciences.

Rating for Criterion I.A. Explaining Phenomena/Designing Solutions	Extensive *(None, Inadequate, Adequate, Extensive)*

The reviewers found extensive evidence that learning is driven by students making sense of phenomena or designing solutions to a problem. Students are provided with numerous opportunities to engage with investigative phenomena using their past experiences, and the unit also supports students' sense-making through an iterative sequence of learning related to components of the unit topic: survival in space. The unit is framed by survival related to the Artemis mission. However, the Artemis mission or other specific space travel is rarely referenced in the unit. There are more topic/problem connections of survival in space within the lessons. The findings in this report are therefore connected to this general topic of space survival versus how the "Artemis plan involves going to and eventually staying on the Moon for up to one month, and future plans involve going to and staying on Mars for even longer" (Teacher Edition, page 43).

Student questions and prior experiences related to the phenomenon or problem motivate some sense-making or problem solving in the unit and motivate students to learn about the broader topic of survival in space. Related evidence includes:

- Lesson 1: Students are asked to watch a video announcing the Artemis missions and are asked to consider questions such as "How is NASA going to do this?" and "Why is NASA doing this?" (Teacher Edition, page 40). These questions serve as a springboard to later work where students consider the nuances behind the "how" question.
- Lesson 1: Students discuss substances required to support life on and off Earth and how resources could be reused or recycled and later bring home questions of "What is a process that people (in our family or in our community) have used to recycle substances?" and "How did the process change the material(s) they were trying to recycle?" (Teacher Edition, pages 48–49).
- Lesson 1: As part of the process leading up to the building of the Driving Question Board (DQB) students "Individually record questions. Display slide DD. Students should individually record the questions that they now have related to recycling or making the substances we need to

survive beyond Earth. Distribute three yellow sticky notes and a marker to each student and give students a few minutes to record their questions. Instruct students to leave the sticky notes in their notebooks to share next period" (Teacher Edition, page 55).

- Lesson 2: "Consider other properties of water. Say, we have spent some time in the first two units of the year studying different properties of water. You have already mentioned a couple. Let's think a little more about those and some of the other properties we have students…What properties of water have we already figured out this year that make it so important for life on Earth?...[and] What is it about the properties that make water essential for life?" (Teacher Edition, pages 66–67).
- Lesson 7: As an alternate activity, teachers are given an opportunity to "…also go back to the DQB at this point and ask students which questions we have that could be answered by figuring out more about bonds or are about bonds. Suggest that we should figure those out next" (Teacher Edition, page 167).
- Lesson 8: Students consider potential substitutions for water as a substance we need to survive away from Earth. "Display slide A. Read the text on the top of the slide, people often search for ways to find or make substitutes for substances when they are in short supply. To do this they often consider what properties the substitute would need to have. Point out that there are lots of examples of this and one that they might be most familiar with is related to cooking or preparing food. Have students consider the two prompts on the slide with a partner, and then discuss examples as a class" (Teacher Edition, page 176).
- Lesson 9: "Take stock of our questions. Display slide W. Distribute Our DQB Questions to each student or make a digital copy of one they can each annotate available. Give students the remaining time to work with a partner to take stock of which questions we have made additional progress on over the last few lessons" (Teacher Edition, page 204).
- Lesson 9: After completing the Mid-Point Assessment, students are asked to "…record what 1–2 new questions they now have on separate sticky notes and save them in [their] science notebook" (Teacher Edition, page 205).
- Lesson 10: "Reflection on the DQB check-in. Display slide A and have the Driving Question Board visible. Have students turn and talk with a partner to share the new questions they developed at the end of Lesson 9. Then share some examples with the whole class. Listen for these ideas: We wanted to figure out more about how people can make substitute substances. We wanted to understand more about or other ways about how people could make different materials off of Earth. Give students the opportunity to add their new questions to the DQB. Generate specific pieces of information needed. Display slide B and point out that early in the unit, we examined lots of different, important materials (like steel and glass) and processes (like photosynthesis). Ask, What else do we have to know to understand how to actually make those things? Listen for these ideas: We need to know how the substances are mixed. We need to know what devices are needed. We need amounts. Say, I have an updated version of a resource we have from earlier in the class that might be able to help us out" (Teacher Edition, page 211).
- Lesson 12: "Motivate the need for additional data about Mars. Say, OK, we found some information on the NASA websites about what elements are on the Moon and Mars. It seems

like Mars has most of what we need to make the substances we need to live and work in space but we are not sure if it has any silicon. And that is something we need to make concrete and glass to build shelters. Ask students if they have ever heard of the Mars rovers. Show slide L and explain that the rovers are robotic vehicles equipped with scientific instruments capable of identifying elements and molecules using spectroscopy, and NASA has sent five rovers to Mars since 1997. Tell students that you have some data from rovers about the composition of rocks and soils on Mars for them to look at" (Teacher Edition, page 249).

- Lesson 12: Students complete a reading about sulfur-based concrete and after discussing the text, revisit the DQB. Students are asked, "How would the explanation provided by the authors help address what we need to live and work permanently on Mars?" and "What line(s) of questions on our Driving Question Board does this solution address?" (Teacher Edition, page 254).
- Lesson 13: "If students had questions about recycling on the driving question board (which there likely will be some), make reference to those now and/or ask students now and ask how both questions are related to the driving question of the unit, 'How can we find, make, and recycle the substances we need to live beyond Earth and on it?'. Students are also asked to question 'what substances do you know that we can recycle?', 'what happens to those substances when they are recycled?', and 'why do we think we can recycle some substances but not others?'" (Teacher Edition, page 263).
- Lesson 14: Students are asked to evaluate claims relating to the feasibility of bringing all needed materials to live and work off of Earth. "Reflect on implications. Display slide G. Give students three minutes to update their Progress Trackers. Return to the question of space survival. Ask students, Given what we know now, do we think people could live and work off of Earth, or should try? Take a couple responses, then acknowledge this is a big question we should return to next time" (Teacher Edition, page 279).
- Lesson 15: Students are asked to synthesize their learning and revisit the class created DQB to determine if all of their questions had sufficiently been answered and whether they were able to answer the overarching question for the unit. "Evaluate what questions the class has answered from the DQB with a partner. Present slide J. Provide students the list of DQB questions, which you started in Lesson 10, to contain all the student questions from the DQB. Add any new questions that have been added and have students tape it into their science notebook. Have students mark additional questions they think the class has answered: We did not answer this question or any parts of it yet: O Our class answered some parts of this question, or I think I could answer some parts of this question: ✓ Our class answered this question, or using the ideas we have developed, I could now answer this question: ✓+ Answer our questions using evidence. Have students select a question and write an answer with supporting evidence. Students will use this in the Consensus Discussion. Mark questions on the classroom DQB. Present slide K. Students should walk up to the DQB and put a checkmark on five questions they think the class made progress on. Reflect on answered questions in a Scientists Circle. Present slide L and lead students in the following Consensus Discussion" (Teacher Edition, page 290).

The focus of the lessons is to support students in making sense of phenomena or problem solving. There are many smaller phenomena such as finding water and creating substitutes from matter in the solar system that contribute to the overall concept of survival in space and how chemistry plays a role in those considerations. Related evidence includes:

- Lesson 1: "Orient to NASA's plans for the near future. Display slide B. Say, I have a video from NASA that lays out pretty ambitious plans. Let's orient ourselves to what some of those plans are and try to figure out why NASA would be trying to do this sort of thing in the first place…suggest that in order to understand what NASA is actually planning to do and why, it may make sense for us to take a moment to analyze what was said in the video more closely. Display slide C. Distribute a copy of NASA Artemis Transcript to each student. Emphasize the four focal questions on the slides and handout that students should use to make sense of the video" (Teacher Edition, page 40).
- Lesson 2: Students identify water as an essential resource at the end of Lesson 1 and, at the start of the second lesson are asked to revisit their thinking to, "Consider other properties of water. Say, we have spent some time in the first two units of the year studying different properties of water. You have already mentioned a couple. Let's think a little more about those and some of the other properties we have students…What properties of water have we already figured out this year that make it so important for life on Earth?...[and] What is it about the properties that make water essential for life?" (Teacher Edition, pages 66–67).
- Lesson 3: Students build on their knowledge of water's properties and associated chemical reactions to consider "…the types of data that would help us determine if water is present…look for students to say: we need zoomed in images of the surface; we need to look at other areas of the surface; or, we need to take samples of the soil and atmosphere" (Teacher Edition, page 79). Students go on to consider how water might interact with the surface of other planetary bodies (e.g., through erosion) compared to other processes that might differently interact with the surface (e.g., through magma released due to volcanic activity).
- Lesson 4: "Build consensus around why water behaves differently than other liquids. Display slide AA. Lead a discussion around Mars Geological Landforms and the freezing models. Ask a few students to share their models and ideas about why water expands when it freezes and causes frost heaving. Listen for language around 'pulls' and 'attracts' as students share their ideas and models. Ideas may include 'what' or 'why' types of reasoning; push students toward explaining why water is so different" (Teacher Edition, page 103).
- Lesson 5: "Discuss substances in atmospheres. Present slide B. Say, water is pretty important for our survival in space but it's not the only substance we will need. Take a minute to turn and talk with a partner about the prompts on the slide. After students have had a few minutes to discuss the prompts, invite students to share their ideas. What substances do we need that we might find in the atmosphere of a moon or planet? How could we determine what substances are in atmospheres?...[and] Have you ever seen the color or brightness (intensity) of the sky change because of what was in the air?" (Teacher Edition, page 118).
- Lesson 6: Students consider what elements, aside from those that make up water, might be necessary for life on other planets. Students attempt to explore the patterns in which elements make up most essential substances through understanding bonds formed. "Create a Progress

Tracker entry to describe how patterns in element properties can be used to organize the elements into t[sic] a chart or table. How might knowing these patterns help us use chemistry to make stuff so we can live beyond Earth?" (Teacher Editon, page 150).

- Lesson 10: Students learn about the use of certain ions as cleaning agents and are asked to several reflection questions. "Reflect on the original reactions. Have students take out Key Chemical Reactions and display slide I. Give students a few minutes to reflect on the reactions using the prompts below, then discuss: How is this cleaning process similar to the other reactions we saw at the start of the lesson? How is it different? How might the structures involved determine how similar or different the reactions are? Listen for these ideas: Bonds break and form in all the reactions. Water is often involved, but not always. Several of the reactions seem to involve chunks of atoms together like we saw in this lesson's water-cleaning reactions. Some have three substances in the inputs. Water might be helpful in breaking apart ionic or other bonds. Reactions with lots of carbon seem to form really big molecules" (Teacher Edition, page 216).
- Lesson 11: Students consider the need to grow food in space and the teacher is asked to "Problematize that these might require additional matter inputs for plants to produce. Display slide B and discuss the question on the slide, What other matter inputs besides water and carbon dioxide do farmers provide their crops to ensure they grow and yield nutritious produce? Students will likely suggest fertilizer. If students do not suggest fertilizer, ask them, what if the soil on Mars doesn't contain nutrients that plants need? Once the class agrees that we may need fertilizer as well, ask students if they know what fertilizer is, or what the main ingredients of fertilizer are. Accept all responses. Suggest that we collect some additional information to see if we can refine our ideas about this process to ensure that we successfully grow nutritious food on Mars or other places off Earth" (Teacher Edition, page 223).
- Lesson 12: "Consider what we need to make other substances for survival off of Earth. Present slide H. Distribute Substances for Survival and Search for Elements. Cue students to think about the amounts of different elements we will need to make other substances for survival in space. Ask, In addition to supplying plants with the elements to make glucose, what elements, and how many of them, would we need to make steel? Glass? Cement? Plastic? Work with a partner and use Substances for Survival to develop a list of elements we would need for each substance. Record them on question 1 of Search for Elements" (Teacher Edition, page 247).
- Lesson 13: "Identify some candidate substances. Display slide Y. Read the text at the top of the slide and then have students discuss the related prompt with a partner for 2–3 minutes. Then discuss these possible candidates as a class. Point out that if we are hopeful to see scientists and engineers develop a substitute for some of these in our near future, that maybe those are actually under development today. Ask students how we could find out if they are. Students will say we could do some additional research on these topics. Work with the class to commit to doing just that—looking into what new research is happening along these lines in our next lesson, based on our different areas of interest. Collect Recycling Ideas Organizer for assessment" (Teacher Edition, page 270).
- Lesson 14: Students are encouraged to reflect on their prior lessons' learning about recycling and potential for substituting one substance for another as they consider potential

> replacements for the materials needed for survival away from Earth. Teachers are asked to, "Elicit ideas about replacements. Display slide B. Ask, What would or could make replacement materials better than the ones we have now? Listen for these ideas: They could be easily recyclable. Maybe they could be made with fewer emissions or less harsh chemicals. They could last longer so we don't have to replace them as often. Say that these are all excellent ideas—ones that scientists and engineers are exploring now. Note that many involve making materials more sustainable—that is, able to be used in the long run without harming ecosystems, human systems, and the environment. Suggest that we check out materials that will help us learn more about them" (Teacher Edition, page 277).

Several lessons, such as Lessons 6, 7, and 8, focus primarily on the development of DCI-related knowledge but do not substantively connect that work back to a phenomenon or problem.

- Lesson 6: Students revisit atomic structure and composition and connect this learning to analyze and organize elemental cards. After they reorganize these cards based on new information about numbers of bonds, they discuss similarities and differences in how the cards were organized. Students update their progress tracker using the prompt "We have figured out so much using patterns in atomic number and number of bonds to help us organize the elements! How might knowing these patterns help us use chemistry to make stuff so we could live beyond Earth?" (Teacher Edition, page 150).
- Lesson 7: Students develop initial models about atomic structure, compare four different models of atomic structure, and then why elements in compounds form a specific bond with another element. An alternate activity is presented to navigate to Lesson 8. "For this Navigation, you could also go back to the DQB at this point and ask students which questions we have that could be answered by figuring out more about bonds or are about bonds. Suggest that we should figure those out next" (Teacher Edition, page 167).
- Lesson 8: Students begin the unit by identifying examples of substituting substances with similar properties. They compare polarity and properties of water and hydrogen sulfide and construct an explanation for why water molecules are more polar than hydrogen sulfide molecules. Students complete the Substitution Reasoning poster as the navigate to the next lesson. "Sum up. Emphasize that because of some its property differences like toxicity, we can't probably use hydrogen sulfide to replace water for any process we would need water for, the type of thinking we did today is what scientists do to try to find or create new substances that are better substitutes for what were currently use" (Teacher Edition, page 191). However, this may not be clear to students based on the information that was presented in the lesson.

Suggestions for Improvement

- Consider more frequently connecting the learning from the unit to the Artemis mission as well as future and current missions or to solving a specific problem rather than the general focus on survival in space. A video that highlights past, present, and future missions might also be helpful.
- Consider having students leverage learning opportunities as a means of continuing to make sense of phenomena or solve problems versus presenting them as "the next step" in the learning sequence, such as the alternate activity in Lesson 7.

I.B. THREE DIMENSIONS

Builds understanding of multiple grade-appropriate elements of the science and engineering practices (SEPs), disciplinary core ideas (DCIs), and crosscutting concepts (CCCs) that are deliberately selected to aid student sense-making of phenomena and/or designing of solutions.

i. Provides opportunities to *develop and use* specific elements of the SEP(s).

ii. Provides opportunities to *develop and use* specific elements of the DCI(s).

iii. Provides opportunities to *develop and use* specific elements of the CCC(s).

Rating for Criterion I.B. Three Dimensions	Adequate *(None, Inadequate, Adequate, Extensive)*

The reviewers found adequate evidence that the materials give students opportunities to build understanding of grade-appropriate elements of the three dimensions. Most claimed elements are grade appropriate and sufficiently developed during the unit, though several CCC elements, in particular, would benefit from more explicit development throughout the unit.

Science and Engineering Practices (SEPs) | **Rating: Extensive**
The reviewers found extensive evidence that students have the opportunity to use or develop the SEPs in this unit because students are supported to develop and use an overwhelming majority of the claimed SEP elements throughout this unit. Supplementary, non-focal SEP elements are present and, while not always developed, support student sense-making and learning throughout the unit.

Asking Questions and Defining Problems

- *Ask questions that arise from careful observation of phenomena, or unexpected results, to clarify and/or seek additional information. (1.1)*
  - Lesson 1: After examining the Artemis mission announcement and analyzing data collected in various space missions, students are told to, "individually record questions. Display slide R. Keep students in their small groups, but emphasize that students should individually record the questions that they now have. Distribute three blue sticky notes and a marker to each student and give them the remaining time to record their questions. Instruct students to leave the sticky notes in their notebooks" (Teacher Edition, page 46).
  - Lesson 9: After completing the Mid-Point Assessment, students are told to, "…record what 1–2 new questions they now have on separate sticky notes and save them in [their] science notebook" (Teacher Edition, page 205).
- *Ask questions that arise from examining models or a theory, to clarify and/or seek additional information and relationships. (1.2)*

- Lesson 1: After students examine particle-level models depicting chemical reactions, the teacher says to students, "Individually record questions. Display slide DD. Students should individually record the questions that they now have related to recycling or making the substances we need to survive beyond Earth. Distribute three yellow sticky notes and a marker to each student and give students a few minutes to record their questions. Instruct students to leave the sticky notes in their notebooks to share next period" (Teacher Edition, page 55).

- *Define a design problem that involves the development of a process or system with interacting components and criteria and constraints that may include social, technical, and/or environmental considerations. (1.8)*
    - Lesson 1: Students complete an Exit Ticket in which they determine the factors that dictate whether a given mission should be crewed or uncrewed and identify the substances or materials needed to survive long enough to complete the mission. The question of what we absolutely need to survive for more than a short time whether on or off of Earth is presented in context of the question "what else could we do to get these substances/materials if we can not[sic] bring them with us nor have them sent from Earth? Possible solutions should use our current technologies" (Day 1 Exit Ticket, page 1).

Developing and Using Models (focal SEP)

- *Evaluate merits and limitations of two different models of the same ~~proposed tool, process, mechanism or system~~ in order to select or revise a model that best fits the evidence ~~or design criteria~~. (2.1)*
    - Lesson 6: Students use a resource called Model Evaluation Support to engage with this SEP. *"*Identify merits and limitations of element tools. Pass out a copy of Model Evaluation Support to each student. Tell students to use the prompts on Model Evaluation Support to guide their interactions while they participate in the activity. Explain to students that when they are visiting other groups they should be looking for data patterns that follow their own organizational model, as well as those that are different. Tell students to make a T-chart in their science notebooks to record patterns that are supported and contradicted within similar element groupings" (Teacher Edition, page 147). They then come to consensus about the model of the element cards after considering different groupings and organizations of the cards to show patterns in the elements. "Let's consider our approach of layering multiple characteristics to help organize the element cards. We agreed that the number of protons was the most important characteristic, so let's begin there. ✱ Start by posting the large sticky note of hydrogen on the board/wall. Then, add helium. Ask, Where should we place lithium? I remember some of you saying that lithium and hydrogen both formed the same number of bonds. Look for students to suggest placing lithium below hydrogen. Continue to work with the class to build out a class consensus organization✱" (Teacher Edition, page 147).

- Lesson 7: Students consider different models of atomic structure. "We have looked at a lot of different atomic models, let's take some time to compare them side by side. Present slide J. Distribute Compare Atomic Models and give students about five minutes to individually complete the four questions handout. ✱ Explain that after we talk about their responses to the four questions, we will work as a class to name each of the atomic models. ✱ Discuss the merits and limitations of the atomic structure models. Present slide K." (Teacher Edition, page 162). They consider which model best fits predicting bonds between electrons. "Which of the four models would be best to show and predict the number of bonds between atoms? Why? All models have limitations, so let's consider, what are some limitations of each model" (Teacher Edition, pages 162–163). Later in the lesson, students use electron shell models and Lewis Dot models to examine valence electrons and explain bonds between elements in compounds. "Have the sets of partners you have already chosen share their models and explain their thinking. Point out areas where the models are in agreement, and summarize how every model illustrates that two of the valence electrons of carbon are shared with each oxygen atom. Ask, How did you know how many electrons from hydrogen interact with the oxygen molecule" (Teacher Edition, page 165).

- *Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. (2.3)*
  - Lesson 1: "Distribute Initial Reaction Model to each student and have them complete the handout individually. Provide at least six minutes for this activity… Begin to develop an initial consensus model. Gather students in a Scientists Circle…" (Teacher Edition, page 50).
  - Lesson 6: After students get more information about the element cards, they reorganize them. "Reorganize element cards by different properties. Present slide H. Explain to the small groups that they will add the number of bonds, or common ion charge that each element forms to the cards then use this new information to update the organization we developed earlier. Explain that groups will share their organization scheme with other groups, so they need to be able to explain how their group used the information on the cards to organize the elements. Give groups 5 minutes to organize their element cards. As groups work, walk around the room and assist as needed. Ask clarifying questions to help groups such as: What piece of information on the cards are you considering most important? Why? What information on the card is informing this decision? Is your group using a specific pattern in the information on the card to guide your organization process" (Teacher Edition, page 145). Later in the lesson they use their model as part of a prompt in their Progress Tracker. "Create a Progress Tracker entry to describe how patterns in element properties can be used to organize the elements into a chart or table. Say, We have figured out so much using patterns in atomic number and number of bonds to help us organize the elements! How might knowing these patterns help us use chemistry to make stuff so we could live beyond Earth? Look for students to suggest: We could predict what elements go together the best. We could predict which elements would dissolve in water because they form ions.

Say, It seems like we have figured out some very important information that would help us use chemistry to live beyond Earth. Let's take a moment to record those understandings in our Progress Trackers. Present slide P. Give students 3–4 minutes to create a Progress Tracker entry in their science notebooks✱" (Teacher Edition, page 150).

- Lesson 8: Students use models to make predictions. "Discuss the question on the slide. Students should say two bonds are being represented. Problematize the bond 'line.' Point out that nothing in the chemical formula tells us this, but the right two models (ball and stick and Lewis Dot) do. Ask how a single bond is being represented in the Lewis Dot model on the right. Students will say it is the two electrons in the overlapping dotted circles around each atom. Point out that the line representations in the second model (ball and stick) makes it seem like there is a physical connection between the atoms, but we know that is a representation that is simplification to show which two atoms are sharing the electrons, and it's not a physical structure connecting them. Identify a replacement atom. Display slide D. Ask the question on the slide, What is another element that should produce the same number of bonds with two hydrogen atoms? Point to where the question mark shown in the new chemical formula and molecular models shown on the slide. Encourage students to refer to their periodic table from lesson 7 to identify a candidate. After giving a half minute to do this, have students share" (Teacher Edition, page 177).
- Lesson 9: Students complete a transfer task where they use models of ibuprofen and an alternative. It is used as an element in questions 1, 2, 5, 6, and 7 (Teacher Edition, page 157).
- Lesson 11: Students develop models of ammonia and ammonium. "Model ammonia and ammonium with a partner. Present slide G. Remind students that they have multiple means of modeling from a previous lesson; if needed, direct them back to Compare Atomic Models to review the various ways they can represent atoms. ✱ Have students work with a partner to develop atomic-scale models of ammonia and ammonium. Tell groups they have about eight minutes to develop the two models. As groups work, rotate around the room and choose a few models to highlight at the beginning of the next class. It is okay if these models differ in how they account for the positive charge in ammonium. You can take photos of the models with your phone to upload to slides or collect these models at the end of class or at the beginning of the next class" (Teacher Edition, page 226).

- *Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena, and move flexibly between model types based on merits and limitations. (2.4)*
    - Lesson 4: Students compare force interaction models and molecular structure models to model water interacting with Mars-like materials. "Develop models to explain investigation results. Say, Last class, we designed our investigation because we were not sure about the surface features on Mars. Now that we have investigation results, and have modeled some properties of water, let's see if we can connect these two together. Let's try to model how these different substances interact with Martian soil to help

explain how these features formed. ✱ Display slide V. Tell students to use the molecule cutouts from Molecule Cutouts to help them think about which liquid would have a greater impact on the landscape based on differences in polarity and the differences in the resulting force interaction with neighboring particles. Encourage students to move the cutouts around on their desks or tables and talk through what is happening with their partners as they do so. Have students do this to help them explain both why some liquids might cause more erosion and why other liquids cause less erosion" (Teacher Edition, page 101).

- Lesson 7: Students compare models with a partner. They move between them as they consider similarities and differences of their models. "Develop initial models of atomic structure to take stock of our current understandings. Present slide B. Say, Let's take a moment to see where we are with how we are thinking about the structure of the atom before we try to figure out why is there a difference between the number of electrons an element has and the number of bonds an element forms. Since we are wondering about carbon, develop an initial model of a carbon atom and its structure which could explain these differences in your science notebook. Give students about 6 minutes to develop their models. After students have developed their models, have them meet with a partner and use the prompts on slide C to guide their discussion. After 4 minutes, lead a discussion using the prompts below: What sources of evidence did you use to develop your models? What similarities did you and your partner have in your models? What differences did you and your partner have in your models?" (Teacher Edition page 157). "Use a simulation to evaluate a new representation of electron structures within an atom. Remind students that yesterday, we decided to examine a different representation of an atomic model to help us make progress on our question, Why is there a difference between the number of electrons an element has and the number of bonds an element forms? ✱ Present slide H. Hand out Evaluate Another Model and have students access the simulation https://phet.colorado.edu/en/simulations/build-an-atom. Give students about 10 minutes to complete Evaluate Another Model…What pattern(s) did you see in these atomic models? How do these patterns relate to the patterns we noticed in the differences between the number of electrons and bonds formed by elements?" (Teacher Edition, page 161). "Compare models of atomic structure to consider electron shells. Say, We have looked at a lot of different atomic models, let's take some time to compare them side by side. Present slide J. Distribute Compare Atomic Models and give students about five minutes to individually complete the four questions handout. ✱ Explain that after we talk about their responses to the four questions, we will work as a class to name each of the atomic models. ✱ Discuss the merits and limitations of the atomic structure models. Present slide K." (Teacher Edition, page 162)
- Lesson 11: "Model ammonia and ammonium with a partner. Present slide G. Remind students that they have multiple means of modeling from a previous lesson; if needed, direct them back to Compare Atomic Models to review the various ways they can

represent atoms. ✱ Have students work with a partner to develop atomic-scale models of ammonia and ammonium." (Teacher Edition, page 226).

Planning and Carrying Out Investigations

- *Plan an investigation or test a design individually and collaboratively to produce data to serve as the basis for evidence as part of building and revising models, supporting explanations for phenomena, or testing solutions to problems. Consider possible confounding variables or effects and evaluate the investigation's design to ensure variables are controlled. (3.1)*
    - Lesson 4: Students design an investigation to collect data relating to different substances' abilities to create various landforms. "Discuss materials for the investigation. Tell students that you have some liquids on hand that they might want to use to investigate landform formation. Show them the water, vegetable oil, acetone, and isopropyl alcohol, as well as the sand and trays. Present slide B and have students discuss the questions on the slide with a partner. After two minutes, ask for students to share what they discussed." The questions on the slides are: "How could we use these materials to investigate if the landforms on Mars were made by water or some other liquid? What other materials or liquid would be important to try if they are/were available? How do the properties of these liquids compare to those of water?" (Teacher Edition, page 94).
    - Lesson 5: An optional extension is provided to allow students to "…include investigation design as desired. It is not a focal component of this lesson, but many students may benefit from revisiting 'control' procedures and thinking through their findings" (Teacher Edition, page 122). As this is optional, it is less likely that all students will use it.

Analyze and Interpret Data

- *Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. (4.1)*
    - Lesson 5: Students collect data about the differences in light that passes through a variety of samples in water. Teachers are directed to, "Give students a few minutes to record their observations about the water control. Students should refer to the spectrum without a sample in the top row of Spectrum Observations in addition to the faded version of that spectrum on each sample row. If necessary, remove and replace the sample in front of the light source so students can compare the light that comes through the sample to the control condition. Replace the water control with samples A–C, giving students 2 minutes per sample to record their observations" (Teacher Edition, page 123). Students observe absorption spectra for water using the Lesson 5 Spectra Demonstration Set-up or using slides 8–16 of C.3 Lesson 5 Transmission Spectra. Students then analyze the transmission spectra they create for each of those substances and use them to note similarities and differences between those substances.
    - Lesson 5: Students are given a set of atmospheric spectra collected from NASA's James Webb Space Telescope and asked to, "…determine what gasses are present in the atmospheres of Earth, Mars, Venus and Enceldaus (a moon of Saturn). Point out that

they can use the strategies that helped them identify the composition of the gas mixtures" (Teacher Edition, page 130).

Using Mathematics and Computational Thinking

- *Create and/or revise a computational model or simulation of a phenomenon, designed device, process, or system (5.1)*
    - Lesson 12: "Balance the equation for photosynthesis. Present slide C. Write down an unbalanced equation for photosynthesis on a piece of chart paper and leave space to balance the equation. Tell students to write down the process in their science notebooks and to leave some space between each reactant or product" (Teacher Edition, page 242). Students go on to balance an addition equation that focuses on how cement is created with the help of water that they may assume will evaporate; rather, through balancing the equation, they come to see that the model indicates that those atoms from water are incorporated into the products (Teacher Edition, page 251).
    - Lesson 15: Students balance equations that could be used to predict a potential molecule formed from the substances they already learned might be present on Mars. Teachers are directed to, "give partners about 10 minutes to develop their balanced chemical equations on their whiteboard. As groups are working, rotate around the room. Assist as needed and make sure partners show how they are balancing the equation. As you rotate around the room, choose 2–3 different balanced chemical equations to display to the class. Fats and proteins are good candidates for this, as they can be built out of components of carbon monoxide or dioxide, nitrogen, and other organic compounds. Steel is a mixture, not a compound, so it cannot be modeled in this way. Students may also realize that they have too many products, so some other 'leftovers' might form" (Teacher Edition, page 288).

Constructing Explanations and Designing Solutions

- *Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. (6.2)*
    - Lesson 8: "Explain some property differences of H_2S vs. H_2O. Display slide K. Emphasize that it may be hard to explain how and why hydrogen sulfide is poisonous without knowing more about the types of substances that make up different parts of our bodies, but we can probably explain other property differences. Discuss the 3 property differences highlighted on the slide. Suggested prompts include: How do differences in polarity explain why water is more cohesive than hydrogen sulfide? How would this also help explain why water has a higher boiling point than hydrogen sulfide? How would this also be related to why water is better at dissolving more things than hydrogen sulfide is as a liquid?" "What to do: Encourage students to recall what their explanations were for the first two properties in lesson[sic] 2 and 4. Encourage students to recall what our model was for why water dissolves salts so well from the prior unit OpenSciEd

Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)" (Teacher Edition, page 183).

- Lesson 8: "Display slide AA. Point out that earlier, we predicted that both H_2O and H_2S were polar, but did not have an explanation for their differences in polarity when we first compared their molecules shown on the slide, but we do now. Give students this time to individually summarize an explanation for why H O molecules are more polar than H S molecules." "What to do: Encourage students to recall what their explanations were for the first two properties in lesson[sic] 2 and 4. Encourage students to recall what our model was for why water dissolves salts so well from the prior unit OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)" (Teacher Edition, page 189).

Obtaining, Evaluating, and Communicating Information (focal SEP)

- *Critically read scientific literature adapted for classroom use to determine the central ideas or conclusions and/or to obtain scientific ~~and/or technical~~ information to summarize complex ~~evidence~~, concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms. (8.1)*
    - Lesson 10: "Set up the reading. Display slide D and distribute Cleaning Metal-Contaminated Water. Explain to students that they have seen similar readings before in OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit), which are based on journal articles written by scientists. Highlight that each section will be based on the scientists engaging with a different practice as they try to answer their question about how to clean water with chemical reactions. Explain the reading strategy below, then give students time to read. Summarize the new information about how the reactions discussed help clean water and record any new questions you have" (Teacher Edition, page 212).
    - Lesson 10: *"*Reflect on the original reactions. Have students take out Key Chemical Reactions and display slide I. Give students a few minutes to reflect on the reactions using the prompts below, then discuss: How is this cleaning process similar to the other reactions we saw at the start of the lesson? How is it different? How might the structures involved determine how similar or different the reactions are?" (Teacher Edition, page 216).
    - Lesson 11: "Read about fertilizers in space. Display slide C. Distribute a copy of Fertilizer from Urine to each student. Go over the instructions on the slide and check if students need any clarification. Give students about 10 minutes to read and complete the questions on Fertilizer from Urine. Rotate around the room and assist as needed. Share ideas with a partner. Display slide D. Give students about 3–4 minutes to discuss the prompts on the slide with a partner. After that time, lead a class discussion" (Teacher Edition, page 223).
    - Lesson 12: "Research where we could find enough elements to build substances for survival. Present slide J. Ask partners to work together to determine which elements are found on the Moon and Mars. Explain that each person will be responsible for

determining which elements are found on one of the locations. Tell students to use the website links provided on Search for Elements to research each location. Give groups about 10 minutes to complete questions 2–5 on Search for Elements. As groups work, rotate around the room and assist as needed" (Teacher Edition, page 247).

  - Lesson 12: "Critically read about Martian research. Present slide M and distribute Mars Rovers Research to each student. Give them 8 minutes to read and annotate Mars Rovers Research, and consider the implications this new evidence has for building a permanent settlement on Mars by responding to the prompts at the end of the reading" (Teacher Edition, page 249).
  - Lesson 12: "Read about sulfur-based concrete. Display slide W. Give students time to annotate Sulfur-Based Concrete and answer the questions on Summarize a Reading. Rotate around the room and assist as needed" (Teacher Edition, page 253).

- *Compare, integrate ~~and evaluate sources~~ of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to address a scientific question or solve a problem. (8.2)*
  - Lesson 2: Students collect data from multiple sources and the teacher is instructed to, "Gather information about properties of water. Distribute a copy of Water's Properties Investigations to each student. Display slide G. Explain the combinations of stations students will visit with their groups. Let students know that the handout contains information for all stations, but that they will only be responsible for completing the questions pertaining to the two stations they visit" (Teacher Edition, page 68). Students are then directed to use what data they've collected to identify key properties of water.
  - Lesson 4: Students use models and readings to develop consensus. "Build consensus around why water behaves differently than other liquids. Display slide AA. Lead a discussion around Mars Geological Landforms and the freezing models. Ask a few students to share their models and ideas about why water expands when it freezes and causes frost heaving. Listen for language around 'pulls' and 'attracts' as students share their ideas and models. Ideas may include 'what' or 'why' types of reasoning; push students toward explaining why water is so different" (Teacher Edition, page 103).
  - Lesson 5: Students use information from several readings to answer questions about "how does this information compare with the types of information we have analyzed in this lesson?" and "what pieces of information in the excerpts help answer our question about how we could detect the presence of substances we need?" (Teacher Edition, page 132).
  - Lesson 12: Students use the *Search for Elements* handout as a starting point to conduct research about the substances we need to survive. Teachers ask, "based on your research, which of the locations contains enough of the elements needed for photosynthesis and to build most of the substances we need for a permanent settlement?" and "which such substances would be most straightforward [or most difficult] to produce? Why?" (Teacher Edition, page 248).

- *~~Evaluate the validity and reliability of and/or~~ synthesize multiple claims, methods, and/or designs that appear in scientific and technical texts or media reports, verifying the data when possible. (8.4)*
    - Lesson 14: Students read about innovative materials (e.g., 3-D Printing/Geopolymer Concrete) and teachers are directed to, "Set students up to discuss with partners. Display slide E and explain the task to students. Highlight that they should first take a few minutes to synthesize across articles, meaning they will help each other complete the table in number 3 and note similarities and differences. Then, they should use number 4 to help evaluate the claims made in the articles. Highlight that our key question when we read pieces like this should be: How does the claim match up against our understanding of scientific evidence and of the problem being addressed?" (Teacher Edition, page 278).
- *Communicate scientific ~~and/or technical information or ideas~~ (e.g. about phenomena ~~and/or the process of development and the design and performance of a proposed process or system~~) in multiple formats (i.e., orally, ~~graphically, textually, mathematically~~). (8.5)*
    - Lesson 2: Students share findings from stations activity. "Prepare to share station findings. Have students meet with their groups from the last class. Display slide J. Give groups some additional time to finalize how they will communicate station information to their classmates. Again, offer chart paper and chart paper markers to groups if they wish to communicate station information visually. As groups develop their plans, circulate around the room to listen to and observe students' interactions with each other" (Teacher Edition, page 70).

Disciplinary Core Ideas (DCIs) | **Rating: Extensive**

The reviewers found extensive evidence that students have the opportunity to use or develop the DCIs in this unit because students use key grade-appropriate elements in service of making sense of phenomena. Each claimed element from the PEs is used in a coherent way in the unit.

PS1.A: Structure and Properties of Matter

- *Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons.*
    - Lesson 6: "Display slide A and have students discuss the prompts on the slide with a partner. After two minutes, ask for students to share what they discussed with the class. What are we looking for in space? Why? Why is it necessary to know which elements are present or missing in other space objects? Other than the elements in water, are there any other elements that seem to be needed more than others" (Teacher Edition, page 140).
    - Lesson 7: Students develop models of carbon as initial models. They also use different models to look at electrons of atoms (Teacher Edition, page 164). They use a PhET simulation to build atoms with subatomic particles.
    - Lesson 11: Students make models of ammonia and ammonium, considering their atoms and sub-structure of atoms. "Students show the atomic structures of NH and NH,

including the number and charge of the protons, neutrons, and electrons" (Teacher Edition, page 227).

- *The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states.*
    - Lesson 6: Students organize and analyze patterns in the periodic table using element cards. "Noticing patterns in element bond and charge numbers. Say, I was able to gather some additional data about some additional elements. Let's see if evidence of their properties helps us identify which elements are more similar and different from each other. Display slide D. Distribute a set of Element Card Set to each group of 3–4 students. Have the students individually read over the questions. Next, have students observe the information found on each of the cards and consider which of the data collected might connect to our possible similarity groupings✱" (Teacher Edition, page 142). "Present slide M. Say, Let's consider our approach of layering multiple characteristics to help organize the element cards. We agreed that the number of protons was the most important characteristic, so let's begin there. ✱ Start by posting the large sticky note of hydrogen on the board/wall. Then, add helium. Ask, Where should we place lithium? I remember some of you saying that lithium and hydrogen both formed the same number of bonds. Look for students to suggest placing lithium below hydrogen. Continue to work with the class to build out a class consensus organization✱" (Teacher Edition, page 148). "Develop a definition for periodicity. Present slide O. Have students turn and talk with a partner about the prompt on the slide. After a few minutes, ask students to share some of the experiences and things they discussed. Accept all suggestions. Say, All of your examples you discussed describe something that occurs at a regular interval or regularly. What are some terms or words you use to describe something happening at a regular interval? Accept all student ideas. Say, One word that we use is to say these occurrences are periodic. The pattern we see with the number of bonds each element makes is an example of a periodic pattern. We call this periodicity. Have students add the word periodicity with a definition to their personal glossaries" (Teacher Edition, page 150).
- *The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms.*
    - Lesson 7: Students use valence electrons to explain bonds between elements in compounds. "Handout Periodic Table to students. Say, Notice that on the back side of the Periodic Table, you have the electron shell and Lewis Dot models of the first 18 elements we have examined. The patterns of the number of valence electrons going down a column that we have identified are the same for the elements shown in the Periodic Table. Develop models of compounds using valence electrons. Say, We have looked at and listed out a lot of different chemical compounds. How might knowing the numbers of valence electrons help us explain why there is a specific number of each type of element found in a compound? Since we have focused on valence electrons in

carbon, let's consider an example using carbon. For example, why does carbon dioxide contain 1 carbon" (Teacher Edition, page 164).

- Lesson 8: Students use a model to explain stability in a bond by discussing questions in a video. "1. Pause at (00:12). Discuss Q1) If the two magnets represent the nuclei of two positive atoms, what force interactions should we see evidence of as we bring them closer together. Listen for repulsion or that they will be pushed apart. Resume the video. 2. Pause at (01:05) Discuss Q2) What did Coulomb's law tell us happens to the strength of the forces between charges as you bring them closer together. Students will say the forces should get stronger 3. Pause at (01:32) Discuss Q3) If the smaller magnet is going to represent an electron, then what force interactions should we see occur between it and the larger magnet representing the nuclei of an atom when we bring them closer together. Students will say they will attract or that they will be pulled together. 4. Pause at (01:58) Discuss Q4) If there are both attractive and repulsive forces being produced in the system, then what will happen when we bring the two parts of these two atoms together? Accept all predictions. Pause at (02:17) Discuss Q5) What forces are causing the system to remain at a relatively stable distance apart? Students will say the attractive and repulsive forces. Ask students to describe how the strength of these forces compare at this point in space, are the attractive ones stronger or are the repulsive ones stronger or are they of equal strength and cancel out. Students will say that they cancel out…" (Teacher Edition page 180).

PS1.B: Structure and Properties of Matter

- *The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.*
  - Lesson 1: Conservation of mass is discussed as the class makes the consensus model of a chemical reaction. "Ask students to share one thing that they agree is happening to some atoms (or ions) in every chemical reaction. Establish consensus around the idea that: Atoms or ions break apart from the other particles they were connected to in the reactants. Those same atoms come back together (connect) in new arrangements when they form the products… Add that representation to the model, pointing out that it shows one way that these atoms combine together. This will lead to our last question…" (Teacher Edition, pages 53–54).
  - Lesson 11: Students model chemical reactions. There is questioning to have students consider that atoms are conserved. "Consider what happens to atoms in a chemical reaction. Display slide R. Point out to students that there seem to be more atoms on the reactants side than the products side. Ask students, Does it make sense that some of these oxygen atoms would just…disappear? Is that what we think happens? Agree as a class that this does not seem likely to happen. Ask, Then how should we show that these atoms are still there? Listen for ideas such as: We can write O twice, like O + O Draw two O molecules. Distribute the molecules cut from Balancing Equations Molecules for either the decomposition of perchlorate or the synthesis of ammonia and give students five minutes with their partner to model the reaction with the cutouts. Stress to

students that they should have the same type and number of atoms on both sides of the arrow…. Give feedback. Circulate and provide feedback to students asking, 'Is matter conserved on both sides? What is your evidence? How are you using mathematical thinking to figure this out?'" (Teacher Edition, page 233).

- Lesson 12: Students balance the chemical reaction for photosynthesis. "Say, In our last class, we talked about conservation of matter. In order to represent this idea in a chemical equation, we need to make sure there are equal amounts of each element on both the reactant and product sides. We can do this by using multiplication to adjust the amounts of each atom on either side of the equation. Walk students through how to balance the equation for photosynthesis" (Teacher Edition, page 243). Later in the lesson they balance more chemical equations considering conservation of mass. "Balance a second chemical equation. Present slide S. Distribute white boards and dry erase markers to each pair of students. Give groups about 3 minutes to balance the chemical equation on the white boards" (Teacher Edition, page 251).
- Lesson 15*: "*Support students in balancing equations and using mathematical models, including coefficients, to show what is possible to build on Mars" (Teacher Edition, page 287).

PS2.B: Types of Interactions

- *Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter,~~ as well as the contact forces between material objects.~~*
  - Lesson 8: Students use a model to explain stability in a bond. "1. Pause at (00:12). Discuss Q1) If the two magnets represent the nuclei of two positive atoms, what force interactions should we see evidence of as we bring them closer together. Listen for repulsion or that they will be pushed apart. Resume the video. 2. Pause at (01:05) Discuss Q2) What did Coulomb's law tell us happens to the strength of the forces between charges as you bring them closer together. Students will say the forces should get stronger" (Teacher Edition, page 179).
  - Lesson 10: "Model water's role in the reaction. Give pairs five minutes to model. Tell half the pairs to assume that the 'new ion' is a carbonate ion (CO_3^{2-}) and the other half to assume that it is a hydroxide ion (OH^-). While students work, use the prompts below to ensure that students are fully considering the changes in matter and role of forces in the reaction. What is different between the 'before' and 'during' steps? The 'during' and 'after' steps? Where might we see forces between ions? Between water and ions? What ratio of negative and positive ions will form? Do we just need one negative ion for every positive ion, or more? What do forces have to do with bonds breaking and forming? Are all forces the same? How do we know? The image below gives an example of some of the forces students might identify" (Teacher Edition, page 214).

PS4.B: Electromagnetic Radiation

- *Atoms of each element emit and absorb characteristic frequencies of light. These characteristics allow identification of the presence of an element, even in microscopic quantities.*
    - Lesson 5: Students analyze spectra. "Prepare to view visible spectra for solutions of substances in water. Tell students that you have solutions of 3 different substances in water for the class to investigate; hold up the bottles of each solution for the class to observe. Present slide I, read the prompt aloud, and ask students to discuss it with a partner. Bring the class back together and use the prompts below to facilitate a quick share out" (Teacher Edition, page 122). "Analyze and interpret transmission spectra for three Earth gasses. Show slide N. Tell students these are the infrared transmission spectra for three gasses commonly found in our atmosphere on Earth: water, carbon dioxide, and ozone. Point out that since we cannot see infrared light, scientists refer to its 'colors' using a number, wavelength, that has units of distance (microns = 1x10 m). Ask students to turn and talk with a partner about the similarities and differences they notice between the spectra for the three substances. Be prepared to answer any questions about the spectra and help students connect them to the graph the class co-created for sample C. Share similarities and differences. Continue to project slide N and ask a few students to share some similarities and differences they discussed with their partner. Invite students to point out specific features on the projected spectra as they share out. Look for students to note the following: Different gasses transmit different wavelengths of light. The level of transmittance (intensity of light transmitted) is different at different wavelengths. The shape of peaks can be broad or sharper" (Teacher Edition, page 127). "Conduct unknown gas mixture investigation. Project slide R. Distribute a copy of Transmission Spectra Library to each student. Explain that this handout is a library of transmission spectra obtained for eight different gasses. Point out that the name of the gas and its chemical formula are listed on the spectra. Tell students that you have 4 unknown gas mixtures for partners to analyze and interpret using the reference spectra" (Teacher Edition, page 128).

ESS1.A: The Universe and Its Stars

- *The study of stars' light spectra ~~and brightness~~ is used to identify compositional elements of stars, ~~their movements, and their distances from Earth~~.*
    - Lesson 5: "Introduce transmission spectra for atmospheres. Recap why we started exploring spectroscopy. Say something like, We started this lesson wondering if we could detect water on objects in space, and now we have this tool-spectroscopy-that we can use to detect water and other substances that we may need to live and work in space. Show slide U and use the diagram to explain how scientists use spectroscopy to determine what is in an object's atmosphere using the light from a star. Tell students that scientists have developed sophisticated instruments for this purpose, and that we will look at some data collected by NASA's James Webb Space Telescope (JWST, pictured on the slide). You can point out that the telescope uses a large mirror to collect light. Present slide V and tell students that you have a set of 4 atmospheric spectra collected

in this way for them to analyze and interpret. Explain that these spectra represent a snapshot of the gasses in an object's atmosphere at a specific point in time. These data also depend on the relative positions of the star (in our case the Sun), the object (and its atmosphere), and the observer (the telescope) in three-dimensional space. Analyze and interpret atmosphere data. Display slide W and distribute a copy of Analyze Atmospheric Spectra to each student. Ask students to work with a new partner to determine what gasses are present in the atmospheres of Earth, Mars, Venus and Enceldaus (a moon of Saturn). Point out that they can use the strategies that helped them identify the composition of the gas mixtures. Answer any questions students may have about their task. Give students at least 10 minutes to work on this with a partner" (Teacher Edition, page 130).

- ~~*The Big Bang theory is supported by observations of distant galaxies receding from our own, of the measured composition of stars and non-stellar gasses, and of the maps of spectra of the primordial radiation (cosmic microwave background) that still fills the universe.*~~
    - This element is listed as being lined out in the unit and is not covered. It is unclear what its presence indicates.
- ~~*Other than the hydrogen and helium formed at the time of the Big Bang, nuclear fusion within stars produces all atomic nuclei lighter than and including iron, and the process releases electromagnetic energy. Heavier elements are produced when certain massive stars achieve a supernova stage and explode.*~~
    - This element is listed as being lined out in the unit and is not covered. It is unclear what its presence indicates.

ESS2.A: Earth Materials and Systems

- *Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes*~~*. A deep knowledge of how feedbacks work within and among Earth's systems is still lacking, thus limiting scientists' ability to predict some changes and their impacts*~~*.*
    - Lesson 4: "Have a Building Understandings Discussion about the Erosion Investigation. Display slide N. Ask students to think for a moment about how the liquids interacted with the Mars-like material you tested in the Erosion Investigation… What patterns did you notice in how the liquids interacted with the Mars-like material in the Erosion investigation?... What do we already know about water from this unit and previous units?" (Teacher Edition, page 98). "Compare investigation results to geologic formations on Mars. Display slide O. Have students compare the images of geologic formations on Mars to the results of their investigations. Instruct them to answer the prompt on Geologic Landforms Investigation. Circulate as students write to check in with struggling students and to see what they are writing in response to the prompt. Look for students to say that the landforms could have been made by water or alcohol. Ask students to consider how an investigation at this small scale can help them make sense of what is happening at the planetary scale of Earth and Mars. Listen for students to suggest: Impacts will look the same in our pans and on planets. Seeing how liquids

affect small amounts of dirt helps us figure out which liquid is doing this to planets" (Teacher Edition, page 98). Note that although some content is related to the idea of feedback, students are not supported to learn this idea explicitly in the unit.

ESS2.B: Plate Tectonics and Large-Scale System Interactions

- ~~*Plate tectonics is the unifying theory that explains the past and current movements of the rocks at Earth's surface and provides a framework for understanding its geologic history. Plate movements are responsible for most continental and ocean-floor features and for the distribution of most rocks and minerals within Earth's crust. (HS-ESS2-1)*~~
    - This element is listed as being lined out in the unit and is not covered. It is unclear what its presence indicates.

ESS2.C: The Roles of Water in Earth's Surface Processes

- *The abundance of liquid water on Earth's surface and its unique combination of physical and chemical properties are central to the planet's dynamics. These properties include water's exceptional capacity to absorb, store, and release large amounts of energy, transmit sunlight, expand upon freezing, dissolve and transport materials,* ~~*and lower the viscosities and melting points of rocks.*~~
    - Lesson 2: Students complete stations to learn about water's unique properties. "Distribute a copy of Water's Properties Investigations to each student. Display slide G. Explain the combinations of stations students will visit with their groups. Let students know that the handout contains information for all stations, but that they will only be responsible for completing the questions pertaining to the two stations they visit" (Teacher Edition, page 68).
    - Lesson 4: "Compare investigation results to geologic formations on Mars. Display slide O. Have students compare the images of geologic formations on Mars to the results of their investigations. Instruct them to answer the prompt on Geologic Landforms Investigation. Circulate as students write to check in with struggling students and to see what they are writing in response to the prompt. Look for students to say that the landforms could have been made by water or alcohol. Ask students to consider how an investigation at this small scale can help them make sense of what is happening at the planetary scale of Earth and Mars. Listen for students to suggest: Impacts will look the same in our pans and on planets. Seeing how liquids affect small amounts of dirt helps us figure out which liquid is doing this to planets" (Teacher Edition, page 98).

ESS3.A: Natural Resources:

- *Resource availability has guided the development of human society.*
    - Lesson 1: Students use data on payload mass and information about maximum time spent on the Moon to identify constraints that limit time available to be spent away from Earth or on another planetary body (Teacher Edition, page 43).

ESS3.C: Human Impacts on Earth Systems.

- *Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste ~~and that preclude ecosystem degradation~~.*
    - Lesson 1: Teachers are instructed to, “Introduce payload limitations. Display slide J. Say, The maximum duration that a crew has stayed on the Moon is 75 hours, or just over 3 days. Ask students to turn and talk about the question on the slide with a partner for three minutes. In this discussion students will begin to identify constraints that you will look for in their Exit Ticket responses at the end of the period… [and later] Emphasize that the Artemis plan involves going to and eventually staying on the Moon for up to one month, and future plans involve going to and staying on Mars for even longer. Suggest that we look at data about a key piece of technology – the rockets that we use to get to these places in space -- to see what additional constraints we can identify” (Teacher Edition, page 43). While this section peripherally touches on the development of relevant technologies that could be considered solutions to existing problems or constraints, it’s not clear that students use or develop this element in this section.
    - Lesson 13: Students consider the given ideas for recycling and creating substitutes for common substances (e.g., vulcanized rubber) and teachers are told to, “Point out that if we are hopeful to see scientists and engineers develop a substitute for some of these in our near future, that maybe those are actually under development today. Ask students how we could find out if they are. Students will say we could do some additional research on these topics. Work with the class to commit to doing just that - looking into what new research is happening along these lines in our next lesson, based on our different areas of interest. Collect Recycling Ideas Organizer for assessment” (Teacher Edition, page 270).

Crosscutting Concepts (CCCs) | Rating: Adequate

The reviewers found adequate evidence that students have the opportunity to use or develop the CCCs in this unit because many of the claimed elements are sufficiently developed or used throughout this unit, though several CCC elements are not developed or explored to the degree claimed.

Patterns

- *Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. (1.1)*
    - Lesson 3: Students brainstorm potential surface features and processes that cause those features to develop over time. In the Supporting Students in **Developing and Using Patterns** callout box, teachers are encouraged to, “Support students in thinking about the scale of these different surface features and how that may impact our ability to view them (CCC: 1.1). Use prompts such as: what scale, or how big, are these different surface features? How might the scale of the features impact our ability to view them on satellite images?” (Teacher Edition, page 80).
    - Lesson 4: Students prepare to complete an investigation about different liquids’ impacts on landform formation. Teachers are asked to prompt students’ thinking by asking

questions such as, "how could we use these materials to investigate if the landforms on Mars were made by water or some other liquid? What other materials or liquid would be important to try if they are/were available? How do the properties of these liquids compare to those of water?" (Teacher Edition, page 94). The Supporting Students in **Developing and Using Patterns** callout box references the need for teachers to, "…provide feedback to students that helps them link causality appropriately to the patterns of water in extra-terrestrial systems." It's not clear from these descriptions how or when these supports would be needed and given the presence of other, relevant prompts, it seems less likely that teachers will utilize this suggestion compared to other, more explicit ones.

- Lesson 4: "Help foreground the different scales we considered and connected in this lesson and the last by reminding students that we initially wanted to explain surface features on Mars. This surface feature was evidence of some sort of change in matter on a very large scale - since canyons or stream beds can be on the order of miles big. Add that once we carried out our investigation in our lab which was at a much smaller scale, we decided we still needed to go down to an even smaller scale, down to the particle level to explain the differences in our results. Make an explicit reference to element CCC: 1.1 at this point and emphasize that this sort of thinking is what we use to try to connect together explanations across different scales" (Teacher Edition, page 104).
- Lesson 4: Lesson materials indicate alignment to CCC: 1.1., but the corresponding key does not show alignment to this element, nor does it appear that this element is present, but simply omitted from the key (Exit Ticket Key).
- Lesson 9: Materials claim the presence of CCC: 1.1, but it's not clear that students are actively differentiating scale differences rather than simply focusing upon the microscopic scale in this activity.

- *Classifications or explanations used at one scale may fail or need revision when information from smaller or larger scales is introduced; thus requiring improved investigations and experiments. (1.2)*
  - Lesson 15: Students are asked to engage in discussion about several key ideas, including "matter must be transformed from existing matter if we are to survive elsewhere" (Teacher Edition, page 387). However, it's unclear that this claimed element will be sufficiently addressed in this context for all students due to the myriad ways and evidence that students might use in addressing this idea within the discussion.
- *Mathematical representations are needed to identify some patterns. (1.4)*
  - Lesson 12: Students will "Balance a second chemical equation." "Say something like, Given that cement doesn't 'dry' as it becomes solid–water actually becomes part of the substance–plus the fact that there does not appear to be a lot of water on Mars makes me wonder, how much water does it really take to make cement? Can we figure that out now?" (Teacher Edition, page 251).
  - Lesson 12: Students complete an Exit Ticket that includes questions related to the use of mathematical representations such as, "Which chemical equation most likely describes

the process? Use ideas about the conservation of matter and mathematical representations of the chemical equations to help you" (Exit Ticket).

- *Empirical evidence is needed to identify patterns. (1.5)*
  - Lesson 2: "Prepare to share station findings. Display slide H. Say, Since we did not visit every station, we need to spend time hearing what the other groups discovered. To make sure we have time to hear from every group, you will have only two minutes to talk about each station. As you share, be sure to show how your findings explain why water is important to life and/or chemical reactions" (Teacher Edition, page 69).
  - Lesson 5: Students use empirical evidence from their investigation to "Discuss spectral observations for different solutions. Show slide K and ask students to take a moment to notice similarities and differences in the patterns of light that passed through each solution. Then facilitate a short share out of similarities and differences students noticed" (Teacher Edition, page 124).
  - Lesson 5: Students use provided data to complete an activity in which they will identify the specific gases that are believed to be present in the assigned unknown and use empirical evidence to support that conclusion (Analyze Unknown Gases, page 1).
  - Lesson 5: "Analyze and interpret atmosphere data. Display slide W and distribute a copy of Analyze Atmospheric Spectra to each student. Ask students to work with a new partner to determine what gasses are present in the atmospheres of Earth, Mars, Venus and Enceldaus (a moon of Saturn). Point out that they can use the strategies that helped them identify the composition of the gas mixtures" (Teacher Edition, page 130).
  - Lesson 6: "As groups work, walk around the room and assist as needed. Ask clarifying questions to help groups such as: What piece of information on the cards are you considering most important? Why? What information on the card is informing this decision? Is your group using a specific pattern in the information on the card to guide your organization process?" (Teacher Edition, page 145). Students should be encouraged to use the sentence frames seen in Model Evaluation Support to guide their thinking along the path of: (1) What has the empirical evidence shown me? (2) How did the other group use this evidence? (3) How does this thinking differ from mine? (4) What do these differences make me think about our group's tool" (Teacher Edition, page 147).

Scale, Proportion, and Quantity

- *The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. (3.1)*
  - Lesson 1: Students complete an activity in which they answer questions such as, "What happens to the matter inputs at a particle level in the reaction you chose? Represent any particle-level changes that occur. Use words and/or pictures to illustrate your thinking. What particle-level interactions occur during the reaction?" (Initial Reaction Model, page 1). Though this is claimed as evidence of this element, it is not clear that students are comparing the significance of this phenomenon at multiple scales.

Systems and System Models

- *Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions — including energy, matter, and information flows — within and between systems at different scales. (4.3)*
    - Lesson 4: This element is not claimed but is built toward. Students complete an Exit Ticket where they consider multiple types of models. "How did using multiple models of atomic and molecular structure help you to make sense of what is happening at the particle level to cause the interactions between liquid and surface materials? Which substance do you think would be the most likely to cause erosion or frost heaving? (looking at formulas and polarity models)" (Teacher Edition, pages 342–343).
    - Lesson 12: Students respond to questions such as, "Based on your research, which of the locations contains enough of the elements needed for photosynthesis and to build most of the substances we need for a permanent settlement? The Moon had a lot of the elements for cement but no C for photosynthesis. Mars had almost everything, including both reactants for photosynthesis-carbon dioxide and water. Mars is smaller than Earth so it might not have enough. It depends on how much we need. Which substances would be most straightforward to produce? Why?" (Teacher Edition, page 248). Though these questions and the activity overall touches on the use of mathematical and syntactical models as means of representing a relevant system, students identify which location in space contains the quantities of elements and compounds needed to create the resources to survive in space.

Energy and Matter

- *The total amount of energy and matter in closed systems is conserved. (5.1)*
    - Lesson 11: Students balance chemical equations while the teacher circulates to "Give feedback. Circulate and provide feedback to students asking, 'Is matter conserved on both sides? What is your evidence? How are you using mathematical thinking to figure this out?' Once students have modeled balanced equations with the manipulatives, write the balanced equations on the board or a piece of chart paper. Circle or underline the coefficients and tell students this is the accepted way to show multiple atoms or molecules of a substance in a chemical reaction" (Teacher Edition, page 233).
    - Lesson 12: Students balance a chemical equation that represents the chemical reaction that occurs during photosynthesis. Through this activity, teachers ask students to note the total number of hydrogen, oxygen, and carbon atoms on both sides of the equation and share what they notice: including that the total number of each atom is conserved in the reaction (Teacher Edition, pages 242–243).
    - Lesson 12: "Additional Guidance: The purpose of slide G is to point out that plants use glucose produced by photosynthesis as a reactant in many other chemical processes to make complex carbohydrates, fats, nucleic acids, and proteins. Although this unit focuses on matter changes, energy is shown as an input for photosynthesis and an output for respiration. Students have seen energy associated with these processes in OpenSciEd Middle School units OpenSciEd Unit 7.3: How do things inside our bodies

work together to make us feel the way we do? (Inside Our Bodies Unit), OpenSciEd Unit 7.4: Where does food come from, and where does it go next? (Maple Syrup Unit), and High School biology unit OpenSciEd Unit B.2: What causes fires in ecosystems to burn and how should we manage them? (Fires Unit). They will explore energy associated with chemical reactions further in OpenSciEd Unit C.5: Which fuels should we design our next generation vehicles to use? (Fuels Unit).” (Teacher Guidance, page 247)

  - Lesson 12: “Balance a second chemical equation. Say something like, Given that cement doesn’t ‘dry’ as it becomes solid–water actually becomes part of the substance–plus the fact that there does not appear to be a lot of water on Mars makes me wonder, how much water does it really take to make cement? Can we figure that out now?” (Teacher Edition, page 251).

- *Energy cannot be created or destroyed — only moved between one place and another place, between objects and/or fields, or between systems. (claimed to be developed across multiple courses) (5.3)*
  - This element is not cited or observed as being used or developed in any lesson.

Structure and Function

- *Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal its function and/or solve a problem. (6.1)*
  - Lesson 8: This element is not claimed but may be built toward. “Students should make the connection between the structure of molecular substitutes and their function due to electronegativity in this lesson. Students should be ‘inferring the function’ of materials because of their molecular substructures (CCC: 6.2)” (Teacher Edition, page 176).
  - Lesson 10: Students use literature and models to consider and investigate removing metals from water. “Explaining the role of water in chemical reactions requires consideration of the way that its structure, as well as that of other substances in the reaction, lead to properties that allow for the reaction to take place (CCC: 6.1)” (Teacher Edition, page 210). “Model water’s role in the reaction. Give pairs five minutes to model. Tell half the pairs to assume that the ‘new ion’ is a carbonate ion (CO_3^{2-}) and the other half to assume that it is a hydroxide ion (OH^-). While students work, use the prompts below to ensure that students are fully considering the changes in matter and role of forces in the reaction. What is different between the ‘before’ and ‘during’ steps? The ‘during’ and ‘after’ steps? Where might we see forces between ions? Between water and ions? What ratio of negative and positive ions will form? Do we just need one negative ion for every positive ion, or more? What do forces have to do with bonds breaking and forming? Are all forces the same? How do we know?” (Teacher Edition, page 214). “Reflect on the original reactions. Have students take out Key Chemical Reactions and display slide I. Give students a few minutes to reflect on the reactions using the prompts below, then discuss: How is this cleaning process similar to the other reactions we saw at the start of the lesson? How is it different? How might the structures involved determine how similar or different the reactions are?” (Teacher Edition, page 216).

- Lesson 11: This element is not claimed but is built toward. “Structure and Function are at the core of this conversation. Be sure to call out that the structures of these substances determine their different functions. Look at student responses for Question 4 in the Handout for ideas to make this discussion coherent (CCC: 6.2)” (Teacher Edition, page 226). “By comparing the formulas of the polyatomic ions to how they are found bonded with other elements (or polyatomic ions) helps students to visualize that the structure of the polyatomic ion is similar to the structure of an atom, or ion. This helps to reinforce thinking about ions developed in OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit) and ionic bonds developed earlier in this unit. Students can think about how this group of atoms functions as a single atom when bonded to other elements (or groups of atoms). (CCC: 6.2)” (Teacher Edition, page 231).
- Lesson 14: “Students continue their exploration of materials with a consideration of sustainability in materials, while still emphasizing the role of structure and function (CCC: 6.1)” (Teacher Edition, page 276). “Set students up to discuss with partners. Display slide E and explain the task to students. Highlight that they should first take a few minutes to synthesize across articles, meaning they will help each other complete the table in number 3 and note similarities and differences. Then, they should use number 4 to help evaluate the claims made in the articles. Highlight that our key question when we read pieces like this should be: How does the claim match up against our understanding of scientific evidence and of the problem being addressed? Give work time. Circulate as students work, pushing partners to compare across articles and consider scientific understandings, their understanding of the problem, and ethics in their evaluations” (Teacher Edition, page 278). Students investigate new materials through a series of readings and respond to questions such as, “how does the engineered material work at the particle level? Use structure/function and matter/force thinking” (Synthesis and Evaluation, page 1).

- *The functions and properties of natural and designed objects and systems can be inferred from their overall structure, the way their components are shaped and used, and the molecular substructures of its various materials. (6.2)*
  - Lesson 4: "Build consensus around why water behaves differently than other liquids. Display slide AA. Lead a discussion around Mars Geological Landforms and the freezing models. Ask a few students to share their models and ideas about why water expands when it freezes and causes frost heaving. Listen for language around ‘pulls’ and ‘attracts’ as students share their ideas and models. Ideas may include ‘what’ or ‘why’ types of reasoning; push students toward explaining why water is so different” and later, answer questions about the role of polarity and structure of molecules can explain its behavior (Teacher Edition, pages 103–104).
  - Lesson 4: Students complete an Exit Ticket in which they use information about a substance’s polarity to infer its ability to causes processes like erosion to occur (Exit Ticket – Google Forms).

- Lesson 7: “Use a simulation to evaluate a new representation of electron structures within an atom. Remind students that yesterday, we decided to examine a different representation of an atomic model to help us make progress on our question, Why is there a difference between the number of electrons an element has and the number of bonds an element forms?” (Teacher Edition, page 161).
- Lesson 8: Students watch a video, and the teacher is told to, “Pause at (00:12). Discuss Q1) If the two magnets represent the nuclei of two positive atoms, what force interactions should we see evidence of as we bring them closer together. Listen for repulsion or that they will be pushed apart. Resume the video. 2. Pause at (01:05) Discuss Q2) What did Coulomb's law tell us happens to the strength of the forces between charges as you bring them closer together. Students will say the forces should get stronger. 3. Pause at (01:32) Discuss Q3) If the smaller magnet is going to represent an electron, then what force interactions should we see occur between it and the larger magnet representing the nuclei of an atom when we bring them closer together. Students will say they will attract or that they will be pulled together. 4. Pause at (01:58) Discuss Q4) If there are both attractive and repulsive forces being produced in the system, then what will happen when we bring the two parts of these two atoms together? Accept all predictions. Pause at (02:17) Discuss Q5) What forces are causing the system to remain at a relatively stable distance apart? Students will say the attractive and repulsive forces. Ask students to describe how the strength of these forces compare at this point in space, are the attractive ones stronger or are the repulsive ones stronger or are they of equal strength and cancel out. Students will say that they cancel out” (Teacher Edition, pages 179–180).
- Lesson 8: “Explain some property differences of H S vs. H O. Display slide K. Emphasize that it may be hard to explain how and why hydrogen sulfide is poisonous without knowing more about the types of substances that make up different parts of our bodies, but we can probably explain other property differences. Discuss the 3 property differences highlighted on the slide. Suggested prompts include: How do differences in polarity explain why water is more cohesive than hydrogen sulfide? How would this also help explain why water has a higher boiling point than hydrogen sulfide? How would this also be related to why water is better at dissolving more things than hydrogen sulfide is as a liquid?” (Teacher Edition, page 183).
- Lesson 8: “Display slide AA. Point out that earlier, we predicted that both H O and H S were polar, but did not have an explanation for their differences in polarity when we first compared their molecules shown on the slide, but we do now. Give students this time to individually summarize an explanation for why H O molecules are more polar than H S molecules” (Teacher Edition, page 189).
- Lesson 11: “Suggest looking at differences in ammonia and ammonium. Say, We are wondering about the differences in the structures of ammonia and ammonium since they have such different functions. Present slide E. Give students a few minutes to jot down any similarities and differences they notice, then lead a discussion with the prompts below” (Teacher Edition, page 225).

Stability and Change

- *Much of science deals with constructing explanations of how things change and how they remain stable. (7.1)*
    - Lesson 8: "Explain some property differences of H S vs. H O. Display slide K. Emphasize that it may be hard to explain how and why hydrogen sulfide is poisonous without knowing more about the types of substances that make up different parts of our bodies, but we can probably explain other property differences. Discuss the 3 property differences highlighted on the slide. Suggested prompts include: How do differences in polarity explain why water is more cohesive than hydrogen sulfide? How would this also help explain why water has a higher boiling point than hydrogen sulfide? How would this also be related to why water is better at dissolving more things than hydrogen sulfide is as a liquid?" (Teacher Edition, page 183). However, it is not clear that students use the nature of science idea from this CCC element ("Much of science deals with...").
- *Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible. (claimed to be developed across multiple courses) (7.2)*
    - This element is not cited or observed being used or developed in any lesson.

Suggestions for Improvement

General

- When listing a Performance Expectation (PE) as being partially covered in this unit, consider specifying which elements of that PE are not intended to be used or developed in this unit.

Science and Engineering Practices

- Consider whether each of the claimed elements is necessary given the current structure of the unit.
- Consider having all students use the chart paper to share their findings using two different modalities, aligning more with the claimed element 8.5.
- Consider explicitly claiming 3.2 in the lessons to better align with the claimed Pes of the unit.

Disciplinary Core Ideas

- Consider whether each of the claimed elements is necessary given the current structure of the unit.
- Consider removing elements that are struck through since they are not addressed in the unit.
- Consider in Lesson 1 providing students with an opportunity to look at other examples of resource availability on Earth as a driving force for human migration and settlement.

Crosscutting Concepts

- Consider implementing CCC element 1.2 throughout the unit (e.g., potentially during the Mars soil erosion investigation).
- Consider revising page 20 so CCC element 6.2 is listed as an intentionally used/developed CCC.

- Consider strengthening the use of scale in relation to the SEPs and DCIs within the unit. At several points, CCC element 1.1 is claimed, but only in the presence of activities or in-class interactions that reference one single scale. At many points, it's unclear that students are leveraging this element of the CCC as intended, though there are moments where they may actively be noting both scales within the same lesson or activity.

I.C. INTEGRATING THE THREE DIMENSIONS

Student sense-making of phenomena and/or designing of solutions requires student performances that integrate elements of the SEPs, CCCs, and DCIs.

Rating for Criterion I.C. Integrating the Three Dimensions	Extensive *(None, Inadequate, Adequate, Extensive)*

The reviewers found extensive evidence that student performances integrate elements of the three dimensions in service of figuring out phenomena or designing solutions to problems because there are multiple three-dimensional learning opportunities of student sense-making related to the central topic of survival in space.

Students frequently use grade-appropriate elements of all three dimensions together in order to work toward figuring out a phenomenon or solving a problem. Some notable examples include:

- Lesson 1: Students develop initial models (SEP) of a chemical reaction to show compositions of reactants and products at the particle-level (CCC).
- Lesson 5: "Conduct unknown gas mixture investigation. Project slide R. Distribute a copy of Transmission Spectra Library to each student. Explain that this handout is a library of transmission spectra obtained for eight different gasses. Point out that the name of the gas and its chemical formula are listed on the spectra. Tell students that you have 4 unknown gas mixtures for partners to analyze and interpret using the reference spectra. Let them know that each pair of students will be assigned a different unknown. Distribute a copy of Analyze Unknown Gasses to each student. Assign each pair of students an unknown gas spectrum and tell them they have 6 minutes to identify the 1 to 3 reference gasses in their unknown. If students finish early, encourage them to try some of the other unknowns" (Teacher Edition, page 128). DCI: PS4.B.4 SEP: 4.1 CCC: 1.5
- Lesson 7: Students evaluate four different models of carbon in the Comparing Atomic Models task. They see that there are limitations and merits for each of the models (SEP) and that the patterns within the models can be used to predict and describe characteristics of that element such as forming bonds (CCC) (Teacher Edition, page 253).

- Lesson 11: Students model (SEP) chemical reactions and consider components of the system of the chemical reaction (CCC) to figure out the law of conservation of matter and connections to survival in space. “Tell students, We can use a new model, called a chemical equation, to model these processes that occur. Ask students to work with a partner to write the chemical equation for the process described in Perchlorate on Mars in their science notebooks. Tell students to write big so that other students will be able to read it from across the room. Give students a few minutes to [sic] this, then ask all students to hold up their whiteboards at the same time. It is likely that many students will have something like: ClO → Cl + O Discuss these models with students. Start by asking if the same elements are present on both sides of the chemical equation. Students should have chlorine and oxygen on both sides… Consider what happens to atoms in a chemical reaction. Display slide R. Point out to students that there seem to be more atoms on the reactants side than the products side. Ask students, Does it make sense that some of these oxygen atoms would just…disappear? Is that what we think happens? Agree as a class that this does not seem likely to happen. Ask, Then how should we show that these atoms are still there? Listen for ideas such as: We can write O twice, like O + O Draw two O molecules. Distribute the molecules cut from Balancing Equations Molecules for either the decomposition of perchlorate or the synthesis of ammonia and give students five minutes with their partner to model the reaction with the cutouts… Give feedback. Circulate and provide feedback to students asking, ‘Is matter conserved on both sides? What is your evidence? How are you using mathematical thinking to figure this out?’ Once students have modeled balanced equations with the manipulatives, write the balanced equations on the board or a piece of chart paper. Circle or underline the coefficients and tell students this is the accepted way to show multiple atoms or molecules of a substance in a chemical reaction” (Teacher Edition, page 233).

Suggestions for Improvement

Implementing suggestions for improvement from Criteria I.A and I.B above could result in more opportunities for students to use the three dimensions together in service of sense-making.

I.D. UNIT COHERENCE

Lessons fit together to target a set of performance expectations.

i. Each lesson builds on prior lessons by addressing questions raised in those lessons, cultivating new questions that build on what students figured out, or cultivating new questions from related phenomena, problems, and prior student experiences.

ii. The lessons help students develop toward proficiency in a targeted set of performance expectations.

Rating for Criterion I.D. Unit Coherence	Extensive *(None, Inadequate, Adequate, Extensive)*

The reviewers found extensive evidence that lessons fit together coherently to target a set of Pes because each lesson builds directly on prior lessons and makes the links between lessons explicit to the students. As students move through the unit, part of what they figure out is used as the next question(s) to pursue.

There is a DQB where students develop and revisit questions, which helps to link the lessons together and build upon what students have figured out. For example:

- Lesson 1: Students build the DQB. “Review the protocol for building the DQB. Have students bring their science notebook, sticky-note questions, marker, and pencil with them to the Scientists Circle. Say, As we build our DQB, it is important that we hear everybody’s questions, and we might find that we have questions similar to some of our classmates’ questions. ✱ We want to group and organize our questions so that they can help us guide our investigations and keep track of what we want to figure out. To help do that we will do two rounds of question sharing, starting with sharing at least one blue sticky note from everyone and then at least one yellow sticky note from everyone” (Teacher Edition, page 56). There is also guidance to help the teacher generate more questions about certain topics after different lessons.
- Lesson 9: Before the transfer task, students meet with a partner and annotate/discuss questions that can be answered on the DQB. “Distribute Our DQB Questions to each student or make a digital copy of one they can each annotate available. Give students the remaining time to work with a partner to take stock of which questions we have made additional progress on over the last few lessons” (Teacher Edition, page 204). After the assessment, students are prompted to think of new questions.
- Lesson 10: At the beginning of the lesson, students share out the questions they developed at the end of Lesson 9. “Have students turn and talk with a partner to share the new questions they developed at the end of Lesson 9. Then share some examples with the whole class… Give students the opportunity to add their new questions to the DQB” (Teacher Edition, page 211).

There are resources that students use throughout the lessons to help answer questions that build unit coherence. Some examples include:

- Materials for Survival
- Progress Tracker
- Key Chemical Reactions
- Compare Atomic Models

The "Navigate" portions of the Teacher Edition and lesson plans allow for the teacher to make deliberate connections between lessons. Some examples include:

- Lesson 1: "Students will identify water as the most critical substance to find, since it is a component of so many of the processes they just looked at. Ask students why it might make sense to prioritize investigating our questions related to water. Highlight that this will be our first line of investigations to pursue next time" (Teacher Edition, page 58).
- Lesson 3: "Say, Last lesson, we determined water is really special and it has so many unique properties. We agreed we would need to find it out in the solar system… Based on our future exploration plans and distance constraints, what three places in our solar system should be our top candidates for evaluating whether water is there or not?" This guides students to narrow down the Space Mission Deck cards from Lesson 1 and choose Mars and the Moon to look at.
- Lesson 4: The teacher is given suggested prompts to connect Lesson 3 to Lesson 4. "What are some uncertainties we have about whether water was responsible for those surface features on Mars, and not some other liquid? How could we investigate possible liquid/landform interactions?" (Teacher Edition, page 94).
- Lesson 6: "In the previous class we looked at what elements could be found on various cosmological objects. With an elbow partner, how we can use this data to help us prepare for future space missions. Have students open their science notebooks to Materials for Survival from Lesson 1. Display slide A and have students discuss the prompts on the slide with a partner. After two minutes, ask for students to share what they discussed with the class" (Teacher Edition, page 140).
- Lesson 8: "Reference students to any classroom artifacts that identicate [sic] all the uses of water we had identified from prior lessons, including those in the chemical reactions from lesson 1, such as Materials for Survival as well as those from lesson 2, such as things our community mentioned using it for like cleaning and washing, as well as a bunch of special properties of water that help support life on Earth. Take a poll for the question on the slide: If another substance had similar properties as water, could it serve as a substitute in at least some of the processes we use water for? Do you think this substitute would have similar structure?... Mentioning cleaning or washing here may help students suggest examples of alternates for water in these processes, such as alcohol or a different substance that dissolves stuff or carries away dirt easily. This provides an opportunity for students to connect back to some of their work in lesson 4" (Teacher Edition, pages 176–177).
- Lesson 10: "Display slide B and point out that early in the unit, we examined lots of different, important materials (like steel and glass) and processes (like photosynthesis). Ask, What else do

we have to know to understand how to actually make those things?" (Teacher Edition, page 211).

- Lesson 11: "Last class we left off with thinking about processes we need clean water to use to live and work on Mars. What were some processes we said we might need clean water for? Accept all answers. Highlight students who suggest producing food" (Teacher Edition, page 223).
- Lesson 12: "What did we figure out we could do to survive off of Earth in our last class?... How do plants do that?... Say, Great! Let's spend some time reminding ourselves of what is happening during photosynthesis since we will definitely need it to grow plants to eat wherever we go in space" (Teacher Edition, page 241).
- Lesson 13: "What was the most surprising to you about the new kind of sulfur-based concrete you encountered in the last lesson? Accept all answers. If students do not mention that it was recyclable, ask this question with a show of hands as a response, How many of you also found the idea of making a new type of concrete that is recyclable also kind of surprising? Then say, NASA has always had a mission of improving the lives of humans on Earth when possible, too. A lot of NASA's work has directly supported human life down here, and these outer-space innovations can reduce pollution and waste and negative impacts on ecosystems. Let's consider this connection to recycling a bit more" (Teacher Edition, page 262).
- Lesson 14: "Ask students, Given what we know now, do we think people could live and work off of Earth, or should try? Take a couple responses, then acknowledge this is a big question we should return to next time" (Teacher Edition, page 279).

The unit builds proficiency in a targeted set of Pes.

- "HS-PS1-1* Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.
- HS-PS1-2 Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.
- HS-PS1-3*: Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.
- HS-PS2-6*: Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.
- 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.
- HS-ESS2-1†: Develop a model to illustrate how Earth's internal and surface processes operate at different spatial and temporal scales to form continental and ocean-floor features.
- HS-ESS2-5: Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes.
- *This PE is developed across multiple units.
- †This PE is developed across multiple courses." (Teacher Edition, page 19).
- The materials claim that two PEs are built towards in this unit exclusively:
    - **HS-PS1-2**: *Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table,*

and knowledge of the patterns of chemical properties. This is developed in Lessons 1, 6, 7, 8, 10, 11, 12, and 15.
- **HS-ESS2-5**: *Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes*. This is developed in Lessons 2 and 4.

Suggestions for Improvement

None

I.E. MULTIPLE SCIENCE DOMAINS

When appropriate, links are made across the science domains of life science, physical science and Earth and space science.

i. Disciplinary core ideas from different disciplines are used together to explain phenomena.

ii. The usefulness of crosscutting concepts to make sense of phenomena or design solutions to problems across science domains is highlighted.

Rating for Criterion I.E. Multiple Science Domains	Adequate *(None, Inadequate, Adequate, Extensive)*

The reviewers found adequate evidence that links are made across the science domains when appropriate because grade-appropriate elements of both the physical science (PS) and Earth and space science (ESS) are used to support sense-making. However, CCCs serve to link student learning across these domains in a limited manner throughout this unit.

Grade-appropriate elements of both PS and ESS are used to make sense of the phenomenon and solve problems during the unit. Related evidence includes:

- Four separate PS DCI elements are used to support student sense-making: **PS1.A**; **PS1.B**; **PS2.B**; and **PS4.B** (Teacher Edition, page 20).
- Portions of four separate ESS DCI elements are used to support student sense-making: **ESS1.A**; **ESS2.A**; **ESS2.B**; and **ESS2.C** (Teacher Edition, page 20).
- Lesson 1: Students use linked PS and ESS elements to make sense of how sources of materials needed for survival could be identified or obtained.
- Lesson 2: Students come to understand many of the relevant properties of water (e.g., polarity or heat capacity) to understand other properties, such as its behavior as a universal solvent.
- Lesson 5: Students analyze light spectra to identify the locations in which specified substances may be found.

- Lesson 13: Students decode complex texts to understand the structures and behavior of plastics and consider their potential applicability as part of a design solution to obtain relevant materials needed to survive off of Earth.

Grade-appropriate elements of CCCs are used to make connections across science domains. These instances are only occasionally explicit such that they support connection-making across science domains in an integrated fashion. Related evidence includes:

- Lesson 1: Students use structure-function relationships to construct an initial model in which they identify "What happens to the matter inputs at a particle level in the reaction you chose? Represent any particle-level changes that occur. Use words and/or pictures to illustrate your thinking" and address "what particle-level interactions occur during the reaction" (Initial Reaction Model, page 1). They then integrate this learning with their concerns about how to find enough of each substance to sustain life away from Earth (Teacher Edition, page 56).
- Lesson 2: Students identify patterns in water's ability to store significant amounts of energy as well as to attract and interact with a wide variety of materials as they "Build the 'Water's Importance for Life and Chemical Reactions' poster. Display slide L. Start building the poster with the properties students investigated at the stations. Then move to properties students heard from their home learning. Finally, have students add properties they know from prior units of study. A sample poster is shown" (Teacher Edition, page 71).
- Lesson 4: Students connect water properties to the M=E-F Poster. "As you reference and add panels and arrows to it, recap how we used thinking related to the matter and forces sections of it throughout this lesson…. Remind students that we decided that some of the property differences of water that we could see evidence of at a droplet scale or capillary tube scale might be relevant to some of the differences we observed at larger geologic scale, like the structure of the surface features that are formed when liquids flow over the surface of a moon or planet or when there is frost heaving below the surface…" (Teacher Edition, pages 105–108).
- Lesson 5: Students utilize patterns and the need for empirical evidence to identify those patterns when analyzing light spectra (PS DCI) and using that to identify specific substances that could comprise a separate planet's atmosphere (ESS DCI) when given known and unknown spectra evidence. "Building toward 5.A.3 Analyze, compare, and integrate empirical evidence to identify patterns in the interaction (study) of a star's light or other light spectrum with substances present in a sample or on an object in space to answer scientific questions about how we can identify which locations have the substances or elements needed to live and work in space. (SEP: 4.1, 8.2; DCI: ESS1.A.2, PS4.B.4; CCC: 1.5)" (Teacher Edition, page 129).

Suggestions for Improvement

Consider providing students with more explicit opportunities to make CCC connections across science domains. When using CCC categories, such as **Patterns** or **Structure and Function**, students' awareness of having leveraged the same elements in more than one scientific domain could be useful to build their capacity to self-select a given CCC in future sense-making efforts.

I.F. MATH AND ELA

Provides grade-appropriate connection(s) to the Common Core State Standards in Mathematics and/or English Language Arts & Literacy in History/Social Studies, Science and Technical Subjects.

Rating for Criterion I.F. Math and ELA	Extensive *(None, Inadequate, Adequate, Extensive)*

The reviewers found extensive evidence that the materials provide grade-appropriate connections to the Common Core State Standards (CCSS) in mathematics, English language arts (ELA), history, social studies, or technical standards because there are callouts for connections to mathematics and ELA standards throughout the unit. There are meaningful ways that mathematics and ELA can aid in sense-making and learning during the unit, especially in using chemical formulas and balancing chemical equations. However, there are a few instances where there is a missed opportunity for a strong connection, or where part of a claimed element is not explicitly covered.

Two mathematics standards are cited in the lessons, "CCSS.MATH.CONTENT.HSS.IC.B.6: Evaluate reports based on data" and "CCSS.MATH.CONTENT.HSA-SSE.A.1.a: Interpret expressions that represent a quantity in terms of its context. A. Interpret parts of an expression, such as terms, factors, and coefficients. Supports and verbiage are provided to make it clear to the student how mathematics is used to help with sense-making for CCSS.MATH.CONTENT.HSA-SSE.A.1.a." However, there is not a clear connection on how mathematics is used in **CCSS.MATH.CONTENT.HSS.IC.B.6**. Students can match the patterns without regard to the quantitative aspects of data, and there is not explicit guidance to have students consider the quantitative aspects of the data in the later part of the lesson.

- Teacher Background Materials: Two standards are listed as "students develop these practices as part of the sensemaking. Thus these standards are not so much prerequisites, as co-requisites. If students are simultaneously developing the skills and vocabulary in math class, you can help by making explicit connections to the mathematical standards below. Talk with the math teacher(s) to identify the strategies students are familiar with for identifying patterns in nonlinear graphs" (Teacher Edition, page 26). The sense-making includes "knowledge of how to multiply coefficients and interpret expressions (Lessons 11 & 12), and calculate averages and represent data in ways that can help them identify patterns in scatterplots (Lesson 5). Students engage in mathematical practices (CCSS.MP) reasoning in Lesson 5 when they describe patterns as they manipulate a dataset using graphs and maps. In order to balance equations, students will benefit from being able to skillfully find least common multiples, but for many students balancing equations may be an opportunity to practice with least common multiples in a way that is concrete and applied" (Teacher Edition, page 26).
- Lesson 5: "CCSS.MATH.CONTENT.HSS.IC.B.6: Evaluate reports based on data. Students use data of known spectra to evaluate data of unknown spectra to determine which gas the unknown spectra represents" (Teacher Edition, page 133). Students use previous spectra discovered in

class and use techniques like looking for patterns and overlaying to determine the unknown spectra. Towards the beginning of the lesson, they set up a graph for relative light intensity versus color. This allows students to use pieces of mathematics in their sense-making. "Explain that you have two pieces of graph paper with 1" squares to help us discuss the positions of colors and that as a class we will try to determine the relative light intensity we observe with our eyes for each position or square. Return to the projector spectrometer, place the water sample in front of the source, and tape the 1" graph paper up on the wall in the middle of the spectrum. Number the squares that have the colors of the visible spectrum on them starting with 1. In a location near the projected spectrum, create the axes for an intensity vs. position graph on a second large piece of 1" graph paper or a whiteboard. Add 5 arbitrary levels of brightness to the y-axis and label it 'intensity'. Add the numbered 1" squares from the grid to the x-axis and label it 'color or position.' Work with students to graph relative intensity points for each numbered square. It may be best to start with the brightest and darkest squares and assign them relative high (5) or low (0 or 1) intensity values. Once the class has assigned values for each numbered square, draw a curve through the points and label it 'water'" (Teacher Edition, page 125). Later in the lesson it prompts "Continue to project slide N and ask a few students to share some similarities and differences they discussed with their partner. Invite students to point out specific features on the projected spectra as they share out. Look for students to note the following: Different gasses transmit different wavelengths of light. The level of transmittance (intensity of light transmitted) is different at different wavelengths. The shape of peaks can be broad or sharper" (Teacher Edition, page 127). "Tell students that you have 4 unknown gas mixtures for partners to analyze and interpret using the reference spectra. Let them know that each pair of students will be assigned a different unknown. Distribute a copy of Analyze Unknown Gasses to each student. Assign each pair of students an unknown gas spectrum and tell them they have 6 minutes to identify the 1 to 3 reference gasses in their unknown. If students finish early, encourage them to try some of the other unknowns" (Teacher Edition, page 128). Students use the charts to look for patterns, but there is not a clear connection to how mathematics is used in sense-making in the later part of the lesson.

- Lesson 11: "CCSS.MATH.CONTENT.HSA-SSE.A.1.a: Interpret expressions that represent a quantity in terms of its context. A. Interpret parts of an expression, such as terms, factors, and coefficients. Students evaluate and choose (coefficients) to add to chemical formulas to ensure there are equal numbers of elements on each side of the chemical equation" (Teacher Edition, page 236). "We can use a new model, called a chemical equation, to model these processes that occur. Ask students to work with a partner to write the chemical equation for the process described in Perchlorate on Mars in their science notebooks… Point out to students that there seem to be more atoms on the reactants side than the products side. Ask students, Does it make sense that some of these oxygen atoms would just…disappear? Is that what we think happens? Agree as a class that this does not seem likely to happen. Ask, Then how should we show that these atoms are still there? Listen for ideas such as: We can write O2 twice, like O2 + O2 Draw two O2 molecules… Circulate and provide feedback to students asking, 'Is matter conserved on both sides? What is your evidence? How are you using mathematical thinking to figure this out?' Once students have modeled balanced equations with the manipulatives, write the balanced equations on the board or a piece of chart paper. Circle or underline the coefficients and tell students this is the accepted way to show multiple atoms or molecules of a substance in a chemical reaction" (Teacher Edition, page 233).

- Lesson 12: CCSS.MATH.CONTENT.HSA-SSE.A.1.a: Interpret expressions that represent a quantity in terms of its context. A. Interpret parts of an expression, such as terms, factors, and coefficients. Students evaluate and choose (coefficients) to add to chemical formulas to ensure there are equal numbers of elements on each side of the chemical equation" (Teacher Edition, page 255). "Distribute white boards and dry erase markers to each pair of students. Give groups about 3 minutes to balance the chemical equation on the white boards. Have the pairs of students show their balanced equations to the class and check for agreement. If students' work does not agree with others', ask them to share the approach they used to balance the equation" (Teacher Edition, page 251).
- Lesson 15: "CCSS.MATH.CONTENT.HSA-SSE.A.1.a: Interpret expressions that represent a quantity in terms of its context. A. Interpret parts of an expression, such as terms, factors, and coefficients. Students evaluate and choose (coefficients) to add to chemical formulas to ensure there are equal numbers of elements on each side of the chemical equation" (Teacher Edition, page 292). "Give partners about 10 minutes to develop their balanced chemical equations on their whiteboard. As groups are working, rotate around the room. Assist as needed and make sure partners show how they are balancing the equation. As you rotate around the room, choose 2–3 different balanced chemical equations to display to the class. Fats and proteins are good candidates for this, as they can be built out of components of carbon monoxide or dioxide, nitrogen, and other organic compounds. Steel is a mixture, not a compound, so it cannot be modeled in this way. Students may also realize that they have too many products, so some other 'leftovers' might form" (Teacher Edition, page 288). "We have mathematical models (balanced equations) for these substances…" (Teacher Edition, page 289).

There are ELA standards cited in the unit. The majority of the claimed connections are present, although note that one portion of a claimed standard in Lesson 1 is not explicitly covered within the lesson.

- Lesson 1: "CCSS.ELA-LITERACY.RST.9-10.9: Compare and contrast findings presented in a text to those from other sources (including their own experiments), noting when the findings support or contradict previous explanations or accounts. When obtaining and evaluating information, students identify all sources that they use, whether these resources agree or disagree with each other, and describe how the sources in combination work to answer their questions" (Teacher Edition, page 58). Students look at different resources in this lesson (models, Artemis Transcript, Space Missions Deck, Transport Rockets), to make the DQB and their Day 1 Exit Ticket. In the Exit Ticket they consider, "Criteria: What types of substances/materials will we need at any of the places off Earth that you looked at today in order to live and work or a longer amount of time? What additional substance/materials would we need to work productively and live happily there as well? Constraints: Based on what we figured out today, what factors will limit the amounts of those substances/materials that we can take with us (crewed) or send (uncrewed) to our chosen destination? Solutions: What else could we do to get these substances/materials if we cannot bring them with us nor have them sent from Earth? Possible solutions should use our current technologies" (Lesson 1: Key: Day 1 Exit Ticket). It is not clear that they note when the findings support or contradict previous explanations or accounts. It is also not clear that they identify all sources used, whether the sources agree or disagree with each other, and how they combine to answer the question within this lesson.

- Lesson 2: "CCSS.ELA-LITERACY.RST.9-10.7: Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words. Students translate quantitative and qualitative data from readings, their own experiments, and simulations to explain why the properties of water support life" (Teacher Edition, page 74). The six stations have both quantitative and technical information expressed in words and visual information that students translate for their peers. "Say, Since we did not visit every station, we need to spend time hearing what the other groups discovered. To make sure we have time to hear from every group, you will have only two minutes to talk about each station. As you share, be sure to show how your findings explain why water is important to life and/or chemical reactions. We also want to make sure that all group members have a chance to be heard. Read through the slide and emphasize the two constraints that groups must plan for: a two-minute time limit, and everyone's voice must be heard. Let students know that chart paper and chart paper markers are available if their group would like to make a visual representation when sharing with the rest of the class" (Teacher Edition, page 69).
- Lesson 5: "CCSS.ELA-LITERACY.RST.9-10.2: Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text. Students read excerpts from peer-reviewed scientific journals to determine what types of data was [sic] measured and the results of the data analysis. They compare this information to that presented earlier in the lesson to summarize the ways scientists use spectra data to determine the presence of substances on objects in space" (Teacher Edition, page 133). After students read, the teacher is prompted to ask, "What pieces of information in the excerpts help answer our question about how we could detect the presence of substances we need? How does this information compare with the types of information we have analyzed in this lesson?" (Teacher Edition, page 132). This is also at the end of the handout.
- Lesson 10: "CCSS.ELA-LITERACY.RST.9-10.2 Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text. Students summarize important ideas from the reading—directly on the reading, in the class debrief, and as they model the reaction from the reading" (Teacher Edition, page 217). "Distribute Cleaning Metal-Contaminated Water. Explain to students that they have seen similar readings before in OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit), which are based on journal articles written by scientists. Highlight that each section will be based on the scientists engaging with a different practice as they try to answer their question about how to clean water with chemical reactions. Explain the reading strategy below, then give students time to read. ✱ Summarize the new information about how the reactions discussed help clean water and record any new questions you have" (Teacher Edition, page 212). "When students

have had time to read and annotate, display slide E and lead a discussion about the reading. Accept all responses to the follow-up questions, as they are intended to help motivate modeling the reaction" (Teacher Edition, page 213).

- Lesson 11: "CCSS.ELA-LITERACY.RST.9-10.2: Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text. Students determine the central ideas of a reading about fertilizers which could be used to grow plants in space and use their summary of the reading to make a claim about which fertilizer is best to use for fertilizing soil off of Earth. Students also determine the central ideas in a text about perchlorate ions in Martian soil." Students map out the two ways fertilizer can be made in space (Lesson 11: Fertilizers from Urine). In the perchlorate reading, students have a question to answer and model the process (Lesson 11: Perchlorate on Mars).
- Lesson 12: "CCSS.ELA-LITERACY.RST.9-10.2: Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text. Students jigsaw and research using information from scientific text to determine which elements are available on specific locations in the solar system" (Teacher Edition, page 255). "Ask partners to work together to determine which elements are found on the Moon and Mars. Explain that each person will be responsible for determining which elements are found on one of the locations. Tell students to use the website links provided on Search for Elements to research each location. Give groups about 10 minutes to complete questions 2–5 on Search for Elements. As groups work, rotate around the room and assist as needed…. Based on your research, which of the locations contains enough of the elements needed for photosynthesis and to build most of the substances we need for a permanent settlement? Which substances would be most straightforward to produce? Why? Which substances would be most difficult to produce? Why?" (Teacher Edition, pages 247–248).
- Lesson 13: "CCSS.ELA-LITERACY.RST.9-10.2: Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text. Students gather information from a scientific text (Recycling Processes) to determine what is common across different recycling processes…" "CCSS.ELA-LITERACY.RST.11-12.7: Integrate ~~and evaluate~~ multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. Students integrate information from a reading, two videos, and a series of molecular models to answer two questions, one about why we can currently recycle some of the substances we need and not others, and a second about how this informs new engineering solutions for living and working off Earth and/or on it in our future" (Teacher Edition, page 271). "Orient to three types of source[sic] of information we will synthesize. Explain that we will complete [sic]Recycling Ideas Organizer by synthesizing information from a reading, two videos, and examining molecular models… Give the remaining time (about twelve minutes) for students to work with a partner on completing row 1 of Recycling Ideas Organizer using Recycling Processes" (Teacher Edition, page 264).
- Lesson 14: "CCSS.ELA-LITERACY.RST.9-10.8 Assess the extent to which the reasoning and evidence in a text support the author's claim or a recommendation for solving a scientific or

technical problem. Students evaluate the authors' claims for two articles based on scientific understandings they have developed through evidence and on reasoning (relationships to human needs and ethical considerations)" (Teacher Edition, page 279). "Highlight that they should first take a few minutes to synthesize across articles, meaning they will help each other complete the table in number 3 and note similarities and differences. Then, they should use number 4 to help evaluate the claims made in the articles. Highlight that our key question when we read pieces like this should be: How does the claim match up against our understanding of scientific evidence and of the problem being addressed?" (Teacher Edition, page 278).

Suggestions for Improvement

Consider enhancing how mathematics is used to aid in students' science sense-making and could connect to the content in the later part of Lesson 5.

OVERALL CATEGORY I SCORE: 2 (0, 1, 2, 3)	
Unit Scoring Guide – Category I	
Criteria A-F	
3	At least adequate evidence for all of the unit criteria in the category; extensive evidence for criteria A–C
2	At least some evidence for all unit criteria in Category I (A–F); adequate evidence for criteria A–C
1	Adequate evidence for some criteria in Category I, but inadequate/no evidence for at least one criterion A–C
0	Inadequate (or no) evidence to meet any criteria in Category I (A–F)

CATEGORY II

NGSS INSTRUCTIONAL SUPPORTS

II.A. RELEVANCE AND AUTHENTICITY

II.B. STUDENT IDEAS

II.C. BUILDING PROGRESSIONS

II.D. SCIENTIFIC ACCURACY

II.E. DIFFERENTIATED INSTRUCTION

II.F. TEACHER SUPPORT FOR UNIT COHERENCE

II.G. SCAFFOLDED DIFFERENTIATION OVER TIME

II.A. RELEVANCE AND AUTHENTICITY

Engages students in authentic and meaningful scenarios that reflect the practice of science and engineering as experienced in the real world.

i. Students experience phenomena or design problems as directly as possible (firsthand or through media representations).

ii. Includes suggestions for how to connect instruction to the students' home, neighborhood, community and/or culture as appropriate.

iii. Provides opportunities for students to connect their explanation of a phenomenon and/or their design solution to a problem to questions from their own experience.

Rating for Criterion II.A. Relevance and Authenticity	Extensive *(None, Inadequate, Adequate, Extensive)*

The reviewers found extensive evidence that the materials engage students in authentic and meaningful scenarios that reflect the real world because students are generally able to see that the central topic is relevant, worth exploring, and of value to humans on Earth. Student sense-making is supported by numerous student-directed investigations in which they come to understand underlying explanations to the phenomena and problems being examined. However, there is a misalignment with the Lesson 1 slides and the Lesson 1 Student Procedure in the materials folder that relates to connections to students' homes, neighborhoods, communities, and cultures.

The phenomena and problems presented are relatable to students and it is generally clear to students that the problem is important to others. Related evidence includes:

- Lesson 1: Student-provided ideas serve as a starting point for examining different Earth systems and use it as a basis for considering how to source materials away from Earth as students "record a list of the ideas that students raise on the board (e.g., growing food, finding water, mining, manufacturing some materials [making them]), recycling stuff from waste (e.g., fertilizer). You will refer to this list throughout the class period" (Teacher Edition, page 44).
- Lesson 1: Students reflect on the Artemis mission promotional video and consider "how could developing ways to reuse or recycle resources in space help us figure out how to more responsibly or efficiently use the resources we have on Earth?" (Teacher Edition, page 46).
- Lesson 2: Students investigate some of the relevant properties of water. "Distribute a copy of Water's Properties Investigations to each student. Display slide G. Explain the combinations of stations students will visit with their groups. Let students know that the handout contains information for all stations, but that they will only be responsible for completing the questions pertaining to the two stations they visit" (Teacher Edition, page 67).
- Lesson 4: Students investigate the impact of different liquids on surface features. "Complete the Erosion Investigation of water on the Mars-like material. Display slide J. Instruct students to work in their groups to set up the Erosion Investigation. Have the investigation materials

available to groups so they can conduct the investigation. Distribute two index cards to each group and ask them to write the liquids used in big letters on the fronts of the cards and their names or initials on the backs. Point out where the data table is located on Geologic Landforms Investigation to record experimental data. Encourage them to write 'most,' 'least,' and 'somewhat' for each substance so they can see a pattern emerge. Sample results can be found on Soil Investigation Guidance" (Teacher Edition, page 96).

- Lesson 5: Students collect relevant data and organize it to "analyze and interpret transmission spectra for three Earth gasses. Show slide N. Tell students these are the infrared transmission spectra for three gasses commonly found in our atmosphere on Earth: water, carbon dioxide, and ozone. Point out that since we cannot see infrared light, scientists refer to its 'colors' using a number, wavelength, that has units of distance (microns = 1x10 m). Ask students to turn and talk with a partner about the similarities and differences they notice between the spectra for the three substances. Be prepared to answer any questions about the spectra and help students connect them to the graph the class co-created for sample C" (Teacher Edition, page 127).
- Lesson 13: "Reflect on surprising aspects of sulfur-based concrete. Display slide A. Discus on the slide as a class, What was the most surprising to you about the new kind of sulfur-based concrete you encountered in the last lesson? Accept all answers. If students do not mention that it was recyclable, ask this question with a show of hands as a response, How many of you also found the idea of making a new type of concrete that is recyclable also kind of surprising? Then say, NASA has always had a mission of improving the lives of humans on Earth when possible, too. A lot of NASA's work has directly supported human life down here, and these outer-space innovations can reduce pollution and waste and negative impacts on ecosystems. Let's consider this connection to recycling a bit more" (Teacher Edition, page 262).

Students have some opportunities to relate the phenomenon and problem to their own lives. Related evidence includes:

- Lesson 1: Students complete a home learning assignment in which students are encouraged to connect learning to their families and communities. "… draw on funds of knowledge from our own families and communities in the past and that this has given us a bigger picture of what we need to consider and what might be possible. Suggest we do that again tonight. Display slide W. Have students record the two questions from the slide on a sheet of looseleaf paper for the home-learning interview" (Teacher Edition, page 48).
- Lesson 2: Students complete a home learning assignment in which teachers "Introduce the home learning. Display slide I. Say, We have spent a lot of time thinking about why water is so special chemically, but we also need to consider water's cultural importance. Then read through the information on the slide" (Teacher Edition, page 70).
- Lesson 2: Students "build the 'Water's Importance for Life and Chemical Reactions' poster. Display slide L. Start building the poster with the properties students investigated at the stations. Then move to properties students heard from their home learning. Finally, have students add properties they know from prior units of study. A sample poster is shown" (Teacher Edition, page 70).

- Lesson 2: "Consider how much water we need each day. Display slide O. Say, We know that water is super important for life. Take a moment to turn and talk with a partner about the prompts on the slide. Give students two minutes to discuss the prompts with a partner. Then ask a few volunteers to share their ideas. Summarize ideas and point out that it sounds like we will need a lot of water!" (Teacher Edition, page 74). An alternate activity extension is available to help students consider the amount of water sent on Apollo 11 and reconciling that with average daily water consumption on Earth.
- Lesson 3: Students are encouraged to consider their local topography. "Identify processes that lead to the development of surface features over time. Present slide D. Say, Think about features here on Earth that are the result of water interacting with the surface, or some other process. Turn and talk with a partner to brainstorm a list of possible features we would look for in an image. Give students a few minutes to brainstorm a list with their partner" (Teacher Edition, page 80).
- Lesson 11: Students consider the impact of potential food contaminants. "Problematize perchlorate as a food-related toxin. Tell students that another polyatomic ion that is relevant to our conversation about growing food on Mars is perchlorate, ClO. Say, Unlike ammonium, which can help us grow food and survive on Mars, perchlorates make survival more difficult. This means that in addition to adding something to soil (NH4), we also need to remove something from the soil. But how would we do that? Distribute Perchlorate on Mars. Give students seven minutes to read with a partner and answer the questions on the reading" (Teacher Edition, page 232).

Suggestions for Improvement

- Consider providing students with a deeper understanding of why Earth-centered benefits, such as sustainable material design and development, are more reliably funded, supported, and pursued when coupled with a space exploration purpose rather than simply for the sake of improving life on Earth.
- Consider including additional connections, background knowledge, paradigms, and potential misconceptions related to space travel and survival in space that come from media such as movies, tv shows, books, etc. These could potentially be added in the Explore Related Phenomena (Step 3) in Lesson 1.
- Consider making a stronger connection to how technologies have already changed because of astronauts living in the International Space Station.

II.B. STUDENT IDEAS

Provides opportunities for students to express, clarify, justify, interpret, and represent their ideas and respond to peer and teacher feedback orally and/or in written form as appropriate.

Rating for Criterion II.B. Student Ideas	Extensive *(None, Inadequate, Adequate, Extensive)*

The reviewers found extensive evidence that the materials provide students with opportunities to both share their ideas and thinking and respond to feedback on their ideas because there are multiple ways for students to interact with information and prompts throughout the unit. These include modeling, drawing, speaking, listening, reading, and writing. There are many opportunities for students to respond verbally to feedback. There are also prompts to help the teacher facilitate class discussions and draw out student thinking, and students receive feedback from both the teacher and their peers. There are opportunities for students to reflect on their participation and classroom community. However, there are some missed opportunities for students to revise their thinking or to respond to feedback on an individual level and three-dimensionally after key sense-making.

Related evidence includes:

- Teacher Background Information: The materials state the importance of valuing student ideas. "It is valuable to think of ideas like these not as misconceptions that need to be erased but as productive ideas that we can use to build understanding. Not only does this help some students feel more comfortable talking about science and build a scientific identity, it improves science learning across the board. Following these ideas, and building explicitly from these ideas to draw connections, is a productive pedagogical tool that will help students construct new, more accurate conceptual models of the structure and properties of matter" (Teacher Edition, page 25).
- There are multiple times where Community Agreement discussions and reflections are used in the unit to help with students sharing ideas. Students reflect on how well they followed the Community Agreements throughout the unit and give feedback to peers using the Community Agreements. "1. Share your focal Community Agreement with your small group. 2. Ask for peer feedback around how well you engaged with the members of your group using that focal agreement. Students may use sentence starters like these: a. I thought you really followed your focal agreement when you ______. b. I felt you were most successful with your focal agreement when we ________. c. I felt you struggled the most with your focal agreement when we _______ because __________. 3. Go back and look at your plan for enacting your chosen Community Agreement. 4. Using the peer feedback you received, reflect on the following prompts: a. How successful were you in enacting your plan? b. What improvements could you make? c. How might those improvements change how you interact with classmates in future group activities? How might your learning improve?" (Lesson 2, Focal Community Agreement). These activities throughout the unit help students reflect on their participation and classroom

community, but not necessarily on how their learning has changed related to the three dimensions.

- There are opportunities for students to revise their thinking based on new learning and feedback as well as see how their thinking has changed. Examples include:
    - Lesson 1: Students complete an initial model. There is guidance to have them revisit the model later in the unit. “Make a copy of this pre-assessment before giving it back to students and consider building additional opportunities into the last third of the unit for students to compare the models they develop at those points to the models they developed here. This can be a powerful catalyst for reflecting on their growth in understanding over time” (Teacher Edition, page 50). The resource is referenced again in Lesson 13. “Ask students to find the one subunit shown on the slide in the matter outputs of Initial Reaction Model from lesson 1. Remind students of any questions they had about the ‘n’ in this model, or point it out now if they did not have questions before. Emphasize the following different scales. Then ask students to talk to a partner about what they notice and wonder about plastics shown on the slide” (Teacher Edition, page 266). However, there is not explicit verbiage in the last third of the unit to remind teachers to have students revise their initial models.
    - Lesson 7: The class analyzes the consensus periodic table regarding the number of connections and the number of electrons. They then use this information to revise their models of the atomic structure of carbon they had in their science notebooks. “Have students look back at their initial models of the atomic structure of carbon. Present slide F. Give students a few minutes to update their models in their science notebooks. Then, have students show their models while in the Scientists Circle. Tell students to take a moment to look at the different models their classmates created” (Teacher Edition, page 160).
    - Lesson 7: Students reconsider their definition of bond after new information from different models (electron shell model and Lewis Dot model). “Present slide T. Have students turn and talk with a partner about the prompts on the slide… How has your definition of bond changed based on this new information?” (Teacher Edition, page 167).
    - There is verbiage of how the Progress Tracker can be used to monitor how thinking has changed throughout a unit based on new information. “Remind students that the Progress Tracker is a thinking tool that is designed to help them keep track of important discoveries the class makes… It is important that what the students write in the Progress Tracker reflects their own thinking at that particular moment. In this way, the Progress Tracker can be used to formatively assess individual student progress throughout the unit” (Teacher Edition, page 150).
- Lesson 1: Students have the opportunity to work with a partner to identify similarities and differences in their initial models. “Have students partner with someone who explained a process involving a different chemical reaction. Instruct pairs to identify parts of their explanations that were similar and different” (Teacher Edition, page 50). Students then develop an initial consensus model using a Scientist Circle. During this time, they orally receive feedback

from peers and the teacher. “Also add any representations of electrons, ions, or charges that students agree are important, if they argue for them..., Ask students to share one thing that they agree is happening to some atoms (or ions) in every chemical reaction. Establish consensus around the idea that: Atoms or ions break apart from the other particles they were connected to in the reactants. Those same atoms come back together (connect) in new arrangements when they form the products” (Teacher Edition, pages 52–53).

- Lesson 2: Students visit two of six stations. They work together in a small group to determine how they are going to communicate their findings to others. “Have students meet with their groups from the last class. Display slide J. Give groups some additional time to finalize how they will communicate station information to their classmates. Again, offer chart paper and chart paper markers to groups if they wish to communicate station information visually. As groups develop their plans, circulate around the room to listen to and observe students’ interactions with each other” (Teacher Edition, page 70). As students are sharing, “If students share terms that others may not be familiar with, ask clarifying questions or prompt students to explain the terms” (Teacher Edition, page 71). After sharing and building the poster, students then reflect on community agreements and give feedback. “Go over the protocol for giving peer feedback. Encourage students to use the sentence starters on Focal Community Agreement as a guide to give peer feedback. Give each group member two minutes to share their focal Community Agreement and receive peer feedback. After each group member has had a chance to give and receive feedback, instruct students to complete the three prompts under item 4 on Focal Community Agreement” (Teacher Edition, page 73).
- Lesson 3: Students have the opportunity to defend claims using evidence from satellite images. “Present slide L and have the ‘Surface Features and Causes’ poster visible. Go through the different processes identified on the poster and have groups hold up which of the satellite images they think was formed by that process. If groups who analyzed the same satellite images do not agree, ask each group to use evidence from the ‘Surface Features and Causes’ poster to defend their claims about the geologic process which formed the surface feature. As students share, organize the images using the class set of each reference you have on a wall using tape so that they are grouped by geologic process. Use the table below as a key for which satellite images were formed by which process. Note that some images may represent multiple processes. It is okay if groups do not point out all of the different processes in the images” (Teacher Edition, page 83). There is guidance for the teacher to ask for evidence from the students as they consider what could have made different surface features on Mars and the moon. “Which portion of an image(s) could have possibly been formed by water? Which portion of an image(s) were possibly formed by something else? How do you know? What is your evidence?” (Teacher Edition, page 85).
- Lesson 4: As students model interactions of water using the molecule cutouts, there is guidance to help the teacher make students explain and justify their thinking orally. “As students work, circulate and ask a few students to explain what they are doing. Specifically, ask students to use the arrows and molecular structures to show force interactions between molecules. Ask students which molecules might exhibit stronger forces or a greater number of force interactions on neighboring particles and why” (Teacher Edition, page 101).

- Lesson 5: Students share their transmission spectra analysis and get peer feedback. “Check-in with students to see if they are ready to check their work by finding out what reference gasses were in each of the unknowns. Ask students to share their analysis. Encourage students who analyzed the same unknown gas to show agreement or disagreement non-verbally” (Teacher Edition, page 129). Later in the lesson, there is guidance to help ensure students are justifying their thinking. “Which reference gasses did we see supporting evidence for in the atmosphere spectra? Which bands helped you determine that? What makes you think that?” (Teacher Edition, page 131).
- Lesson 6*:* As students reorganize their element cards, the teacher is prompted with verbiage to provide feedback that they verbally respond to. *“*As groups work, walk around the room and assist as needed. Ask clarifying questions to help groups such as: What piece of information on the cards are you considering most important? Why? What information on the card is informing this decision? Is your group using a specific pattern in the information on the card to guide your organization process?” (Teacher Edition, page 145).
- Lesson 8*:* Students use a whiteboard to model a chemical equation before holding up the whiteboard. The teacher then discusses the models with students. Students then use cutout molecules and model a reaction with a partner. As they work the teacher is prompted to, “Circulate and provide feedback to students asking, ‘Is matter conserved on both sides? What is your evidence? How are you using mathematical thinking to figure this out?’ Once students have modeled balanced equations with the manipulatives, write the balanced equations on the board or a piece of chart paper. Circle or underline the coefficients and tell students this is the accepted way to show multiple atoms or molecules of a substance in a chemical reaction” (Teacher Edition, page 233).
- Lesson 15: Students are given a choice to model one of the simple compounds from the unit. As they work, the teacher is prompted to, “Circulate around the room and give formative feedback tied to the positions of electrons, the use of the periodic table, and the pulls that students represent in their molecules. Reference their balanced equations from the previous step, as well” (Teacher Edition, page 289).
- Teacher Reference Materials: There is guidance for the teacher on how to use peer-assessment. “Peer feedback is most useful when there are complex and diverse ideas visible in student work. That is, peer feedback works best when not all work is the same. Student models and explanations are good times to use a peer feedback protocol. They do not need to be final pieces of student work. Rather, peer feedback will be more valuable to students if they have time to revise after receiving peer feedback. It should be a formative, not summative, type of assessment. It is also necessary for students to have experience with past investigations, observations, and activities where they can use these experiences as evidence for their feedback” (Teacher Edition, page 297).

Suggestions for Improvement

- Consider providing explicit verbiage about when would be most impactful for students to revise their initial model from Lesson 1 along with potential questions to spur meta-cognitive thinking about their learning over time.

- Consider more opportunities for students to revise their thinking through model or explanation revisions on the individual level, especially after key learning moments or after consensus conversations have happened.

II.C. BUILDING PROGRESSIONS

Identifies and builds on students' prior learning in all three dimensions, including providing the following support to teachers:

i. Explicitly identifying prior student learning expected for all three dimensions
ii. Clearly explaining how the prior learning will be built upon.

Rating for Criterion II.C. Building Progressions	Extensive *(None, Inadequate, Adequate, Extensive)*

The reviewers found extensive evidence that the materials identify and build on students' prior learning in all three dimensions because prior learning is discussed coherently and in great detail, including specific support to what prior knowledge is expected for individual SEP, DCI, and CCC elements as well as how that prior learning will be built upon throughout the unit.

Prior student learning expected for all three dimensions is identified in the materials. Within the Teacher Background Knowledge section there is reference to specific elements of DCIs, SEPs, and CCCs that would have been developed in middle school Open Sci Ed units. Specific elements for SEPs are listed for **Developing and Using Models** and **Obtaining, Evaluating, and Communicating Information**. Specific elements are also listed for the CCC of **Structure and Function**. Related evidence includes:

- Teacher Background Knowledge: This unit is the third in the OpenSciEd High School Chemistry course sequence. In the second unit of OpenSciEd HS Chemistry, students developed ideas around electrostatics (Teacher Edition, page 14).
- Teacher Background Information: There is reference to what prior student learning is done for the SEP of **Developing and Using Models**. "Students' use of Developing and Using Models increases its sophistication from middle school as models used in a predictive manner in high school. In the OpenSciEd MS unit OpenSciEd Unit 8.4: How are we connected to the patterns we see in the sky and space? (Space Unit), students intentionally developed and used models to explain physical and Earth and space science phenomena at very different scales of time and space. Students develop, use, and revise models from the start and throughout the unit to explain patterns in the sky ranging from why Manhattanhenge occurs twice a year in the same spot, why the seasons in Australia are opposite of seasons in the Northern Hemisphere, why the Moon appears redder during a lunar eclipse but does not go completely dark, why planets go around the Sun and moons go around planets, our place in the solar system and galaxy (MS

Modeling 2.2, 2.4, 2.5, 2.6). In OpenSciEd MS unit OpenSciEd Unit 7.1: How can we make something new that was not there before? (Bath Bombs Unit), students investigate bath bombs, modeling the transformation of matter of bath bombs using particles that are round, but not investigating any subatomic structures. These middle-school models do not move across scales" (Teacher Edition, page 18).

- Teacher Background Information: There is reference to what prior student learning is done for the SEP of **Obtaining, Evaluating, and Communicating Information**. "In MS OpenSciEd, students developed Obtaining, Evaluating, and Communicating Information as they read, evaluated, compared, and synthesized information from multiple sources including text, data, maps, graphs, and images (MS Obtaining, evaluating, and communicating information 8.1, 8.2) in the unit OpenSciEd Unit 8.4: How are we connected to the patterns we see in the sky and space? (Space Unit), building on their experience with this practice from prior units. While students continue to use several close reading and listening protocols, some of the scaffolding from previous units is eventually removed so they can execute the practice on their own" (Teacher Edition, page 18).
- Teacher Background Information: There is reference to what prior student learning is done for the CCC of **Structure and Function**. "This unit builds upon Crosscutting Concepts that students should have previously developed in connection with Structure and Function within the OpenSciEd Middle School unit [unit: CA]. In OpenSciEd Middle School Unit [material: ca], students looked for patterns of macroscopic occurrences in the bath bomb phenomena to figure out the particle-level patterns that explain the phenomena (MS Patterns 1.2, 1.3, 1.4). Students develop the idea that these particles must be made of constituent parts (atoms) because of the patterns they observe in their investigations. They use discrepant patterns to reason that the way these parts are put together is unique to different substances. Students intentionally develop patterns across the three-year OpenSciEd Middle School sequence. In OpenSciEd Middle School Unit [material: ca], substructure ideas about matter were limited to the ideas that some atoms could combine with others and make new substances (e.g., bath bombs + water yield new gasses). In other words, they model structures and parts, but do not indicate the causal mechanisms that link function to structure (MS Structure & Function 6.1, 6.2). Students describe and analyze the bath bomb system and attempt to account for the properties of bath bombs, but they do not have the mechanisms of the DCI1.A necessary to completely explain the atomic structures that contribute to the function of these materials" (Teacher Edition, page 19).

There are clear indications of how the focal SEPs and CCCs will be built upon during the unit. Related evidence includes:

- Each lesson has a portion in the "Where we are going and NOT going" section where it states what elements of the DCIs, SEPs, and CCCs are being built upon in the lesson. Examples include:
  - Lesson 1: "Students build on understanding around conservation of matter that they developed in OpenSciEd Middle School units… Students engage in SEP 1.1, 1.2, 1.8, and 2.3 partially… Students engage in CCC: 6.2 partially…. This is the first time students have used this crosscutting concept element in the OpenSciEd High School Chemistry course.

Students have developed portions of this element not addressed in this lesson in Genetics Unit…" (Teacher Edition, page 38).

- Lesson 3: "The goal of this lesson is to have students apply their prior knowledge of geologic processes when developing claims about which process formed surface features we see on satellite images. This lesson is designed to coherently build ideas related to the following disciplinary core idea: ESS1.C: The History of Planet Earth. Although active geologic processes, such as plate tectonics and erosion, have destroyed or altered most of the very early rock record on Earth, other objects in the solar system, such as lunar rocks, asteroids, and meteorites, have changed little over billions of years. Studying these objects can provide information about Earth's formation and early history. Crossout[sic] explanation: ESS1.C.2 is fully developed in OpenSciEd High School physics OpenSciEd Unit P.4: Meteors, Orbits, and Gravity (Meteors Unit)… Students work with the class to develop a poster of possible surface features and their causes to look for as they examine images of Earth. The class orients how to interpret images of two river systems in the United States at different scales (CCC: 1.1). Students work in small groups to develop claims about the geologic process which caused the formation of four surface features on Earth (SEP: 7.5). They defend these claims using student-generated evidence from the class-developed poster. Students then practice individually developing and defending claims about the geologic processes that caused surface features on Mars and the Moon (SEP: 7.5). Students engage in SEP: 7.5 partially. For SEP: 7.5: Make and defend a claim based on evidence about the natural world or the effectiveness of a design solution that reflects scientific knowledge and student-generated evidence. Students developed this element in a prior unit, OpenSciEd Unit B.3: Who gets cancer and why? Where should we focus efforts on treatment and prevention? (Genetics Unit). Students engage in the full element of CCC: 1.1 in their analysis of images of the surface both at a planetary scale as well from images of the surface that range from meters to 100s of kilometers across. CCC: 1.1 is reused and extended to consider patterns at multiple scales, including the particle level, in lessons 4, 7, 8, 9, and 15" (Teacher Edition, page 78).
- Lesson 6: "The goal of this lesson is for students to begin to identify some of the patterns used to organize the Periodic Table. This lesson is designed to coherently build ideas related to the following disciplinary core ideas: PS1.A: Structure and Properties of Matter. The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states. Crossout[sic] explanation: PS1.A.2 is fully developed in Lesson 7 of this unit… Students engage in SEP: 2.1 and 2.3 partially…. Students will fully engage with this element later in the unit as they revise their element tools and use the Periodic Table to predict relationships between compounds (components of a system) when they balance and write chemical equations" (Teacher Edition, page 139).
- Lesson 9: "This lesson is designed to coherently build ideas related to the following disciplinary core ideas: PS1.A: Structure and Properties of Matter. The periodic table

orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states. PS1.A: Structure and Properties of Matter. The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms… Students have engaged with the elements of all three dimensions in the lesson-level performance expectation in several prior lessons. The end of this lesson includes the Mid-point Assessment which serves as a summative assessment of a student's progress in using each of those three dimensions" (Teacher Edition, page 197).

- Teacher Background Information: There is reference to what DCIs will be built upon in the unit. "This unit is designed to build on student's ideas about the structure of matter, with an emphasis on the formation of covalent bonds, polarity, the periodic table, and the structure of molecules. It also contributes to core ideas for Earth and Space Science, especially the interactions of water with Earth's surface. While ESS2-5 and HS-PS1-2 are addressed in this unit alone in the OpenSciEd course sequence, many of the Performance Expectations (PEs) in this unit are shared across other Chemistry or Physics units" (Teacher Edition, page 14)
- Teacher Background Knowledge: There is a section "How does the unit build three-dimensional progressions across the course and the program?" where specific DCI elements are listed and in what other courses they are used within the OpenSciEd High School Resources (Teacher Edition, pages 22–23).

Suggestions for Improvement

Consider providing an at-a-glance reference for teachers to understand the progression of all three dimensions within this unit like the table presented for the SEPs and CCCs (Teacher Edition, pages 23 and 24) of all the OpenSciEd High School units.

II.D. SCIENTIFIC ACCURACY

Uses scientifically accurate and grade-appropriate scientific information, phenomena, and representations to support students' three-dimensional learning.

Rating for Criterion II.D. Scientific Accuracy	Extensive *(None, Inadequate, Adequate, Extensive)*

The reviewers found extensive evidence that the materials use scientifically accurate and grade-appropriate scientific information. The readings, media, and simulations are reliable, accurate, and grade appropriate. There is special attention paid to not create misconceptions in the unit. Verbiage is in the unit to help students see the value and limitations of different types of models that are used in the unit.

Information, resources, and instruction in the unit are overall scientifically accurate. Related evidence includes:

- There is a section “What are recommended adult-level learning resources for the science concepts in this unit?” (Teacher Edition, page 27) and “What are some common ideas that students might have?” (Teacher Edition, page 25).
- Leson 1: The video students watch that helps define the “anchoring phenomenon” is from NASA.
- Lesson 2: The readings for the stations site sources such as the USGS, College Physics, NOAA, and the National Weather Service.
- Lesson 4: There may be a misconception with synthetic versus natural liquids occurring when students complete the investigation lab with water, vegetable oil, isopropyl alcohol, and white vinegar.
- Lesson 5: Transmission spectra are generated using NASA’s online Planetary Spectrum Generator.
- Lesson 9: Dietary Salts is a reading used that is adapted for classroom use from an article from the European Journal of Physiology.
- Lesson 10: Cleaning Metal-Contaminated Water is a reading adapted from a paper written by scientists about their research. Citations are made at the bottom of the resource.
- Lesson 11: Fertilizer from Urine is a reading that has citations from NASA, Tokyo University of Science, and the CDC.
- Lesson 14: 3-D Printing/Geopolymer Concrete cites multiple reliable sources.

There is guidance to help the teacher not create misconceptions for students or go beyond the scope of NGSS. For example:

- Lesson 2: “If students show interest in comparing the properties of water to the properties of other materials they have studied in Electrostatics Unit, take time to co-create a parallel poster. For example, you could discuss properties of metals, such as conductivity, and their importance for life. Additionally, you could present students with specific heat values of metals and have students use their understanding of specific heat to explain what happens to those metals as energy is applied to them. Take care not to develop a cause-effect relationship between conductivity and specific heat values, as the basis of these two material properties is different” (Teacher Edition, page 73).
- Lesson 4: “Display slide Y and distribute Mars Geological Landforms. Have students read with a partner and work together to answer the questions in the reading. This reading and the modeling activity will be debriefed during the Building Understandings Discussion that follows the modeling activity. You do not need to spend time debriefing the reading here unless there are student questions or misconceptions that will hinder them in the modeling activity” (Teacher Edition, page 103).
- Lesson 9: “In this lesson students will work with manipulatives that will show the four bonds in carbon atoms in three-dimensions. They will see computer visualizations of two carbon-based molecules in three dimensions as well for question 6 of Mid-point Assessment. The unit will not

go any deeper in helping students think about why molecules are shaped the way they are. Do not discuss why electronegativities of transition metals might not follow the expected trends and avoid modeling the shells of atoms that have d-orbitals, as these ideas fall outside the bounds of the NGSS" (Teacher Edition, page 197).

- In the lessons, different types of models are used. There is guidance on how to help students see the values and limitations of the different types of models. Some examples include:
  - Lesson 7: "Say, We have looked at a lot of different atomic models, let's take some time to compare them side by side. Present slide J. Distribute Compare Atomic Models and give students about five minutes to individually complete the four questions handout. ✱ Explain that after we talk about their responses to the four questions, we will work as a class to name each of the atomic models. ✱ Discuss the merits and limitations of the atomic structure models. Present slide K…. Which of the four models would be best to show and predict the number of bonds between atoms? Why?" (Teacher Edition, page 162).
  - Lesson 8: "Problematize the bond 'line.' Point out that nothing in the chemical formula tells us this, but the right two models (ball and stick and Lewis Dot) do. Ask how a single bond is being represented in the Lewis Dot model on the right. Students will say it is the two electrons in the overlapping dotted circles around each atom. Point out that the line representations in the second model (ball and stick) makes it seem like there is a physical connection between the atoms, but we know that is a representation that is simplification to show which two atoms are sharing the electrons, and it's not a physical structure connecting them" (Teacher Edition, page 177).
  - Lesson 11: "How does this representation help or not help us consider the differences between ammonia and ammonium? How does using Lewis Dot models help explain how atoms of one element bond with atoms of another element to form molecules?" (Teacher Edition, page 230).

Suggestions for Improvement

None

II.E. DIFFERENTIATED INSTRUCTION

Provides guidance for teachers to support differentiated instruction by including:

i. Supportive ways to access instruction, including appropriate linguistic, visual, and kinesthetic engagement opportunities that are essential for effective science and engineering learning and particularly beneficial for multilingual learners and students with disabilities.

ii. Extra support (e.g., phenomena, representations, tasks) for students who are struggling to meet the targeted expectations.

iii. Extensions for students with high interest or who have already met the performance expectations to develop deeper understanding of the practices, disciplinary core ideas, and crosscutting concepts.

Rating for Criterion II.E. Differentiated Instruction	Extensive *(None, Inadequate, Adequate, Extensive)*

The reviewers found extensive evidence that the materials provide guidance for teachers to support differentiated instruction because the materials provide multiple and varied individualized learning strategies that support three-dimensional sense-making throughout most of the materials. Students with disabilities, such as difficulties with vision, may benefit from additional supports that are not provided. There are also extensions in the units, however the extensions do not always provide new learning in all three dimensions for students.

Differentiation strategies to address the needs of multilingual learners are provided in the unit. Related evidence includes:

- Teachers Edition: "It is especially important for emergent multilingual students to have a reference for this important vocabulary, which includes an accessible definition and visual support. Sometimes defining a word is a challenge. The Teacher Guide provides a suggested definition for each term to support you in helping your class develop a student-friendly definition that is also scientifically accurate" (Teacher Edition, page 29).
- Lesson 4: Teachers are encouraged to note the -ian suffix for students. They are encouraged to "…highlight that Martian = of Mars to help students make these linguistic connections (e.g., American, Guatemalan, Nigerian, Cambodian, Philadelphian, Oklahoman) (Teacher Edition, page 101).
- Lesson 5: Students can be reminded that "the plural of most words in English is simple: you just add an -s or -es to the end. However, 'spectra' is the plural form and 'spectrum' is the singular. This is an uncommon pattern in everyday English, although is more common in biology and chemistry. It can be useful to teach spectra and spectrum as a pair of words so students know they refer to the same thing. This -a / - um pattern is also true for a few other words students

may have encountered by 10th grade: Bacteria / bacterium Mycelia / mycelium (related to fungus) Fora / forum" (Teacher Edition, page 120).

- Lesson 10: Students should be reminded that "in the text, 'precipitate' is used as both a noun and a verb. Making this explicit can help all learners participate in the language of science more readily (Teacher Edition, page 212).
- Lesson 11: Teachers are asked to "encourage students to use their funds of knowledge to think of other words that relate to the 'poly' prefix. Here is a translanguaging tip: 'Poly-' in English is a cognate to 'poli-' in Spanish. You can support Emerging Multilingual Learners and other language development by highlighting that the prefix 'poly-' means 'many,' as in 'polyglot, meaning someone who speaks multiple languages,' 'polygon, meaning a shape with many sides,' or 'monopoly, meaning one that owns too many related businesses'" (Teacher Edition, page 231).
- Lesson 12: Teachers are provided a reference of text structures and features that can support a range of student needs, such as translator access and interactive features that pair action with language (UDL for Jigsaw Readings).

Differentiation strategies are provided to address learners who read well below grade level. Related evidence includes:

- Lesson 10: "If you feel students need additional strategies in place to support reading before they summarize, consider the following: Read and underline places that connect to what we already know about water. Star new information about how the reactions discussed help clean water" (Teacher Edition, page 212).
- Lesson 12: The strategy outlined in the resource, *Summarize a Reading*, provides students with prompts to support their comprehension of a reading with specific prompts to annotate each section as well as prompts for understanding before moving on (Summarize a Reading, pages 1–2).
- Lesson 12: "If students struggle to summarize the text found on Sulfur-Based Concrete, see additional reading support in The OpenSciEd High School Teacher Handbook (Teacher Edition, page 254).
- Lesson 12: Teachers are provided a reference of text structures and features that can support a range of student needs, such as translator access and interactive features that pair action with language (UDL for Jigsaw Readings). This resource provides guidance for differentiation, including suggested student proficiencies for each reading. For example, the Mars reading is described as "…a good article to assign to students who struggle with reading long sentences in English…" (Teacher Edition, page 368).

Supports are provided for students who are struggling with the material. Related evidence includes:

- Lesson 2: "All sample Progress Tracker entries contain a 'Source of evidence' column, but this is not a requirement. We have provided this information so that if students have incomplete, or are struggling to complete, Progress Tracker entries, you can use the examples listed to support these struggling students. Point students back to the sample 'Sources of evidence' and incorporate any assessment guidance found in that lesson's Teacher Guide" (Teacher Edition, page 333).

- Lesson 4: "Circulate as students write to check in with struggling students and to see what they are writing in response to the prompt. Look for students to say that the landforms could have been made by water or alcohol. Ask students to consider how an investigation at this small scale can help them make sense of what is happening at the planetary scale of Earth and Mars" (Teacher Edition, page 98).
- Lesson 4: "If students struggle, help them get started by thinking about charges and what would make water molecules attract to one another" (Teacher Edition, page 103).
- Lesson 5: As students analyze and interpret transmission spectra for gas mixtures, students that are struggling should be "…encourage[d] to lay their unknown spectrum on top of the known spectra found on Transmission Spectra Library. Demonstrate how to overlay an unknown and reference spectrum so it can be held up to the light to look for patterns between them to aid in identification" (Teacher Edition, page 129).
- Lesson 7: As students examine the models of atomic structure, "if students are struggling to figure out the relationship, have them look at an element card and compare it to the same element on https://phet.colorado.edu/en/simulations/build-an-atom. This will help them adjust their mental model for the structure of atoms from a 'cloud' to a shell model" (Teacher Edition, page 163).
- Lesson 7: For students struggling to model interactions between valence electrons in one atom and the nucleus of another, "…offer students paper clips to represent valence electrons on the element cards or suggest they use different colors or other representations to keep track of valence electrons" (Teacher Edition, page 166).
- Lesson 9: "If students are struggling, ask students to circle the corresponding part of Modeling Molecular Polarity they feel they need more practice on. If so, then after slide R, provide that opportunity for practice with additional examples before administering Mid-point Assessment" (Teacher Edition, page 201).
- Lesson 11: "Students who do the following may need additional support, such as use of a screen reader or reading the text aloud: Don't notice the differences in ammonia and ammonium. Miss the dangers of storage of ammonia. Note that there are possibilities for making fertilizer out of urine" (Fertilizer Reading Key, page 2).
- Lesson 15: "If students are struggling to balance the equation with just the substance they chose, tell them to consider adding additional products, such as oxygen, to aid in their balancing. Point out that when they balanced the chemical equation for photosynthesis in Lesson 11, there were additional products besides glucose" (Teacher Edition, page 289).

Differentiation strategies are provided to address learners who have already met the targeted PEs or who have high interest in the subject matter. Related evidence includes:

- Lesson 2: There is an extension opportunity. "If students show interest in comparing the properties of water to the properties of other materials, they have studied in Electrostatics Unit, take time to co-create a parallel poster. For example, you could discuss properties of metals, such as conductivity, and their importance for life. Additionally, you could present students with specific heat values of metals and have students use their understanding of specific heat to explain what happens to those metals as energy is applied to them. Take care not to develop a cause-effect relationship between conductivity and specific heat values, as the basis of these two material properties is different. An additional handout, Thinking About Aquaculture, is included to help students consider other potential food sources by leveraging water's ability to transmit light. Since it mentions the existence of water oceans on some moons in our solar system, this handout may be placed after Lesson 4 or with Lesson 11" (Teacher Edition, page 73). These specific examples can help teachers extend learning for some students, but there is not clear guidance on how to develop deeper understanding within all three dimensions.

- Lesson 2: "Extension opportunity: If you have additional time, or if students are interested in figuring out just how much water we have sent with astronauts in the past, you can lead them in a discussion using some of the following data… Students could use this data to then determine just how much water we would need each day to survive beyond Earth" (Teacher Edition, page 74). There is a missed opportunity to connect this to three-dimensional learning and to the literacy standard cited in this lesson.
- Lesson 9: There is an optional at-home learning opportunity for students who are interested in medicine as a potential career path. "Take a half of a minute to explain that since we are starting to consider chemistry connections to diet and tomorrow will consider connections to medicine in our transfer task and that this is an area many people consider as a career path, that students can take a copy of Dietary Salts if they want to learning[sic] more about how the chemistry we are figuring out impacts body processes related to the dietary salts we eat" (Teacher Edition, page 203). There is a missed opportunity to connect this to home with foods commonly eaten before or after physical activity and explicit connections to three-dimensional learning.
- Lesson 9: On the Mid-Point Assessment, question 7 is marked as an optional question with potential for an extension opportunity. "If you want to use this as an Extension Opportunity then do the following: Encourage students to describe how either changes in relative strength OR the number of attractive forces between neighboring molecules could explain these outcomes. This may lead them to argue that there are either: Weaker or few number of attractive forces between neighboring sila-ibuprofen molecules compared to neighboring ibuprofen molecules - Stronger or greater number of attractive forces between water molecules and sila-ibuprofen molecules compared to water molecules and neighboring ibuprofen molecules. You could also ask students to argue how changes in repulsive force interactions might also contribute to this. This may lead them to argue that there are either: Stronger or greater number of repulsive forces between neighboring sila-ibuprofen molecules compared to neighboring ibuprofen molecules. Weaker or fewer repulsive forces between water molecules and sila-ibuprofen molecules compared to water molecules and neighboring ibuprofen molecules. Ask students to consider why there would be a limit to how much sila-ibuprofen can dissolve in water. This is an excellent preview of concentration thinking at a particle level and what might be affecting that, which will be a focus of the next unit, OpenSciEd Unit C4…" (Lesson 9, Mid-Point Assessment Key). There are key elements tagged for this question; it is explicit how three-dimensional learning is expanded upon.

- Lesson 12: "If students are interested in extended molecular structure of cement, they can check out the open access chemical research paper, The Atomic-Level Structure of Cementitious Calcium Aluminate Silicate Hydrate (Mohamed et al., 2020) at: https://pubs.acs.org/doi/10.1021/jacs.0c02988#. Figure 6 gives students an idea of how a single unit repeats to form a layered extended structure. Students should be invited to flip through it and you can print and share copies with the class to familiarize them with the format of journal articles, including the abstract, introduction, methods, and results sections they have seen in other peer reviewed papers presented in this unit. This extension opportunity further supports development of SEP: 8.1" (Teacher Edition, page 251).
- Lesson 14; "If students are interested in materials other than ceramics (like concrete) or polymers, such as metals, electronic materials, or composites, you may wish to have them research these materials. They can still use Synthesis and Evaluation to summarize findings and evaluate arguments, although additional time will need to be allowed for research. Additionally, these articles intentionally reference careers such as materials scientist, chemical engineering, food technology, and biochemical engineering. You may have students research these and related careers through the Bureau of Labor Statistics Occupational Outlook Handbook: https://www.bls.gov/ooh/" (Teacher Edition, page 278).
- Lesson 15: "The limit of this unit's Disciplinary Core Ideas (PS1.3.B) is to simple chemical reactions involving main group elements, such as carbon and oxygen, or of carbon and hydrogen. The NGSS Assessment Boundary indicates that assessment is limited to chemical reactions involving main group elements and combustion reactions. For this activity, you can limit students to investigating N its triple bond O and its bond, CaO, SiO, or Al O. However, the unit materials have prepared students to balance larger compounds if you wish to extend student thinking past this boundary" (Teacher Edition, page 289).

Suggestions for Improvement

- Consider including additional supports for students with vision-related disabilities or other visual impairments to supplement the text present for readings, particularly in Lesson 11.
- Consider explicitly connecting three-dimensional learning opportunities to the extension opportunities so teachers clearly understand how they can use all three dimensions within an "Alternate Activity/Extension Opportunity."

II.F. TEACHER SUPPORT FOR UNIT COHERENCE

Supports teachers in facilitating coherent student learning experiences over time by:

i. Providing strategies for linking student engagement across lessons (e.g. cultivating new student questions at the end of a lesson in a way that leads to future lessons, helping students connect related problems and phenomena across lessons, etc.).

ii. Providing strategies for ensuring student sense-making and/or problem-solving is linked to learning in all three dimensions.

Rating for Criterion II.F. Teacher Support for Unit Coherence	Extensive *(None, Inadequate, Adequate, Extensive)*

The reviewers found extensive evidence that the materials support teachers in facilitating coherent student learning experiences over time because student engagement is linked across lessons not only at the lesson level teacher instructional front matter, but also in the unit overview materials. There are strategies and routines explicitly taught and reinforced throughout the unit to support sense-making in all three dimensions.

The Teacher Edition has supports to help teachers understand how lessons link together. For example:

- There is a graphic organizer that shows how lessons link together and breaks the lessons down into Lesson Sets with a question for each lesson set and key things students do in each piece of the lesson sets (Teacher Edition, pages 16–17).
- Each lesson begins with a "Where We Are Going and NOT Going" section that outlines student engagement in the lesson and how to make purposeful connections between lessons, content, and prior knowledge.
- Each lesson contains guidance for teachers based on formative assessment opportunities as to "What to look/listen for in the moment" and "What to do." These are linked to three-dimensional learning and provides elements students should be using in their sense-making.
- The Navigate sections of each lesson have verbiage for teachers to use that link lessons together.
- There is a DQB that is established in Lesson 1. "Review the protocol for building the DQB. Have students bring their science notebook, sticky-note questions, marker, and pencil with them to the Scientists Circle. Say, As we build our DQB, it is important that we hear everybody's questions, and we might find that we have questions similar to some of our classmates' questions. ✱ We want to group and organize our questions so that they can help us guide our investigations and keep track of what we want to figure out. To help do that we will do two rounds of question sharing, starting with sharing at least one blue sticky note from everyone and then at least one yellow sticky note from everyone" (Teacher Edition, page 56). They revisit the DQB in Lessons 7 (Alternate Activity), 9, 10, 11, 12, and 15. In the Unit Storyline, it is claimed that the DQB is revisited in Lesson 5. "We read about other ways spectroscopy is used

to determine what substances are out there and revisit the driving question board before we move onto the next lesson set" (Teacher Edition, page 5). However, it is not referenced in the lesson or in the materials for the lesson (Teacher Edition, pages 112–114). Students complete a progress tracker entry instead. There is not a reference to the DQB between Lessons 2 and 8, other than an Alternate Activity that some teachers may not complete.

- Students use a Progress Tracker to track their thinking and ideas over the unit. The Progress Tracker is used in Lessons 1, 2, 4, 5, 9, 12, and 14. There is guidance to use it to help students keep track of important discoveries the class makes. "Teachers use this tool to support progressive sensemaking throughout the unit…suggestions are given for supporting students in using the tracker in a way to identify and use discoveries to continually revisit, revise, and prioritize ideas" (Teacher Edition, page 333).

There is guidance on linking lessons and days of lessons together. Some notable examples include:

- Lesson 2: There is verbiage to help link together Day 1 and Day 2 of the lesson. "Have students meet with their groups from the last class. Display slide J. Give groups some additional time to finalize how they will communicate station information to their classmates" (Teacher Edition, page 70).
- Lesson 4: There is verbiage to help link together Day 1 and 2 of the lesson. "Welcome students back to class and have a brief discussion to help students remember where they left off last class. Display slide L. After recapping the investigation, ask students to think about the differences they might want to look for across groups. Listen for: More or less erosion caused by the different liquids Holes Dry 'riverbeds'" (Teacher Edition, page 97).
- Lesson 11: There is verbiage to motivate learning about growing food. "Say, Last class we left off with thinking about processes we need clean water to use to live and work on Mars. What were some processes we said we might need clean water for? Accept all answers. Highlight students who suggest producing food" (Teacher Edition, page 233).
- Lesson 12: "Say, In our last class, we talked about conservation of matter. In order to represent this idea in a chemical equation, we need to make sure there are equal amounts of each element on both the reactant and product sides. We can do this by using multiplication to adjust the amounts of each atom on either side of the equation. Walk students through how to balance the equation for photosynthesis" (Teacher Edition, page 243).

The materials provide strategies for ensuring student sense-making or problem solving is linked to learning in all three dimensions with special attention paid to the CCC of **Structure and Function**. There are callouts to other elements as well. Many have specific elements attached to them. These exist in the margins of all lessons as "supporting Students in…" callouts. Some examples include:

- Lesson 3: "Support students in thinking about the scale of these different surface features and how that may impact our ability to view them (CCC: 1.1). Use prompts such as: What scale, or how big, are these different surface features? How might the scale of the features impact our ability to view them on satellite images?" (Teacher Edition, page 80).
- Lesson 4: "Patterns: The element of focus in this lesson is the HS CCC for patterns: Different patterns may be observed at each of the scales at which a system is studied and can provide

evidence for causality in explanations of phenomena. (CCC: 1.1) Throughout this lesson, provide feedback to students that helps them link causality appropriately to the patterns of water in extra-terrestrial systems." (Teacher Edition, page 94).

- Lesson 4: Students complete an Exit Ticket where they consider multiple types of models. "How did using multiple models of atomic and molecular structure help you to make sense of what is happening at the particle level to cause the interactions between liquid and surface materials? Which substance do you think would be the most likely to cause erosion or frost heaving? (looking at formulas and polarity models)" (Teacher Edition, pages 342–343).
- Lesson 6: "The purpose of this activity is to support students in seeing how the merits and limitations they've evaluated from different element tools can be used to revise their own tools (SEP 2.1). To make these evaluations students will have to refine and apply their own thinking around (sub)atomic properties and characteristics (DCI: PS1.A.2) which they've developed using the patterns observed in the empirical evidence (CCC: 1.5). Students should be encouraged to use the sentence frames seen in Model Evaluation Support to guide their thinking along the path of: (1) What has the empirical evidence shown me? (2) How did the other group use this evidence? (3) How does this thinking differ from mine? (4) What do these differences make me think about our group's tool" (Teacher Edition, page 147).
- Lesson 8: "Students should make the connection between the structure of molecular substitutes and their function due to electronegativity in this lesson. Students should be 'inferring the function' of materials because of their molecular substructures (CCC: 6.2)" (Teacher Edition, page 176).
- Lesson 11: "Structure and Function are at the core of this conversation. Be sure to call out that the structures of these substances determine their different functions. Look at student responses for Question 4 in the Handout for ideas to make this discussion coherent (CCC: 6.2)" (Teacher Edition, page 226). "By comparing the formulas of the polyatomic ions to how they are found bonded with other elements (or polyatomic ions) helps students to visualize that the structure of the polyatomic ion is similar to the structure of an atom, or ion. This helps to reinforce thinking about ions developed in OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit) and ionic bonds developed earlier in this unit. Students can think about how this group of atoms functions as a single atom when bonded to other elements (or groups of atoms). (CCC: 6.2)" (Teacher Edition, page 231).

Suggestions for Improvement

- Consider ensuring a match between claimed activities in the Unit Storyline to activities that happen in the lesson.
- Consider including additional opportunities for students to revisit the DQB sometime during Lessons 2–8 as they initially come to understand the bounds of the central phenomenon in a way other than an Alternate Activity

II.G. SCAFFOLDED DIFFERENTIATION OVER TIME

Provides supports to help students engage in the practices as needed and gradually adjusts supports over time so that students are increasingly responsible for making sense of phenomena and/or designing solutions to problems.

Rating for Criterion II.G. Scaffolded Differentiation Over Time	Adequate *(None, Inadequate, Adequate, Extensive)*

The reviewers found adequate evidence that the materials support teachers in helping students engage in the practices as needed and gradually adjust supports over time. Students supports are clearly reduced over time for several elements and there is clear guidance for how the teacher should facilitate students' increased responsibility for employing targeted elements in support of sense-making, but two elements are listed as learning goals but are only addressed within one lesson each, making a clear reduction in support challenging.

The materials claim that the unit intentionally develops students' engagement in **Developing and Using Models** and **Obtaining, Evaluating, and Communicating Information**.

- **Developing and Using Models** has three elements that are claimed as "intentionally" developed: "Evaluate merits and limitations of two different models of the same proposed tool, process, mechanism or system in order to select or revise a model that best fits the evidence or design criteria. Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena, and move flexibly between model types based on merits and limitations." (Teacher Edition, page 20). Evidence related to reduced scaffolding over time for each of these is below.
    - *Evaluate merits and limitations of two different models of the same proposed tool, process, mechanism or system in order to select or revise a model that best fits the evidence or design criteria.*
        - Lesson 6: Students have a resource to evaluate the limitations and merits of the different groups' organization of the element cards. "Identify merits and limitations of element tools. Pass out a copy of Model Evaluation Support to each student. Tell students to use the prompts on Model Evaluation Support to guide their interactions while they participate in the activity. Explain to students that when they are visiting other groups they should be looking for data patterns that follow their own organizational model, as well as those that are different. Tell students to make a T-chart in their science notebooks to record patterns that are supported and contradicted within similar element groupings" (Teacher Edition, page 147). They then use this to discuss similarities and differences of the model and ultimately have a class consensus for the card organization. "As students share, encourage them to share evidence from their

element cards and Compound Representations to support the different patterns used to develop the class consensus organization. By pushing students to use these different sources of evidence, they build understanding about the various patterns used to organize elements into the periodic table" (Teacher Edition, page 150).

- Lesson 7: Students evaluate another model of atomic structure. "Remind students that yesterday, we decided to examine a different representation of an atomic model to help us make progress on our question, Why is there a difference between the number of electrons an element has and the number of bonds an element forms? ✱ Present slide H. Hand out Evaluate Another Model and have students access the simulation https://phet.colorado.edu/en/simulations/build-an-atom. Give students about 10 minutes to complete Evaluate Another Model…. We have realized by now that our current atomic models aren't adequate for explaining the differences between the number of electrons and connections that are made between different elements. Here, we are presenting an additional model to students which can account for the differences between the number of electrons an element has and the number of bonds formed by the element." (Teacher Edition, page 161). "We have looked at a lot of different atomic models, let's take some time to compare them side by side. Present slide J. Distribute Compare Atomic Models and give students about five minutes to individually complete the four questions handout. ✱ Explain that after we talk about their responses to the four questions, we will work as a class to name each of the atomic models. ✱" (Teacher Edition, page 162). "Which of the four models would be best to show and predict the number of bonds between atoms? Why? All models have limitations, so let's consider, what are some limitations of each model?" (Teacher Edition, page 163). There is not a clear reduction in scaffolding for this element as both activities are similar in that students complete a handout then discuss as a class. There is a missed opportunity to consider the merits and limitations of Electron Shell models vs. Lewis Dot models more clearly in Step 8.

- *Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.*
  - Lesson 1: Students complete an initial model. "Distribute Initial Reaction Model to each student and have them complete the handout individually. Provide at least six minutes for this activity… Make a copy of this pre-assessment before giving it back to students" (Teacher Edition, page 50). The class works to develop a consensus model of what happens to the atoms in a chemical reaction. "Write the question, 'What particle-level changes happen in a chemical reaction?' at the top of the initial consensus model" (Teacher Edition, page 51).

- Lesson 6: Students use element cards to begin to illustrate and predict relationships between elements. “As groups work, walk around the room and assist as needed. Ask clarifying questions to help groups such as: What piece of information on the cards are you considering most important? Why? What evidence on the card is informing this decision? Is your group using a specific pattern to identify similar elements?” (Teacher Edition, page 142).
- Lesspn 8: “Use Lewis Dot models to make predictions. Display slide I. Discuss the question on the slide as a class, How should polarity and the properties of H S compare to H O? Students will likely argue that it should have the same polarity due to its similar structure. ✱… Compare polarities and the properties of H S to H O. Display slide J. Distribute H2O vs. H2S to each pair of students and give them five minutes to discuss the question on the slide. Then discuss this question as a class…How do the patterns in the polarity and properties of H O and H S compare to your predictions?” (Teacher Edition, page 183).
- Lesson 9: “Orient to a new electronegativity reference. Display slide C. Distribute a copy of [sic] Electronegativity Periodic Table to each student and have them add it to their science notebooks. Point out that this periodic table has only electronegativities on it, and use the prompts to help students make connections to the bonds that would form…How do the electronegativities in this reference compare to trends we predicted?... How can we use the electronegativities listed in this reference and the key below it to predict the bond character between two atoms?” (Teacher Edition, pages 198–199). “H. Cue students to take two minutes to work on part A of Modeling Molecular Polarity. After giving two minutes for this, display slide I. The information on this slide will help students check their predictions, so you will probably only need to keep it projected for a half a minute” (Teacher Edition, page 200). This is a type of reduction of scaffolding as students complete this part independently then check their work.
- Lesson 11: “Develop ammonia and ammonium class consensus model. Say, We have some different ideas of what happens to the electrons in the nitrogen atom of ammonium and why ammonia reacts or functions differently than ammonium. Let’s develop a class consensus model. Present slide J and lead students in developing a class consensus model” (Teacher Edition, page 229).
- Lesson 15: “Say, We have mathematical models (balanced equations) for these substances, but can we show HOW they are structured? Let’s revisit how this molecular stuff works by modeling one of the substances you have used! Allow students to select one of the simple compounds (longer chains and rings will be too complicated) they used in their balanced chemical equations from the previous step. It can be a reactant or a product. ✱ Share a list of requirements for the model. Point out that students should model and show: atoms, valence electrons, and electronegativity ‘pulling’ on electrons in their model. Circulate around the room and give formative feedback tied to the positions of electrons,

the use of the periodic table, and the pulls that students represent in their molecules. Reference their balanced equations from the previous step, as well" (Teacher Edition, page 289). There is a reduction of scaffolding as students do this independently after completing similar tasks as this as a class and in partners earlier in the unit.

- *Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena, and move flexibly between model types based on merits and limitations.*
    - Lesson 4: Students use models from their investigations and model cutouts to explain the investigation results. "We designed our investigation because we were not sure about the surface features on Mars. Now that we have investigation results, and have modeled some properties of water, let's see if we can connect these two together. Let's try to model how these different substances interact with Martian soil to help explain how these features formed. ✱ Display slide V. Tell students to use the molecule cutouts from Molecule Cutouts to help them think about which liquid would have a greater impact on the landscape based on differences in polarity and the differences in the resulting force interaction with neighboring particles. Encourage students to move the cutouts around on their desks or tables and talk through what is happening with their partners as they do so. Have students do this to help them explain both why some liquids might cause more erosion and why other liquids cause less erosion" (Teacher Edition, page 101). Students complete an Exit Ticket where they consider multiple types of models. "How did using multiple models of atomic and molecular structure help you to make sense of what is happening at the particle level to cause the interactions between liquid and surface materials? Which substance do you think would be the most likely to cause erosion or frost heaving? (looking at formulas and polarity models)" (Teacher Edition, pages 342–343)
    - Lesson 7: Students look at another model of atomic structure and complete a handout. The teacher poses the question, "How do these patterns relate to the patterns we noticed in the differences between the number of electrons and bonds formed by elements?" (Teacher Edition, page 161). In the handout it is asked, "Evaluate this model and another we have looked at. How do these models compare to other atomic models you have examined?" (Lesson 7: Evaluate Another Model). There is not a clear reduction of scaffolding for this element.
    - Lesson 9: Students use models to determine molecular polarity using the three-dimensional molecular models with a partner. This is done before the independent transfer task. "Display N. Emphasize that students should try to model at least two of the electron shifts with their partner shown using the manipulatives in their bin by sliding the bobby pins in different directions along each bond by different amounts. Compare to an alternate visualization. Show

slide O. Explain that these images are output from a computer program that renders a visualization of the molecules in three dimensions. Use the question on the slide to discuss how close we came to predicting the overall polarity of these different molecules. Students will say that overall we were able to predict many aspects of the overall polarity. Forecast that this sort of thinking is a part of the transfer task. Tell students that trying to visualize and predict overall polarity or a region in a molecule with a drawing or manipulatives like they just did is something they will try to do again in the transfer task, but only for a region of a few bonds within a much larger molecule" (Teacher Edition, page 201). "In the transfer task, they use different models of ibuprofen and sila-ibuprofen as well as their knowledge about trends in the periodic table to a) describe the patterns and relationships between the parts of an atom and the bonds formed between atoms, b) predict polarity differences, and c) explain property differences based on the relative differences in the strength of forces between atoms and molecules" (Lesson 9, Mid-Point Assessment Key).

- **Obtaining, Evaluating, and Communicating Information** has four elements that are claimed as "intentionally" developed: "Critically read scientific literature adapted for classroom use to determine the central ideas or conclusions and/or to obtain scientific and/or technical information to summarize complex evidence, concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms. Compare, integrate, and evaluate sources of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to address a scientific question or solve a problem. Evaluate the validity and reliability of and/or synthesize multiple claims, methods, and/or designs that appear in scientific and technical texts or media reports, verifying the data when possible. Communicate scientific and/or technical information or ideas (e.g., about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically)" (Teacher Edition, page 20). The second two elements are only claimed once in the **Developing and Using Science and Engineering Practices** (by Lesson) Document, and therefore do not show evidence of reduced scaffolding over time.
- Evidence related to the other two elements is as follows:
    - *Critically read scientific literature adapted for classroom use to determine the central ideas or conclusions and/or to obtain scientific and/or technical information to summarize complex evidence, concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.*
        - Lesson 10: "Display slide D and distribute Cleaning Metal-Contaminated Water. Explain to students that they have seen similar readings before in OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit), which are based on journal articles written by scientists. Highlight that each section will be based on the scientists engaging with a different practice as they try to answer their question about how to clean water with chemical reactions. Explain the reading strategy below, then give

students time to read. ✱ Summarize the new information about how the reactions discussed help clean water and record any new questions you have" (Teacher Edition, page 212). The handout asks them to "Summarize the new information about how the reactions discussed help clean water. Make sure to use your own words, while still giving an accurate meaning" (Lesson 10: Cleaning Metal-Contaminated Water).

  - Lesson 12: "Critically read about Martian research. Present slide M and distribute Mars Rovers Research to each student. Give them 8 minutes to read and annotate Mars Rovers Research, and consider the implications this new evidence has for building a permanent settlement on Mars by responding to the prompts at the end of the reading. ✱ Connect our findings to living in space. Display slide N and give students a few minutes to turn and talk to a partner about the implications of the rover data for living and working in space by sharing their responses to the prompts at the end of Mars Rovers Research. Bring the class back together after a few minutes to share their ideas" (Teacher Edition, page 249). Students annotate and then answer application-based questions. This is a reduction of scaffolding between these two lessons claimed by the materials.

- *Compare, integrate, and evaluate sources of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to address a scientific question or solve a problem.*
  - Lesson 2: Students complete two of six stations then share their findings with the class to figure out more about properties of water and why water is a key substance for survival. "Work with students in the Scientists Circle to build a poster relating properties of water to its importance for life and chemical reactions" (Teacher Edition, page 60).
  - Lesson 4: Students complete a reading with a partner before returning to their models of water and use the cutouts to model expansion during freezing. "Now that you have thought about a smaller-scale property or interaction you have observed with water and these other liquids, and have observed differences in the polarity due to their molecular structures, let's try to explain some of these properties using these differences. Distribute the molecule cutouts from Molecule Cutouts and display slide T. Remind students that they just brainstormed these properties and force interaction differences. Give students three or four minutes to work with the cutouts, and circulate while students work with the molecule cutouts. If students are unsure how to model a particular property with the cutouts, push them to think about how the stronger charges on water could lead to water exhibiting this property that other liquids do not. You can also encourage students to think of a different property to model" (Teacher Edition, page 101). "Return to molecular models of water. Display slide X and hand out the molecule cutouts from Molecule Cutouts again. Tell students, 'This time, I want you to focus on freezing water. See if you can

figure out why water expands and causes these bumps when it freezes.' Tell students to start by thinking about what happens to particle motion and arrangement when liquid freezes. Help them recall from Polar Ice Unit that water molecules' speed will slow down as water turns to ice. Then remind students to use the molecule cutouts and to pay attention to the charges shown on water. Ask students to consider how those charges might affect the arrangement of water molecules as they slow down. Encourage students to use the reading to help them, and to explain their thinking to their partner as they use the molecule cutouts to model expansion and frost heaving" (Teacher Edition, page 103).

- Lesson 5: Students use spectra resources to determine unknown gases.
- Lesson 12: There is adjustment to supports with the readings in this lesson that aligns with "12.B Gather, read, and interpret information presented in different formats and adapted from scientific literature" (Teacher Edition, page 237). With the websites there is a graphic organizer, and they work in groups. They then independently read and annotate an article adapted from a conference, *Mars Rover Research,* which has two questions at the end. They have the opportunity to turn and talk with a partner. They then read *Sulfur Based Concentrate [sic]* which is adapted from an academic journal. There is a resource to help them as the texts get more complex throughout the lesson. "Prior to this point in the lesson students have obtained information about what elements are present on the Moon and Mars from NASA websites (SEP: 8.2). The current reading, based on a paper presented at a conference, serves as a bridge between the websites and the upcoming adapted primary research paper (SEP: 8.1). Check in with students to gain insight into the support they might need while reading the adapted research paper" (Teacher Edition, page 249).
- Lesson 12: Students read two handouts and revisit the DQB. "How would the explanation provided by the authors help address what we need to live and work permanently on Mars? What line(s) of questions on our Driving Question Board does this solution address?" (Teacher Edition, page 254).
- Lesson 13: Students use a graphic organizer as they compare and integrate sources of information about recycling. "Synthesize information from a reading. Display slide D. Give the remaining time (about twelve minutes) for students to work with a partner on completing row 1 of Recycling Ideas Organizer using Recycling Processes…. Watch and discuss the first video. Play https://www.youtube.com/watch?v=-igxhoGEQFU with closed captioning on. Then discuss the related questions on slide F… Watch and discuss the second video. Display slide G. Play https://www.youtube.com/watch?v=MSraRbRFmPY&t=230s and https://www.you tube.com/watch?v=1cvpciDk1FM with closed captioning on. Then discuss the related questions on the slide. Suggested prompt" (Teacher Edition, pages 264–265).

- Lesson 14: “Display slide D and distribute Synthesis and Evaluation to all students and one of CO2 Plastic/Bioplastics or 3-D Printing/Geopolymer Concrete to each student. Explain to students that they will read the summary with their partner, then each read one of the two articles in the reading. They should use Synthesis and Evaluation numbers 1–2 to support their thinking before and during reading. Ensure that students are comfortable with checking sources. Emphasize that they can skim available articles if they are short, or at least check the abstract for articles that are longer or behind a paywall. ✱ Then, give students the rest of the activity time to read individually. The Synthesis and Evaluation key gives an idea of what might come up in their reading and discussion” (Teacher Edition, page 277).

Suggestions for Improvement

- Consider including additional opportunities for reduction of scaffolding for each of the claimed SEP elements that is developed during the unit.
- Consider using a unit-level resource in the unit front matter to highlight the specific ways in which students come to rely less on teacher supports to show proficiency with each claimed element.

OVERALL CATEGORY II SCORE: **3** (0, 1, 2, 3)	
Unit Scoring Guide – Category II	
Criteria A-G	
3	At least adequate evidence for all criteria in the category; extensive evidence for at least two criteria
2	Some evidence for all criteria in the category and adequate evidence for at least five criteria, including A
1	Adequate evidence for at least three criteria in the category
0	Adequate evidence for no more than two criteria in the category

CATEGORY III

MONITORING NGSS STUDENT PROGRESS

III.A. MONITORING 3D STUDENT PERFORMANCES

III.B. FORMATIVE

III.C. SCORING GUIDANCE

III.D. UNBIASED TASK/ITEMS

III.E. COHERENT ASSESSMENT SYSTEM

III.F. OPPORTUNITY TO LEARN

III.A. MONITORING 3D STUDENT PERFORMANCES

Elicits direct, observable evidence of three-dimensional learning; students are using practices with core ideas and crosscutting concepts to make sense of phenomena and/or to design solutions.

Rating for Criterion III.A. Monitoring 3D Student Performances	Extensive *(None, Inadequate, Adequate, Extensive)*

The reviewers found extensive evidence that the materials elicit direct, observable evidence of students using practices with DCIs and CCCs to make sense of phenomena or design solutions. There are numerous opportunities for students to produce three-dimensional artifacts of their learning throughout the unit. However, there are many key pieces of learning that do not elicit direct evidence for EACH student or do not produce observable artifacts for each student's learning. Verbal sense-making and class discussions are used often, but there is not explicit guidance to help the teacher gather evidence of learning from EACH student during these moments.

Materials routinely elicit evidence that students are integrating the three dimensions in service of making sense of phenomena and solving problems. Related evidence includes:

- Lesson 5: "What to look/listen for in the moment: Students analyze the spectra of unknown substances by comparing it to spectra of known substances. (SEP: 4.1; DCI: PS4.B.4) Students identify and use patterns in spectra of known substances (empirical evidence) to identify unknown substances. (DCI: PS4.B.4; CCC: 1.5) What to do: If students are struggling to connect the two spectra images, encourage them to lay their unknown spectrum on top of the known spectra found on Transmission Spectra Library. Demonstrate how to overlay an unknown and reference spectrum so it can be held up to the light to look for patterns between them to aid in identification. Building toward 5.A.3 Analyze, compare, and integrate empirical evidence to identify patterns in the interaction (study) of a star's light or other light spectrum with substances present in a sample or on an object in space to answer scientific questions about how we can identify which locations have the substances or elements needed to live and work in space. (SEP: 4.1, 8.2; DCI: ESS1.A.2, PS4.B.4; CCC: 1.5)" (Teacher Edition, page 129).
- Lesson 7: "Determine which atomic model best illustrates patterns in atomic structures at the atomic scale, which can be used to predict interactions between elements. (SEP: 2.1; DCI: PS1.A.2; CCC: 1.1) What to look/listen for across opportunities 1-3: See Comparing Atomic Models Key for guidance. Students use either the electron shell or Lewis Dot model to explain how valence electrons of two elements interact to form specific numbers of bonds with another element. (SEP: 2.1; DCI: PS1.A.2) Students show a structure with two bonds emerging at the scale of a single atom (CCC: 1.1)" (Teacher Edition, page 302).
- Lesson 11: 'What to look/listen for in the moment: Students develop models of NH and NH + based on evidence from the reading to predict the relationship between charges and number of electrons. (SEP: 2.3; DCI: PS1.A.1) Students show the atomic structures of NH and NH, including

the number and charge of the protons, neutrons, and electrons. (DCI: PS1.A.1; CCC: 6.2) What to do: Use the suggested prompts embedded in the teacher guide to help students with areas of confusion. Building toward: 11.A.2 Critically read and determine central ideas of a text to develop a model which explains how using different reactants leads to the development of different fertilizers which can be used to grow plants off of Earth. (SEP: 8.1, 2.3; DCI: PS1.A.1, PS1.B.3; CCC: 6.2)" (Teacher Edition, page 227).

- Lesson 12: "What to look/ listen for in the moment: Students should use mathematical representations of the numbers of elements for evidence that the amount of matter on either side of a chemical reaction is not equal. (CCC: 5.1; DCI: PS1.B.3) Students should use a chemical equation (computational model) to account for the amounts of elements. (SEP: 5.1; DCI: PS1.B.3) Students should use mathematical thinking to revise a chemical equation in order to show equal amounts of elements in products and reactants. (SEP: 5.1; DCI: PS1.B.3) What to do: Since this is being co-constructed with students, check in with students for understanding. Optional activities would be to balance some other equations with a partner or individually. Another support would be to show students images of the molecules on the optional slide E to aid them in counting the numbers of each type of atom to balance the equation or provide the physical manipulative models introduced in Lesson 8. At the end of the lesson, students will work with a partner to balance an equation for one of the reactions involved in the hardening of cement. Building toward: 12.A.2 Create balanced chemical equations (computational models) using mathematical representations of elements to demonstrate matter is conserved. (SEP: 5.1; CCC: 5.1; DCI: PS1.B.3)" (Teacher Edition, page 246).

Students produce a variety of artifacts. Most of these artifacts show evidence of grade level SEPs and DCIs, with some artifacts showing evidence of students using the CCC elements. Related evidence includes:

- Lesson 4: Students complete an Exit Ticket in which they use models to support their understanding of which substance's molecular structure (DCI: **PS1.A.3**) is most likely to contribute, at the bulk scale (CCC: **6.2**) to erosion or frost heaving by identifying patterns (**1.1**) in collected data (SEP: **2.4**).
- Lesson 5: "Students complete *Analyze Atmospheric Spectra* in which they use features of the provided unknown spectra to identify regions that correlate to a known reference spectrum. In doing so, students use the Crosscutting Concept of patterns (1.5) to appropriately leverage the targeted SEP (4.1) and DCI (PS4.B.4)" (Teacher Edition, page 130).
- Lesson 14: Students complete the activity *Synthesis and Evaluation* in which they collaborate to synthesize learning from two articles to evaluate their claims and draw from their learning about molecular-level structures and its impact on bulk properties of substances (Synthesis and Evaluation, pages 1–2).

Phenomena and problems are used in formal assessment tasks and are used to drive student sense-making. Related evidence includes:

- Lesson 9: The mid-point assessment includes a phenomenon students have not likely encountered, relating to drug development using an example of a single-element substitution that students should find reminiscent of the H_2O vs. H_2S discussion earlier in the unit. Students are required to apply similar particle-level knowledge to uncover how similarity and differences in each molecules patterns in interactions are likely to relate to its macro-scale behavior in our bodies (Mid-point Assessment, pages 1–5).

- Lesson 15: The end of unit assessment includes a phenomenon that students have likely experienced, but not thought deeply about — hard water. In doing so, students examine the molecular structure of substances such as calcium stearate, potassium carbonate, and magnesium bicarbonate. Students develop models of these substances to illustrate the interactions they believe to be responsible for the behavior that is described for clogged pipes and development of soap scum (Unit Assessment, pages 1–7).

Missed opportunities for three-dimensional artifacts include:

- Lesson 1: Students complete an initial reaction model. There is a suggestion that teachers can have students revise the model in the last portion of the unit. However, a formal revision is not done or suggested later in the unit (explicitly within the last portion of the unit). A revision of student models would serve as a strong, three-dimensional, student individual artifact on the progress of student learning.
- Lesson 2: Students complete two stations then share their findings and receive information about the other four stations they did not complete. A consensus poster is made about "Water's Important for Life and Chemical Reactions." Students then complete a Progress Tracker entry, but the entry key example is not three-dimensional. "Water has several properties which help to support life: high specific heat, transparency to light, ability to dissolve substances, stickiness to itself (cohesion) and other materials (adhesion). The ability of water to dissolve substances also explains its importance for chemical reactions" (Answer Key Progress Tracker).
- Lesson 5: Students Analyze Spectra for atmospheres of four different bodies in space. There is "additional guidance" that relates to three dimensions, and students are asked to circle and label gases that match the reference gas they think it matches. However, the handout itself may not elicit a three-dimensional artifact and could elicit guessing without reason as some of the prompts that relate to pattens and using empirical evidence are not on the handout. The prompts that facilitate using empirical evidence are done as a whole-class discussion only. "Which reference gasses did we see supporting evidence for in the atmosphere spectra? Which bands helped you determine that? What makes you think that? What other gasses do we have strong evidence for? Did any other atmospheres have ozone or carbon monoxide? How do you know? What gasses were clearly not present? What gasses do we think we have inconclusive evidence for?" (Teacher Edition, page 131).
- Lesson 10: Students use models for Water Cleanup Modeling. There are prompts to help the teacher "ensure that students are fully considering the changes in matter and role of forces in the reaction," but there is not guidance to ensure that the teacher is getting evidence about each student's understanding (Teacher Edition, page 214). There is key sense-making discussion as a whole group (Teacher Edition, pages 214–215). Students update their personal glossaries and reflect on the original reactions (Key Chemical Reactions). However, there is not a chance

for the teacher to elicit direct observable evidence of three-dimensional learning for all students during this lesson.

Suggestions for Improvement

- Consider including the Progress Tracker Key in all lesson folders where the Progress Tracker is used, instead of just the Lesson 2 folder. Alternately, consider breaking the key up into sections for each lesson in which it is used.
- Consider including what potential three-dimensional elements students might produce in their progress trackers and label them within the Progress Tracker key or in the Teacher Edition each time the Progress Tracker is used, such as the "building towards" verbiage in Lesson 5 (Teacher Edition, pages 132–133).
- Consider individual quick write opportunities for students, particularly after critical learning that occurs as a whole group or in small groups, so teachers have an individual record of student's progress during these.

III.B. FORMATIVE

Embeds formative assessment processes throughout that evaluate student learning to inform instruction.

Rating for Criterion III.B. Formative	Extensive *(None, Inadequate, Adequate, Extensive)*

The reviewers found extensive evidence that the materials embed formative assessment processes throughout that evaluate student learning and inform instruction because there are strategies to help teachers react to student responses during formative assessments. There are assessment opportunities embedded into the unit and sample student responses show the ideal student as well as how to support students who are not giving the ideal response. There is less guidance regarding varied levels of proficiency in student responses. Formative assessment supports typically focus on making instructional decisions based on most students. There are a few examples of where ideas for instruction are provided based on three differing levels of student understanding, but these are rare and are not included for all key learning opportunities.

Related evidence includes:

- The "Assessment System Overview" provides a snapshot of different times formative opportunities are provided within the unit. There are marked formative opportunities for Lesson 4, 5, 6, 7, 9, 10, 11, 12, 13, and 14 (Teacher Edition, pages 294–297).

- There is a resource entitled, "Lesson-by-Lesson Assessment Opportunities." In this resource each Lesson-Level PE is provided with guidance on when to check for understanding and what to look/listen for across the checks for understanding (Teacher Edition, pages 297–306).
- Progress Tracker: "The progress tracker is a formative and self-assessment tool that is designed to help students keep track of important discoveries that the class makes while investigating the phenomena, and to help them figure out how to prioritize and use these discoveries to focus on explaining the phenomena they're working on" (Teacher Edition, page 333).
- In each lesson there are embedded assessment opportunities. These contain what to look/listen for in the moment and what to do if students are not reaching the proficiency expected. There are also callouts for what elements of the three dimensions are being assessed and how to support students in those assessments. For example:
    - Lesson 4: "Complete an exit ticket. Have students complete the electronic exit ticket… What to look/listen for in the moment: Students use models to make predictions about bulk properties of substances. (DCI: PS1.A.3) Students relate a substance's polarity to its ability to create erosion and frost heaves. (CCC: 6.2) Students use patterns in data and models as evidence to support their predictions. (SEP: 2.4; CCC: 1.1) What to do: See Exit Ticket Key for answers and explanations to the exit ticket questions, as well as how to support students during and after the exit ticket" (Teacher Edition, pages 108–109)
    - Lesson 5: "Assign an exit ticket. Share slide O and ask students to respond to the prompts on a sheet of paper in their science notebooks… What to look/listen for in the moment: Students identify and use patterns in spectra of known substances (empirical evidence) to identify unknown substances. (DCI: PS4.B.4; CCC: 1.5) What to do: It is important that at this point in the lesson, students begin to connect how spectral lines and graphs of known substances can be used to identify unknown substances. If students do not make this connection, prompt them to think about how we could use the two sets of empirical data to make inferences about unknown substances. Ask, How could we use the spectral graphs of the three gasses on Earth to help us identify the unknown samples we previously examined?" (Teacher Edition, page 127).
    - Lesson 7: "Make predictions about how the patterns might inform our ideas about atomic structure. Have students look back at their initial models of the atomic structure of carbon. Present slide F. Give students a few minutes to update their models in their science notebooks. Then, have students show their models while in the Scientists Circle. Tell students to take a moment to look at the different models their classmates created… What to look and listen for in the moment: Students should revise initial models of a carbon atom to try to explain differences in electrons and connections formed by including some new way to organize electrons that may not have been in the initial model. (SEP: 2.4; DCI: PS1.A.1, PS1.A.2) Students should consider advantages or disadvantages of revised models, particularly related to the organization of electrons. (SEP: 2.4; DCI: PS1.A.2) What to do: Leverage the differences in student models, but point out how each of those differences may help us work toward answering our question. Ask students to consider if they have had to use different models of the same phenomenon to account for different mechanisms. Invite students to share their prior

experiences with moving between different mechanistic models of a phenomenon" (Teacher Edition, page 160).

- Lesson 11: "Read about fertilizers in space. Display slide C. Distribute a copy of Fertilizer from Urine to each student. ✱ Go over the instructions on the slide and check if students need any clarification. Give students about 10 minutes to read and complete the questions on Fertilizer from Urine. Rotate around the room and assist as needed. Share ideas with a partner. Display slide D. Give students about 3–4 minutes to discuss the prompts on the slide with a partner. After that time, lead a class discussion… What to look/listen for in the moment: See Fertilizer Reading Key for guidance. The key indicates levels of understanding for supporting struggling readers. What to do: Encourage students to underline only the key ideas in the reading. If a student has underlined most of the reading, you can provide students assistance by reminding them about the questions we want to answer about the type of fertilizer we could use. If students need motivation, remind them we are working to figure out 'space food.' Building toward: 11.A.1 Critically read and determine central ideas of a text to develop a model which explains how using different reactants leads to the development of different fertilizers which can be used to grow plants off of Earth. (SEP: 8.1, 2.3; DCI: PS1.A.1, PS1.B.3; CCC: 6.2)" (Teacher Edition, pages 224–225).

- In the lessons there are "talk moves" provided to help the teacher assess understanding and to adjust instruction based on student response. There are sometimes not explicit ways to adjust instruction based on individual student responses with individual levels of understanding. Some strong examples of" talk moves" include:
  - Lesson 3: "Have a Building Understandings Discussion about the Erosion Investigation. Display slide N. Ask students to think for a moment about how the liquids interacted with the Mars-like material you tested in the Erosion Investigation. How did we control our investigations to yield results we could fairly compare? What patterns did you notice in how the liquids interacted with the Mars-like material in the Erosion investigation? What do we already know about water from this unit and previous units?... Circulate as students write to check in with struggling students and to see what they are writing in response to the prompt. Look for students to say that the landforms could have been made by water or alcohol. Ask students to consider how an investigation at this small scale can help them make sense of what is happening at the planetary scale of Earth and Mars. Listen for students to suggest: Impacts will look the same in our pans and on planets. Seeing how liquids affect small amounts of dirt helps us figure out which liquid is doing this to planet… Guide students through the suggested prompts. Check their work as you circulate. If students need additional help, ask them to review Geologic Landforms Investigation. Use written feedback like these to help students reason about the strength of water's interaction with the materials: Why do you think that? What's your evidence? How did you arrive at that conclusion? Can anyone repeat the evidence stated and push it a little further?" (Teacher Edition, pages 97–98).

- Lesson 4: "Display slide V. Tell students to use the molecule cutouts from Molecule Cutouts to help them think about which liquid would have a greater impact on the landscape based on differences in polarity and the differences in the resulting force interaction with neighboring particles. Encourage students to move the cutouts around on their desks or tables and talk through what is happening with their partners as they do so. Have students do this to help them explain both why some liquids might cause more erosion and why other liquids cause less erosion…. As students work, circulate and ask a few students to explain what they are doing. Specifically, ask students to use the arrows and molecular structures to show force interactions between molecules. Ask students which molecules might exhibit stronger forces or a greater number of force interactions on neighboring particles and why. In the next activity, you will lead a discussion highlighting these differences in order to motivate the next lesson on molecular charge distribution and bond polarity" (Teacher Edition, pages 101–102).
- Lesson 11: "Consider what happens to atoms in a chemical reaction. Display slide R. Point out to students that there seem to be more atoms on the reactants side than the products side. Ask students, Does it make sense that some of these oxygen atoms would just…disappear? Is that what we think happens? Agree as a class that this does not seem likely to happen. Ask, Then how should we show that these atoms are still there? Listen for ideas such as: We can write O twice, like O + O Draw two O molecules. Distribute the molecules cut from Balancing Equations Molecules for either the decomposition of perchlorate or the synthesis of ammonia and give students five minutes with their partner to model the reaction with the cutouts. Stress to students that they should have the same type and number of atoms on both sides of the arrow…. You can give half of the students the cutouts to model the synthesis and half the students the cutouts to model the decomposition of perchlorate. You can also give everyone the same set of molecules and reserve the other set for students who finish quickly or who may benefit from extra practice…. Give feedback. Circulate and provide feedback to students asking, 'Is matter conserved on both sides? What is your evidence? How are you using mathematical thinking to figure this out?' Once students have modeled balanced equations with the manipulatives, write the balanced equations on the board or a piece of chart paper. Circle or underline the coefficients and tell students this is the accepted way to show multiple atoms or molecules of a substance in a chemical reaction" (Teacher Edition, page 233).

* Some examples of formative assessments with very strong feedback guidance include:
  - Lesson 1: Exit Ticket has three differing levels of understanding with "feedback/what do[sic] do as well as 'ideas for instruction.'" For linked understanding: "Give students a chance to revise their Exit Ticket responses before discussing them as a class on day 2. This could be done by pairing up students to compare their responses" (Teacher Edition, page 333).
  - Lesson 8: "Introduce electronegativity. Display slide L. Read the text on the slide, Electronegativity is a measure of how strongly a nucleus is attracted to another atom's electrons. Larger electronegativity corresponds to stronger attraction. Give students the

remaining time to individually write responses to the two questions on the slide as an exit ticket. Give feedback. Review exit tickets by doing a quick sort based on characteristics in Question 2 responses, described below. You will begin the next day by sharing a likely divergence: whether and how polarity is related to the intramolecular (inside the molecule) forces" (Teacher Edition, page 184).
    - Lesson 9: Midpoint Assessment Ticket has three differing levels of understanding with "feedback/what do" as well as "ideas for instruction." For foundational understanding: "Provide physical manipulatives that you used on day 1 of this lesson to model the shifts in electros for question 5…" (Teacher Edition, page 363).
    - Not all formative assessments have this detail of guidance for the teacher about how to adjust instruction based on varying levels of student responses.
- There are sidebars for notes to teachers to attend to equity. For example:
    - Lesson 6: As students build consensus around the element cards "Emphasize to students that when they work together to build consensus, everyone's ideas matter" (Teacher Edition, page 148).
    - Lesson 6: "Remind students that the Progress Tracker is a thinking tool that is designed to help them keep track of important discoveries the class makes. The sample Progress Tracker included in these materials serves as teacher guidance for what students may say at various points throughout the unit. Some students may say more, while others may say less. It is important that what the students write in the Progress Tracker reflects their own thinking at that particular moment. In this way, the Progress Tracker can be used to formatively assess individual student progress throughout the unit. When the class develops ideas together and comes to agreement, students will record this in their Progress Tracker and indicate the sources of evidence, but make it clear that this is a classroom consensus model" (Teacher Edition, page 150).
    - Lesson 8: "During this assessment moment, you may hear a number of student ideas. Encourage students to write their ideas down or draw them. This supports students' by providing multiple means of representation and action & expression. Many students may still prefer to share their ideas out loud" (Teacher Edition, page 184).

Suggestions for Improvement

Consider providing more guidance for how to adjust instruction when there are varying levels of proficiency, like the guidance in Lesson 11 with the model cutouts or the "ideas for instruction" on some of the Exit Tickets (Teacher Edition, pages 101–102, page 333, page 363).

III.C. SCORING GUIDANCE

Includes aligned rubrics and scoring guidelines that provide guidance for interpreting student performance along the three dimensions to support teachers in (a) planning instruction and (b) providing ongoing feedback to students.

Rating for Criterion III.C. Scoring Guidance	Extensive *(None, Inadequate, Adequate, Extensive)*

The reviewers found extensive evidence that the materials include aligned rubrics and scoring guidelines that help the teacher interpret student performance for all three dimensions because teachers have access to rubrics and exemplars that can be used in conjunction with scoring guidance to inform subsequent teaching steps and how to leverage feedback to support ongoing student learning.

Assessment targets for grade-appropriate elements of all dimensions being assessed together are clearly stated in the scoring guidance along with information that can be used to interpret responses. Related evidence includes:

- Lesson 5: In the *Analyze Atmospheric Spectra* activity, guidance is provided for teachers to score student work. It explains that "the table below shows what gasses students should be able to identify in the object's atmosphere using the reference spectra provided in (material.CR.L5.REF). Note that although other gasses may be present, evidence for them is not easy to see because of their low concentration or because they are buried under bands from other substances" (Answer Key Analyze Atmospheric Spectra, page 1).
- Lesson 5: Students use their Progress Tracker to record learning throughout the unit. In this lesson, students reflect on their learning around spectroscopy and its ability to provide information about atmosphere and solids on the surface of planetary bodies. Teachers are encouraged to examine the *Progress Tracker Key* to support students as they build toward the targeted lesson-level PE of: Analyze, compare, and integrate empirical evidence to identify patterns in the interaction (study) of a star's light or other light spectrum with substances present in a sample or on an object in space to answer scientific questions about how we can identify which locations have the substances or elements needed to live and work in space. (SEP: 4.1, 8.2; DCI: ESS1.A.2, PS4.B.4; CCC: 1.5)" (Teacher Edition, pages 132–133).
- Lesson 7: In the *Comparing Atomic Models* activity, question alignment to specific elements of the SEP, DCI, and/or CCC claimed is described along with specific scoring guidance for how to use the assessment and that "The goal here is to compare the different atomic models they have had exposure to in the prior OpenSciEd High School Chemistry unit, OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit) and this unit. They should identify both the merits and limitations of each of the four atomic models (SEP:2.1)." (Answer Key Comparing Atomic Models, pages 1–2).

- Lesson 9: Students complete a mid-point assessment that includes teacher guidance describing student evidence of "foundational understanding", "linked understanding", and "organized understand" including specific samples for each category as well as suggested "feedback/what to do" to support those students in further developing their understanding. Also embedded is a table that displays each question (1–7) and their alignment to the assessment SEP, DCI, and CCC elements (Answer Key Mid-Point Assessment, pages 1–8).
- Lesson 15: Students complete the unit assessment that includes teacher guidance describing student evidence of "foundational understanding," "linked understanding," and "organized understanding" including specific samples for each category as well as suggested "feedback/what to do" to support those students in further developing their understanding. Also embedded is a table that displays each question (1, 2, 3a, 3b, 3c, and 4) and their alignment to the assessment SEP, DCI, and CCC elements (Answer Key Unit Assessment, pages 1–10).

Students are provided with ways of tracking their own progress. Related evidence includes:

- Lesson 5: Students use their Progress Tracker to record learning throughout the unit. In this lesson, students reflect on their learning around spectroscopy and its ability to provide information about atmosphere and solids on the surface of planetary bodies. Teachers are encouraged to examine the *Progress Tracker Key* to support students as they build toward the targeted lesson-level PE of: "Analyze, compare, and integrate empirical evidence to identify patterns in the interaction (study) of a star's light or other light spectrum with substances present in a sample or on an object in space to answer scientific questions about how we can identify which locations have the substances or elements needed to live and work in space (SEP: 4.1, 8.2; DCI: ESS1.A.2, PS4.B.4; CCC: 1.5)" (Teacher Edition, pages 132–133).
- Lesson 7: Students discuss newly uncovered patterns in the number of connections between elements and the number of electrons. Students are encouraged to consider "how might we use this pattern to revise our models of atomic structure?" (Teacher Edition, page 159).

Suggestions for Improvement

- Consider including the specific assessment plan/scheme at the beginning of each lesson's front matter to clearly communicate how students will be assessed and what the purpose for each assessment is (e.g., self-assessment vs. summative).
- Consider providing guidance for students to be able to interpret their progress on meeting expectations.
- Consider providing the three levels of student understanding (foundational understanding, linked understanding, and organized understanding) for more of the assessment opportunities.
- Consider including more specific ways to adjust instruction based upon a range of student responses.

III.D. UNBIASED TASK/ITEMS

Assesses student proficiency using methods, vocabulary, representations, and examples that are accessible and unbiased for all students.

Rating for Criterion III.D. Unbiased Task/Items	Extensive *(None, Inadequate, Adequate, Extensive)*

The reviewers found extensive evidence that the materials assess student proficiency using accessible and unbiased methods, vocabulary, representations, and examples because assessments and activities that lead to assessments are accessible for most students. There are UDL and equity strategies that are embedded within the unit. The use of the Personal Glossary helps with unbiased vocabulary acquisition throughout the unit. In the unit, multiple modalities are used. However, the two large assessments do not have student choice in how they present their knowledge.

Vocabulary and text volume in student assessments are grade-level appropriate. Support is provided for students to access tasks when needed. Related evidence includes:

- Guidance and strategies to support student access are highlighted in the teacher guide under the headings of “attending to equity; supporting emerging multilingual learners; supporting universal design for learning; additional guidance; alternate activity; key ideas; and discussion callouts” (Teacher Edition, pages 26–27).
- Guidance is provided to support students in developing their personal glossaries, including “words we co-construct” (e.g., adhesion) and “words we encounter” (e.g., payload) as an integral part of their science notebook (Teacher Edition, pages 29–30).
- The text of the unit often has other representations such as graphs, infographics, and pictures. These representations are overall clear and assist with understanding. Some of the images are blurry and difficult to read, especially on the Space Spectroscopy Studies handout (Lesson 5).
- Lesson 12: The strategy outlined in the resource, *Summarize a Reading*, provides students with prompts to support their comprehension of a reading with specific prompts to annotate each section as well as prompts for understanding before moving on (Summarize a Reading, pages 1–2).
- Lesson 12: “If students struggle to summarize the text found on Sulfur-Based Concrete, see additional reading support in The OpenSciEd High School Teacher Handbook” (Teacher Edition, page 254).

Multiple modalities for presenting and providing information are available throughout the unit. For many tasks the specific modality is determined by the teacher rather than the student. Related evidence includes:

- Lesson 1: Students examine particle-level models depicting chemical reactions and are asked to "Individually record questions. Display slide DD. Students should individually record the questions that they now have related to recycling or making the substances we need to survive beyond Earth. Distribute three yellow sticky notes and a marker to each student and give students a few minutes to record their questions. Instruct students to leave the sticky notes in their notebooks to share next period" (Teacher Edition, page 55).
- Lesson 12: Students complete a reading about sulfur-based concrete and after discussing the text, revisit the DQB. Students are asked, "How would the explanation provided by the authors help address what we need to live and work permanently on Mars?" and "What line(s) of questions on our Driving Question Board does this solution address?" (Teacher Edition, page 254).
- Lesson 4: Students "build consensus around why water behaves differently than other liquids. Display slide AA. Lead a discussion around Mars Geological Landforms and the freezing models. Ask a few students to share their models and ideas about why water expands when it freezes and causes frost heaving. Listen for language around 'pulls' and 'attracts' as students share their ideas and models. Ideas may include 'what' or 'why' types of reasoning; push students toward explaining why water is so different" (Teacher Edition, page 103).
- Lesson 12: Students "balance the equation for photosynthesis. Present slide C. Write down an unbalanced equation for photosynthesis on a piece of chart paper and leave space to balance the equation. Tell students to write down the process in their science notebooks and to leave some space between each reactant or product" (Teacher Edition, page 242).

Suggestions for Improvement

- Consider revising task prompts to use multiple modalities to present information to ensure all students understand what is expected.
- Consider offering students choice in which modality they choose to demonstrate their progress toward mastery as a formative assessment opportunity when appropriate.
- Consider revising materials that may have blurry or unclear images to ensure students can use materials effectively.

III.E. COHERENT ASSESSMENT SYSTEM

Includes pre-, formative, summative, and self-assessment measures that assess three-dimensional learning.

Rating for Criterion III.E. Coherent Assessment System	Extensive *(None, Inadequate, Adequate, Extensive)*

The reviewers found extensive evidence that the materials include pre-, formative, summative, and self-assessment measures that assess three-dimensional learning because materials include assessments that connect to learning goals and require students to apply grade-appropriate elements of the three dimensions to make sense of phenomena or solve problems.

The assessment purpose and rationale are coherent across the materials and are explicitly described for all three dimensions, including how the different types of assessment (including informal assessment opportunities) work together to provide feedback to teachers to inform instruction.

There are resources to help teachers make sense of the assessment system and how it works within the unit. For example:

- "Lesson-by-Lesson Assessment Opportunities" is a resource that shows what lesson-level PEs are present in each lesson. This document provides checks for understanding and what to look/listen for (Teacher Edition, pages 297–306).
- "Assessment System Overview" provides a map for teachers of the different types of assessments. Pre-Assessment, Formatives, Self-Assessments, and Summative Assessments are marked in the document. There is a purpose of assessment listed (Teacher Edition, page 296).

There are opportunities for pre-assessments in the unit. For example:

- Lesson 1: There is a pre-assessment*, Initial Reaction Model*, that students complete individually. "This is an important pre-assessment to collect at the end of the class period. It will help inform you of students' models of chemical reactions from middle school as well as provide them with an opportunity to bring ideas from their work in Electrostatics Unit to the table. Examples of prior models that students will have worked with in OpenSciEd courses are included in Prior Chemical Reactions. Make a copy of this pre-assessment before giving it back to students and consider building additional opportunities into the last third of the unit for students to compare the models they develop at those points to the models they developed here. This can be a powerful catalyst for reflecting on their growth in understanding over time" (Teacher Edition, page 50).

- Lesson 1: The DQB is used as a pre-assessment to gather student questions and prior knowledge.
- Lesson 4: "Use this handout as a pre-assessment of the students current understanding about the relationship between electrons and bonds formed between elements." (Teacher Edition, page 353).

Formative assessments are included throughout the unit. For example:

- The Progress Tracker is used throughout the unit. "It is important that what the students write in the Progress Tracker reflects their own thinking at that particular moment. In this way, the Progress Tracker can be used to formatively assess individual student progress throughout the unit" (Teacher Edition, page 150). However, the Progress Tracker does not always address students' three-dimensional learning.
- There are callouts for "Assessment Opportunities" that can be used to formatively assess students' progress. Each Assessment Opportunity has information about what to look/listen for in the moment bullet points.
- Additional evidence related to formative assessment is listed under Criterion III.B.

There are summative assessments within the unit. The main two summative assessments are the Lesson 9 transfer task Mid-Point Assessment and the Lesson 15 Unit Assessment. However, there is somewhat of a mismatch between the summative assessment targets and the unit learning goals.

- Lesson 9: "This assessment targets the following Lesson-level performance expectation (LLPE): 9.A Use a variety of models (periodic table, ball and stick, dipole arrows) and evidence (electronegativities, atomic radii, and solubilities) to a) describe the patterns and relationships between the parts of an atom and the bonds formed between atoms, b) predict polarity differences, and c) explain property differences based on the relative differences in the strength of forces between atoms and molecules (SEP: 2.3; DCI: S2.A.3, PS2.A.2; CCC: 1.1, 6.2)" (Mid-Point Assessment Key).
- Lesson 15: "NGSS performance expectations being addressed: HS-PS1-1. Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms. (SEP: 2.3; DCI: PS1.A.1, PS1.A.2; CCC: 1.1) HS-PS1-2. Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties. (SEP: 6.2; DCI: PS1.A.2, PS1.B.3; CCC: 1.1)." SEP 6.2 is used in two-thirds of the questions on the summative assessment. However, this SEP element is not listed as a development goal in the unit and is used only in one lesson (Lesson 8) before being summatively assessed.

There are self-assessment opportunities in the unit. For example:

- Lesson 2: There are self-assessment prompts as students reflect on the community agreements. "We spent a lot of time going public with our ideas. As you did this, you worked with others and synthesized information from different sources. We will be practicing this more and more throughout the unit. In order to ensure we follow our Community Agreements so that we continue to communicate effectively, take a moment to complete the post-investigation reflection section of the handout. Display slide M. Go over the protocol for giving peer feedback. Encourage students to use the sentence starters on Focal Community Agreement as a guide to give peer feedback. Give each group member two minutes to share their focal[sic] Community Agreement and receive peer feedback. After each group member has had a chance to give and receive feedback, instruct students to complete the three prompts under item 4 on Focal Community Agreement." (Teacher Edition, page 73). This self-assessment opportunity is unlikely to elicit assessment related to learning goals in the three dimensions.

- Lesson 9: "Slides G, I, K, M, and Q, provided incremental check points for students to self-assess their understanding. Check in with students now to see how they are feeling. If students are struggling, ask students to circle the corresponding part of Modeling Molecular Polarity they feel they need more practice on. If so, then after slide R, provide that opportunity for practice with additional examples before administering Mid-point Assessment" (Teacher Edition, page 201).
- Lesson 15: "Complete self-reflection on the unit. Present slide N. Direct students to complete a quick write in their science notebook about any or all of these questions and then discuss them with the whole class" (Teacher Edition, page 292). The prompts are: "In your science notebook, reflect on: What was most challenging in this unit? What was most rewarding in this unit? Think about how you engaged in using Community Agreements with your classmates: How would you want to engage in them for the next unit? What would you do the same? What would you do differently?" (Lesson 15, Slide N). This self-assessment opportunity is unlikely to elicit assessment related to learning goals in the three dimensions.
- There is a self-assessment discussion rubric provided as a resource. "This resource is available in the OpenSciEd Teacher Handbook: High School Science. The student self-assessment discussion rubric can be used any time after a discussion to help students reflect on their participation in the class that day. Choose to use this at least once a week or once every other week. Initially, you might give students ideas for what they can try to improve for the next time, such as sentence starters for discussions. As students gain practice and proficiency with discussions, ask for their ideas about how the classroom and small-group discussions can be more productive" (Teacher Edition, page 296). This self-assessment opportunity is unlikely to elicit assessment related to learning goals in the three dimensions.

Suggestions for Improvement

- Consider including in more than one lesson opportunities for students to engage with SEP elements that make up large portions of the summative assessment.
- Consider including additional self-assessment opportunities that induce students to reflect on how their ideas have shifted with three-dimensional lenses.

III.F. OPPORTUNITY TO LEARN

Provides multiple opportunities for students to demonstrate performance of practices connected with their understanding of disciplinary core ideas and crosscutting concepts and receive feedback.

Rating for Criterion III.F. Opportunity to Learn	Extensive *(None, Inadequate, Adequate, Extensive)*

The reviewers found extensive evidence that the materials provide multiple opportunities for students to demonstrate performance of practices connected with their understanding of DCIs and CCCs. There are multiple opportunities throughout the unit in which students give and receive actionable feedback about their progress in the targeted learning tasks and can apply the feedback to demonstrate their growth. However, there are few opportunities to receive and act on CCC-specific feedback.

Students are provided with multiple opportunities to receive and respond to feedback throughout the unit. Related evidence includes:

- Lesson 2: "Lead a discussion to reflect on Community Agreements. Say, We spent a lot of time going public with our ideas. As you did this, you worked with others and synthesized information from different sources. We will be practicing this more and more throughout the unit. In order to ensure we follow our Community Agreements so that we continue to communicate effectively, take a moment to complete the post-investigation reflection section of the handout. Display slide M. Go over the protocol for giving peer feedback. Encourage students to use the sentence starters on Focal Community Agreement as a guide to give peer feedback. Give each group member two minutes to share their focal[sic] Community Agreement and receive peer feedback. After each group member has had a chance to give and receive feedback, instruct students to complete the three prompts under item 4 on Focal Community Agreement" (Teacher Edition, page 73).
- Lesson 5: "Students use their progress tracker to record learning throughout the unit. In this lesson, students reflect on their learning around spectroscopy and its ability to provide information about atmosphere and solids on the surface of planetary bodies. Teachers are encouraged to examine the *Progress Tracker Key* to support students as they build toward the targeted lesson-level performance expectation of: Analyze, compare, and integrate empirical evidence to identify patterns in the interaction (study) of a star's light or other light spectrum with substances present in a sample or on an object in space to answer scientific questions about how we can identify which locations have the substances or elements needed to live and work in space. (SEP: 4.1, 8.2; DCI: ESS1.A.2, PS4.B.4; CCC: 1.5)" (Teacher Edition, pages 132–133).
- Lesson 6: Students complete an element card sort, do a gallery walk and provide feedback, and use the peer suggestions to revise their models (Teacher Edition, pages 146–147).

- Lesson 7: Students discuss newly uncovered patterns in the number of connections between elements and the number of electrons. Students are encouraged to consider “how might we use this pattern to revise our models of atomic structure?” (Teacher Edition, page 159).
- Lesson 11: “Give feedback. Circulate and provide feedback to students asking, ‘Is matter conserved on both sides? What is your evidence? How are you using mathematical thinking to figure this out?’ Once students have modeled balanced equations with the manipulatives, write the balanced equations on the board or a piece of chart paper. Circle or underline the coefficients and tell students this is the accepted way to show multiple atoms or molecules of a substance in a chemical reaction” (Teacher Edition, page 233).
- Lesson 15: “Share a list of requirements for the model. Point out that students should model and show: atoms, valence electrons, and electronegativity ‘pulling’ on electrons in their model. Circulate around the room and give formative feedback tied to the positions of electrons, the use of the periodic table, and the pulls that students represent in their molecules. Reference their balanced equations from the previous step, as well” (Teacher Edition, page 289).

The unit presents multiple opportunities for students to use many of the claimed CCC elements, but there are relatively few instances in which students receive specific feedback about the CCC portion of their thinking or work. Related evidence includes:

- Lesson 4: Students prepare to complete an investigation about different liquids’ impacts on landform formation. Teachers are asked to prompt students’ thinking by asking questions such as “how could we use these materials to investigate if the landforms on Mars were made by water or some other liquid? What other materials or liquid would be important to try if they are/were available? How do the properties of these liquids compare to those of water?” (Teacher Edition, page 94). The Supporting Students in Developing and Using Patterns callout box references the need for teachers to “…provide feedback to students that helps them link causality appropriately to the patterns of water in extra-terrestrial systems.” It’s not clear from these descriptions how or when these supports would be needed and given the presence of other, relevant prompts, it seems less likely that teachers would use this suggestion compared to other, more explicit ones.
- Lesson 4: “Help foreground the different scales we considered and connected in this lesson and the last by reminding students that we initially wanted to explain a surface features on Mars. This surface feature was evidence of some sort of change in matter on a very large scale - since canyons or stream beds can be on the order of miles big. Add that once we carried out our investigation in our lab which was at a much smaller scale, we decided we still needed to go down to an even smaller scale, down to the particle level to explain the differences in our results. Make an explicit reference to element CCC: 1.1 at this point and emphasize that this sort of thinking is what we using to try to connect together explanations across different scales” (Teacher Edition, page 104).

Suggestions for Improvement

- Consider providing an assessment scheme at the unit or lesson-level front matter that focuses on the progression of feedback and opportunity for students to revise and respond in a later task.
- Consider strengthening suggested opportunities for feedback for individual students based on their performance.

OVERALL CATEGORY III SCORE: **3** (0, 1, 2, 3)	
Unit Scoring Guide – Category III	
Criteria A-F	
3	At least adequate evidence for all criteria in the category; extensive evidence for at least one criterion
2	Some evidence for all criteria in the category and adequate evidence for at least five criteria, including A
1	Adequate evidence for at least three criteria in the category
0	Adequate evidence for no more than two criteria in the category

SCORING GUIDES FOR EACH CATEGORY

UNIT SCORING GUIDE – CATEGORY I (CRITERIA A-F)

UNIT SCORING GUIDE – CATEGORY II (CRITERIA A-G)

UNIT SCORING GUIDE – CATEGORY III (CRITERIA A-F)

OVERALL SCORING GUIDE

Scoring Guides for Each Category

Unit Scoring Guide – Category I (Criteria A-F)	
3	At least adequate evidence for all of the unit criteria in the category; extensive evidence for criteria A–C
2	At least some evidence for all unit criteria in Category I (A–F); adequate evidence for criteria A–C
1	Adequate evidence for some criteria in Category I, but inadequate/no evidence for at least one criterion A–C
0	Inadequate (or no) evidence to meet any criteria in Category I (A–F)

Unit Scoring Guide – Category II (Criteria A-G)	
3	At least adequate evidence for all criteria in the category; extensive evidence for at least two criteria
2	Some evidence for all criteria in the category and adequate evidence for at least five criteria, including A
1	Adequate evidence for at least three criteria in the category
0	Adequate evidence for no more than two criteria in the category

Unit Scoring Guide – Category III (Criteria A-F)	
3	At least adequate evidence for all criteria in the category; extensive evidence for at least one criterion
2	Some evidence for all criteria in the category and adequate evidence for at least five criteria, including A
1	Adequate evidence for at least three criteria in the category
0	Adequate evidence for no more than two criteria in the category

OVERALL SCORING GUIDE	
E	**Example of high quality NGSS design—**High quality design for the NGSS across all three categories of the rubric; a lesson or unit with this rating will still need adjustments for a specific classroom, but the support is there to make this possible; exemplifies most criteria across Categories I, II, & III of the rubric. (total score ~8–9)
E/I	**Example of high quality NGSS design if Improved—**Adequate design for the NGSS, but would benefit from some improvement in one or more categories; most criteria have at least adequate evidence (total score ~6–7)
R	**Revision needed—**Partially designed for the NGSS, but needs significant revision in one or more categories (total ~3–5)
N	**Not ready to review**—Not designed for the NGSS; does not meet criteria (total 0–2)