Chemical Reactions in Our World

DEVELOPER: OpenSciEd

GRADES: 9–12 **|** **DATE OF REVIEW:** June 2023

Educators Evaluating Quality Instructional Products

Chemical Reactions in Our World

EQuIP RUBRIC FOR SCIENCE EVALUATION

OVERALL RATING: E

TOTAL SCORE: 8

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	Adequate	**C.**	Scoring Guidance	Extensive
D.	Unit Coherence	Extensive	**D.**	Scientific Accuracy	Extensive	**D.**	Unbiased Tasks/Items	Adequate
E.	Multiple Science Domains	Extensive	**E.**	Differentiated Instruction	Extensive	**E.**	Coherent 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	Extensive			

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. It is obvious that this unit was thoughtfully crafted, and it is strong in several areas, including the use of a real-world engaging phenomenon that is connected to the local context of food justice. Students have numerous opportunities to ask questions and guidance is provided for the teacher to use their questions to drive learning. The materials also provide supports for student modeling and multiple opportunities for peer feedback to revise their models throughout the learning sequence.

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

- **Three-Dimensional Learning.** While the materials provide numerous opportunities for students to use grade-level elements of all three dimensions, additional opportunities for students to be supported in developing the claimed Crosscutting Concept (CCC) elements and developing the ESS Disciplinary Core Idea (DCI) elements would further strengthen the unit.
- **Building Progressions**. Prior student learning for DCI elements is clearly communicated in the materials. Communicating prior learning of CCC and Science and Engineering Practice (SEP) elements in a similar way in the teacher-facing materials would significantly strengthen the materials.
- **Differentiation**. Consider the timing of supports provided and whether they support the students' current level of learning in that lesson activity. For example, the suggestion to use a translator device in Lesson 13 appears rather late in the learning progress and does not appear to serve students' emerging language needs for articulating their understanding of a complex text, especially after having already read and engaged with numerous texts in prior lessons.

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 definitely 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 and/or designing solutions to a problem because all learning experiences in the unit are anchored in designing solutions to the central problem of oyster shell degradation and students have many opportunities to investigate and figure out subsequent subproblems related to the anchoring problem.

The materials are organized so that students are figuring out a central phenomenon and designing a solution to a problem. Students regularly revisit the phenomenon throughout the unit. Related evidence includes:

- The “What is the anchoring phenomenon and why was it chosen?” section of the Teacher Edition describes the anchoring phenomenon and why it was chosen. “For the anchoring phenomenon, students use the novel phenomenon of oyster larvae die-offs, overnight events that became widespread in the Pacific Northwest in the mid-2000s as ocean pH reached a new low in that area. Ocean acidification causing larvae die-offs provides the context in which to investigate acids and bases, reversible reactions and chemical equilibria, stoichiometry, reaction rates, carbon’s movement through Earth’s systems, and how people can apply ideas from chemistry and Earth science to decrease the effects of ocean acidification on oysters. Ocean acidification’s effect on oysters was chosen for this unit after examining previously collected student interest data and consulting with our state advisory panel” (Teacher Edition, page 13).
- Each lesson outlined in the “Unit Resources and Lessons Documents” landing page shows guiding questions intended to be realized in each lesson, such as in Lesson 3: “Can carbon dioxide make the ocean more acidic?” These questions all appear to relate to the central phenomenon.
- Lesson 1: The following teacher guidance is provided for introducing the unit: “Introduce the unit. Show slide A. Say, Our next unit will focus on some really special foods. What are some special foods in our community/families? Ask about special foods. Think about foods you share that are especially nourishing, foods you eat at special times, or any foods that your family has lost that you wish you could eat. Ask students to share with a partner for 30 seconds and then ask students to share what they heard. Press students to share ingredients of their foods and

the histories of the foods. You may ask questions like: You have a really long history with that food. Did anyone else hear about a grandparent or great-grandparent's recipe? Did anyone hear a story from their partner about a food that was lost? Sum up. Say, I asked around before we started this unit. Do any of you recognize some of these foods? Show slide B containing images you have added of locally important foods. Say, A lot of us have lost our traditional foods over the last century or so for a lot of reasons like moving, industrialization, and 'big food' industries. We are going to hear from someone who almost lost a really important food for their family and community" (Teacher Edition, page 30).

- Lesson 1: Students watch a video introducing the importance of oysters to the Swinomish Tribal Community. "Show Alana Quintasket video. Display slide C. Show https://youtu.be/zKyfbGbRz7c. After the video, say, This connection to food and being able to get your important foods is sometimes called 'food sovereignty.'" (Teacher Edition, page 31). The following guidance is provided after students watch the video: "Focus on restoration efforts. Ask students to identify what Alana said about indigenous efforts to restore oysters. Students should identify that the Swinomish Tribal Community has a 'Swinomish Shellfish company' that is working to help with oysters. If they do not remember this from the video, ask them to consult the transcript or rewatch the video" (Teacher Edition, page 31).
- Lesson 1: "Show a video about oyster die-offs. Display slide F. Say, A scientist working with Alana's community talked to us about oyster die-off events and how scientists are helping restore this special food to the Swinomish Trival Community. Distribute the Stuart Thomas Transcript. Then play https://www.youtube.com/watch?v=UlOSbJD92og" (Teacher Edition, page 32).
- Lesson 2: "Students break down engineering problems that are large and global, such as ocean acidification, into smaller problems that can be investigated in class (SEP: 7.6; DCI: ETS1.A.2). This relationship of large problems to smaller subproblems brings into play interrelated issues of scale and patterns (CCC: 1.1, 3.1). Finally, students build an argument about the focus of their initial search for solutions to ocean acidification (SEP: 7.6). They evaluate proposals by comparing scale and patterns, and prioritize counteracting negative human impacts on oyster systems (SEP: 7.6; DCI: ETS1.A.2; CCC: 1.1, 3.1). One argument is that students are well positioned to design solutions for local mitigation in chemistry class (SEP: 7.6; DCI: ETS1.A.2). This motivates future investigations centered around chemical engineering" (Teachers Edition, page 50).
- Lesson 2: Students begin filling out the Progress Tracker. "Progress Tracker is designed to guide students through the engineering design process. It focuses on the main subproblems identified in Lesson 2, and asks students to separately record the science ideas they figure out, how they might apply those ideas, and the criteria and constraints that impact how they apply those ideas. As students return to the Progress Tracker, prompt them to consider the interrelation of these columns, and how all subproblems are important to investigate in order to design solutions that address the large, complex problem identified in the Anchoring Phenomenon Routine. Progress Tracker Key offers some possible ideas that students will have added to their Progress Trackers by Lesson 12. This also provides an opportunity to remind students that there are many ways to solve big problems, and that it is important to learn as much as we can about the problem, the people affected by it, and the people working on it, to make sure we can design solutions that do not further harm those who are already marginalized" (Teacher Edition, page 53).
- Lesson 3: After completing an investigation students engage in a class discussion. The following prompt is provided: "How do the data either support or refute the claim that increasing atmospheric CO levels cause ocean water to become more acidic?" (Teacher Edition, page 66).

- Lesson 4: Students are asked to discuss the following prompt: "What new ideas do you have now for how increases in the concentration of CO_2 in the atmosphere cause the ocean to become more acidic?" (C.4 Lesson 4 Slides, Slide V).
- Lesson 5: "Model initial ideas for how CO interacts with water to make it acidic. Display the class consensus model from Lesson 1 for students to examine. Remind students that we were wondering about how carbon dioxide moves from the atmosphere into the ocean and what interactions between carbon dioxide and water result in an increase in H ions in the water" (Teacher Edition, page 93).
- Lesson 5: "Update progress trackers. Show slide M. Celebrate all of the progress we have made over the last three lessons. Say, We have figured out so many new science ideas that could help us address the problem happening to the oysters! Let's take a moment to update our Progress Trackers with these new ideas. Give students the remaining time to update Progress Tracker with information from Lessons 3, 4, and 5. You can allow students to work independently, with a partner, or in a small group" (Teacher Edition, page 98).
- Lesson 5: Students apply the carbon cycle model to oysters. "Apply the carbon cycle model to oysters. While students are in the Scientists Circle, show slide V…. Summarize areas of agreement, such as: Humans have put more CO in the atmosphere than used to be there. We are getting it from the ground where it was not hurting anybody. More CO gets into the ocean than used to in the past. CO reacts to make the water acidic, which hurts oysters. Consider possible solutions to help oysters. Display slide W. Have students turn and talk about the prompt on the slide for 2 minutes. They will not share out their discussions, but students will use them as they update their Progress Trackers in the next step. Update Progress Trackers. Present slide X. Say, Let's take a moment to record our ideas about how the carbon cycle model helps us understand oyster die-offs and improve access to them as an important food source. Say, Update your Progress Trackers for a second time this lesson" (Teacher Edition, page 104).
- Lesson 6: "Direct students to their Progress Trackers. Show slide AA. Ask them to add their new thinking from the day and note what subproblem(s) their science ideas might connect to. Close the lesson by thanking students for their deep thinking. See Progress Tracker Key for a sample progress tracker entry" (Teacher Edition, page 125).
- Lesson 7: "Return to our unit question. Display slide B. Remind students of the overarching question we are trying to figure out: Why are oysters dying, and how can we use chemistry to protect them? Say, We want to think about how we can use chemistry to protect the oysters. Based on what we have figured out so far, what are some ideas that we have for how we can do that? Call on several students for responses. Say, Let's think about our own experiences for a minute" (Teacher Edition, page 130).
- Lesson 8: Students work to apply what they have learned about neutralization reactions to solving the problem of ocean acidification. "Think about neutralization in the ocean. Display slide I. Say something like, In order to consider how we might be able to use this idea to neutralize the acid in the ocean, let's recall what we know about the chemistry of what is causing the ocean to become more acidic in the first place. Discuss both questions on the slide as a class" (Teacher Edition, page 147).
- Lesson 8: "Discuss how we can use what we have learned today. Display slide MM. Cue students [sic] think about how they can apply our new knowledge to helping oysters next class. Give students a few minutes to discuss the prompt with a partner, then ask for volunteers to share what they discussed with their partners" (Teacher Edition, page 161).
- Lesson 9: Students add to their Progress Tracker. "Students update their Progress Trackers. Students should add what they have figured out to the science ideas and possible solutions

sections of their Progress Tracker. Display slide L. Possible ideas students add to their progress trackers are found in Progress Tracker Key in Lesson 12" (Teacher Edition, page 173).

- Lesson 10: Students update the Progress Tracker and discuss possible new solutions. "Update Progress Trackers. Display slide U. Have students summarize their annotated models from Shell-Building Model into their Progress Trackers. A sample progress tracker entry can be found on Progress Tracker Key in Lesson 12. After students finish adding to their Progress Tracker, ask if we can use this knowledge to support new solutions. Give students a chance to brainstorm in pairs, then discuss as a class" (Teacher Edition, page 192).
- Lesson 11: Students connect their learning to the original problem/phenomenon. Students are instructed to talk about one of the two prompts: "How could what we have figured out about temperature and reaction rates help oyster larvae build their shells?", and "How could what we have figured out about concentration and reaction rates help oyster larvae build their shells?" (C.4 Lesson 11 Slides, Slide P).
- Lesson 11: "Update Progress Trackers. Show slide V. Ask students to work with a partner to update their Progress Trackers with any new ideas from the day's discussion. Say, At this point, we now have come up with a lot of interesting ways to use chemistry to help oysters. In order to determine if any of those solution(s) are ones that we would recommend for helping protect oysters, we will need to evaluate them in light of the different criteria and constraints we need to keep in mind. Let us plan to do that tomorrow. See Progress Tracker Key for samples of what students can add to their Progress Trackers" (Teacher Edition, page 220).

Student learning is frequently driven by students' questions, ideas, and prior experiences. Related evidence includes:

- Lesson 1: The "Engaging in Asking Questions and Defining Problems" box states, "Initial questions about a phenomenon are intended to clarify what information is known and not known and, as is often the case, there are more questions than answers when scientists begin their investigations. Develop a safe and supportive space for students' uncertainty, and focus on the need to ask and answer questions to help address and resolve their uncertainty over the course of the unit" (Teacher Edition, page 33).
- Lesson 1: Students use information from the lesson and their classroom consensus model to create a Driving Question Board (DQB). An example DQB is provided containing some sample student questions. The following guidance is provided for how questions may apply to specific lessons: "Possible 'umbrella' topics (and the lessons in which students will explore them) could be: acidity (Lessons 3 & 4) CO (Lesson 5) impact on oysters (Lesson 7) how to grow oysters (Lessons 9-12) impact on ecosystems (Lesson[sic] 12-15)" (Teacher Edition, page 45). In addition, the following guidance for helping students generate questions is provided in the assessment opportunity box: "Accept all student questions, but if only a small number are related to the ideas listed above, wait until all students have posted a question. Then ask students to connect their question to a specific point of confusion on the class consensus model. Many students will not be able to make that connection, so ask them to generate a question related to the model that can be posted and then viewed by their classmates in a gallery-walk style" (Teacher Edition, page 45). Additionally, the following guidance is provided to help teachers connect student questions to specific lessons within the unit: "Label the questions. After all students have shared their questions, you will have several different clusters of questions on the DQB. As a class, decide on 'umbrella' questions or topics for the clusters of questions and then label them. Then, if you have not already done so, post the overarching unit question at the top of the DQB: How and why are oysters dying from ocean acidification? Possible 'umbrella' topics (and the lessons in which students will explore them) could be: acidity (Lessons 3 & 4) CO (Lesson 5) impact on

oysters (Lesson 7) how to grow oysters (Lessons 9-12) impact on ecosystems (Lesson[sic] 12-15)" (Teacher Edition, page 45).

- Lesson 1: Students brainstorm possible investigations. "Generate ideas for investigations. Display slide DD. Say, We have so many ideas to explore! How could we start to investigate the answers to some of these questions? Title the next page in your science notebook 'Ideas for Investigations.' Choose one question or category of questions from our Driving Question Board and talk with a partner or partners near you to consider how we might find the answer—what investigation could we design, what data should we gather, and how could we figure this out in our classroom? Keep track of your ideas in your notebook…. Student ideas may include the following: We should see if CO actually makes water acidic so we can figure out how it works. We should research how people are approaching this problem now, since that might give us some clues about what to do. We could try dissolving oyster shells or something like them in water to see what happens. We can try figuring out how CO is actually interacting with water to make an acid. We need to research how oysters build their shells so we can figure out how acidity is stopping it" (Teacher Edition, page 45).
- Lesson 2: "Consider approaches to solving big problems in students' everyday experiences. Display slide B...Think about how you and your classmates have solved problems in the past. What are some ways we have approached solving a large-scale problem differently from a small-scale problem?...Listen for the following responses, related to students' work from prior units: We evaluated different types of solutions individually for preventing polar ice melt (microbeads vs. a berm). Polar Ice Unit[;] We looked at different boundaries/parts that were interacting within a single system (e.g., light/surface, light/air, water/water, water/ice, water/air). Polar Ice Unit[,] We explored a smaller scale version of the interactions at work in a large system (e.g., with water in a cup, a water dropper to explore lightning, rubbing materials together to produce charges). Electrostatics Unit[,] We looked at the possibility of using chemistry to make the things we need (large scale) by examining how individual elements combine with each other (atomic scale). Space Survival Unit" (Teachers Edition, page 51).
- Lesson 3: "If students do not suggest some of the examples found on the Connect and Extend posters, prompt them to think about what we already knew about pH, acids, or bases. Leverage student prior knowledge by making this visible" (Teachers Edition, page 69).
- Lesson 5: "If you have time, consider having students share some of their wonderings. This may include a discussion about what a (carbon) sink is as described in Table 1 on Carbon Data. One way to do this is to have students consider whether the values presented in the table show a gain (+) or loss (-). Provide time for students who need it to add carbon sink to their personal glossaries. Students who have experienced the OpenSciEd High School Biology unit Fires Unit may have an idea already of what a carbon sink is. You may also have students take a moment to add their wonderings to the DQB and/or answer some questions using the information from Carbon Data" (Teacher Edition, page 101). Prior learning derived from a previous OpenSciEd unit or learning around the topic of carbon sinks is elicited through this optional discussion prompt. Making this optional would prevent all students from having an opportunity to specifically operationalize prior learning to support their continued learning around carbon's movement through different spheres — particularly between the atmosphere and hydrosphere.
- Lesson 6: "Use the snowball protocol to share ideas and questions. Say, When we left off in the last lesson, we noticed that our water sample with carbon dioxide was no longer acidic. It had changed back in color! At the end of the lesson, you recorded responses to two prompts on a sheet of paper. Display slide A. Read through the directions of the snowball protocol on the slide. Ask if students have any clarifying questions, then carry out the snowball protocol to share

student ideas and questions from Lesson 5. As students share questions, tape them to the DQB or have students copy them onto a 3x3 sticky note with a marker and then add them" (Teacher Edition, page 111).

- Lesson 7: "Take stock of DQB. Display slide K. Say, We have figured out so many ways to restore oysters to help food access issues with the Swinomish Tribal Community. Let's take stock of all we've figured out. Distribute Our DQB Questions with the list of questions developed on the Driving Question Board. Have students work individually to mark questions they think the class has answered using the key on the handout, replicated here: 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 developed, I could now answer this question: ✓+ Say, Next class we will revisit the Driving Question Board as a class to take stock of what we have figured out so far" (Teacher Edition, page 136). Students later have an opportunity to add questions to the DQB. "Add questions to the Driving Question Board. Have 3x3 sticky notes available for any students who suggest adding questions to the DQB. Ask, Do we have any new questions to add? Provide students with a few minutes to write down questions if they have them. Call on students to share their questions and add them to the DQB. Some new questions that may arise at this point include: How can we reverse ocean acidification? Who gets to decide what criteria we use to evaluate an engineering solution? How could we use plants to help prevent ocean acidification? Is there any way we could use reversible reactions to help prevent oysters from being harmed? The next lesson set will take on questions about 'how much' base would need to be added to help the ocean and tanks be more habitable for oyster larvae. The final lesson set focuses on all wider engineering choices. You can group students' ideas this way to increase coherence during these two lesson sets" (Teacher Edition, page 137).
- Lesson 15: "Students work in pairs for 5 to 10 minutes to mark questions they think the class has answered using the symbols on the handout, replicated here. We did not answer this question or any parts of it yet: o Our class answered some parts of this question, or the ideas we developed help me see how I could now answer some parts of this question: ✓ Our class answered this question, or Using the ideas we developed, I could now answer this question: ✓+ Mark questions on the DQB, individually. Display slide C. Ask individual students to come to the DQB and mark questions that the class has answered in whole or in part through our investigations. Have as many students as possible participate until all the questions that the class has answered have been marked. If there is time, ask students to share evidence that we have answered the questions as each one is checked off. At the end, you may ask them to summarize which groups of questions have and have not been answered. Thank students again for all their hard work on this unit and celebrate just how much we have figured out through our efforts" (Teacher Edition, page 265).

Suggestions for Improvement

- Consider providing guidance for teachers to elicit students' prior experiences related to the anchoring problem such as connections to local foods with possible examples of different regional foods that could be locally valued and used in various geographic areas throughout the country (e.g., Great Lakes region, Southwest region, etc.).

Chemical Reactions in Our World

EQuIP RUBRIC FOR SCIENCE EVALUATION

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 because students have numerous opportunities to develop and use claimed SEPs and DCIs throughout the materials, though there is some mismatch in CCC elements claimed.

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 there are sufficient SEP elements developed and used throughout the unit and there is a strong match between SEP elements claimed and those developed and used.

Asking Questions and Defining Problems (Focus SEP)

- *Ask questions that arise from examining models or a theory, to clarify and/or seek additional information and relationships.*
  - This element is claimed as a focus element in the unit.
  - Lesson 1: Students are provided with an opportunity to brainstorm questions based on the consensus model they have created as well as the other classroom discussions from this lesson. “Predict the problem’s root cause. Show slide I. Have students take out their science notebook. Ask them to write a few things that might cause these die-off events. Then have them share their list with a partner and circle the things they have in common” (Teacher Edition, page 33). Students are asked to consider the potential reasons for the preliminary root causes that they identified and attempted to capture in their initial models. “Direct students to look back at their notebooks and the consensus model and think about discussions they had today to identify relevant questions...Lead students in building a Driving Question Board” (Teacher Edition, page 43).
  - Lesson 1: “Generate questions. Display slide BB. Say, It seems like we know of some things that are similar to oyster shells being ‘eaten away,’ but based on our models we are not 100% sure what’s happening with oysters. Let’s take this opportunity to record our questions so we can think about useful next steps. Direct students to look back at their notebooks and the consensus model and think about discussions they had today to identify relevant questions. Students should write down at least two new questions that

they have now about the phenomenon of oyster die-off due to ocean acidification. Remind students to write big so their questions are easier to read. Give students a few minutes to record their questions on 3x3 sticky notes" (Teacher Edition, page 43).
  - While this is identified as a focus element, it is only used in Lesson 1; therefore, students are not provided with the opportunity to develop the practice over the course of the learning sequence.
- *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*.
  - This element is claimed as a focus element in the unit.
  - Lesson 7: "Return to our unit question. Display slide B. Remind students of the overarching question we are trying to figure out: Why are oysters dying, and how can we use chemistry to protect them? Say, We want to think about how we can use chemistry to protect the oysters. Based on what we have figured out so far, what are some ideas that we have for how we can do that? Call on several students for responses...What can we learn from other people who also care about oysters? Why is it important to listen to people who are already working on this problem?" (Teachers Edition, page 132). Students later connect the initial questions they generated to potential solutions needed to address these issues they have come to begin to understand during Lessons 1–6.
  - Lesson 7: "Redefine the problem. Say, We have been recording how our science ideas could help us create a design solution to address subproblems. What is our subproblem? Can we define that again? Introduce criteria and constraints. We will want to know if the design solution we come up with is good or not. How do we decide if an engineering design solution is effective or not? Look for students to mention: It needs to work without causing additional problems. It shouldn't be too expensive. If students do not mention criteria and constraints, take a moment to introduce the terms. Ask students what each of those terms mean" (Teacher Edition, page 132). Students then go into expert groups to learn more about potential criteria and constraints. Students share their criteria and constraints on posters around the room.
  - Lesson 7: Students use vignettes about interested parties to define additional social, technical, and environmental criteria and constraints that will inform the development of their engineering design solution (Teacher Edition, page 136).
  - Lesson 11: "If students are struggling to articulate how criteria and constraints might be interrelated, contradictory, or contextual, refer back to the Lesson 7 readings Poultry Farmers, Northwest Indian Fisheries, Oyster Farmers, and Restaurant Personnel and discuss possible examples. For instance, a solution that supports supply-chain issues and cost effectiveness for restaurants in the Pacific Northwest might interfere with ceremonial harvests (aesthetics, values) in Indigenous communities. See STEM Teaching Tool Practice Brief 64 http://stemteachingtools.org/brief/64", and later, "Consider other possible criteria and constraints we are missing. Display slide G. Say, We have also figured out quite a bit more science since the first time we discussed criteria and constraints. And, we have our own knowledge and experiences that can help us build out this list. What else do we need to consider? Invite students to turn and talk, then share with the whole class any criteria and constraints that are not already presented." (Teacher Edition, page 230).
  - Lesson 12: Students revisit initial ideas developed in Lesson 7 related to priorities of different interested parties. They discuss how requirements for and limitations on a

particular design solution are interrelated, at times contradictory, and context dependent (Teacher Edition, page 225).

- Lesson 12: Students work to identify criteria and constraints for their solutions based upon a variety of factors. Students engage in a discussion about which solution should be developed. The following prompts are provided: "How should we decide which direction to pursue?", and "What should we prioritize?" The following additional guidance is provided to the teacher: "When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. This discussion should attend to reliability, safety, and cost. Consider asking about these ideas directly. Students may also bring up aesthetics, which are part of the cultural significance of oyster -- their shells are beautiful and part of many indigenous jewelry and clothing traditions" (Teacher Edition, page 227). Students then discuss the following prompt: "Review the criteria and constraints columns in your Progress Tracker. What criteria and constraints are important to the interested parties who are most impacted by this problem?" (C.4 Lesson 12 Slides, Slide E). This is followed by a class discussion. "Lead the class in a discussion about criteria and constraints important to interested parties. Write a new summary of the criteria and constraints students raise on a whiteboard, a piece of chart paper, or a slide. Ask students to record the list in a T-chart in their science notebooks" (Teacher Edition, page 228). However, the focus of these criteria and constraints are in relation to possible solutions rather than defining the problem.

Developing and Using Models

- *Design a test of a model to ascertain its reliability.*
  - Lesson 8: Students check their assumptions as to what the coefficients in a balanced chemical equation represent by carrying out the specified reaction and testing the pH. When the first does not yield the expected results, they revise their models, calculate needed quantities, document a revised procedure that meets the safety guidelines, and carry out the reaction a second time (Teacher Edition, page 147).
  - Lesson 8: Students develop an investigation to test if the coefficients in the chemical equation could help predict the amount of base required to neutralize the acid. "Display slide M. Tell students we can try balancing this equation, which involves two solids, making it easier to ensure an accurate measurement of the two substances. Give students time to balance the equation using the cards from Balancing Equations Cards. Then after balancing, display slide N and use the prompts on the slide to discuss what these reactions tell us and how testing one of them might help us determine if we have a way to predict how much base is needed to neutralize an acid" (Teacher Edition, page 149). Students later test this idea by conducting a neutralization reaction using the mole ratio derived from their balanced equation.
  - Lesson 8: Students reflect on their data from the investigation, noting that rather than a neutral solution resulting, each group has a rather basic solution, indicating that their initial model required some revision. In the **Supporting Students in Engaging in Developing and Using Models** box, "Emphasize to students that they will use models for a purpose. Models are dynamic and can change as new information is learned, and models need to be 'applied' to be useful. Models are not used to describe something, but rather students should learn to use them to develop an explanation. Avoid asking students to simply repeat back an element of a model or even an entire model as an inert 'fact'" (Teacher Edition, page 150). The teacher is then asked to facilitate a discussion around the unexpected outcome, converging on the idea that mole ratio and

mass ratio are not the same thing, moving students to think in terms of numbers of molecules and moles rather than simple mass. Students do not appear to be designing a test of the model for the sake of determining its reliability. Rather, they seem to be utilizing the model, assuming that it is reliable.

- *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 4: "Develop an initial explanation. Display slide P. Problematize something we cannot yet explain about the results by reading the top of the slide. Say, Even when we made solutions with the same concentration of substances added to them, different substances produced a different concentration of H+ or OH ions when they dissolved in the water. Suggest that we try to make sense of this outcome by developing a model. Distribute Modeling H+ Concentrations. Direct students to use the prompts on the handout to help them model what could be happening to the molecules of two different acids to account for our results. Give students five minutes for this. Collect the handout before the end of the period" (Teacher Edition, page 81). Students are provided a handout with questions and diagram stems to construct their models. The following student prompt is provided: "Choose two acids with different pH values. In the empty boxes, show what may be happening to the particles in each of the solutions to explain our observation that one acid produced a higher concentration of H ions than another" (C.4 Lesson 4 Handout Modeling H+ Concentrations, page 1). Students are asked to connect their understanding of dissociation with data collected about changes in pH, illustrating the relationship between dissociation of acids of varying strengths and its subsequent impact on pH (and more broadly, impacts on oyster populations).
  - Lesson 5: "Annotate our class consensus model with findings from the data handouts. Show slide S. Display the class consensus model and ask students to use their 3x3 sticky notes to annotate it with the quantitative data they gathered. Students should post their notes where they think the data addresses or relates to the model. Emphasize that the model becomes a better representation of the phenomena at hand with more specific and quantifiable data. Then have students repeat the process with the sticky notes that contain other types of data" (Teacher Edition, page 102). Students' data is used to provide evidence for the features of the class consensus model, which illustrates the relationship between different components of the ocean-oyster system.
  - Lesson 7: The following questions are asked on the assessment: "Question 3a: Use what you know about the properties of acids and the data in the table above to develop a model of the behavior of each acid when dissolved in water. Be sure to include a key for your models", and "Question 3b: Use your models to briefly explain how the two acids are behaving differently from each other in water" (C.4 Lesson 7 Assessment Acid Behavior Assessment, pages 1–2). Students' models are revised to account for the behavior of acids in water and how differences in dissociation leads to differing changes in pH. Connections between those changes and subsequent changes in the oysters' environments are continuing to be developed in this and subsequent lessons.
  - Lesson 15: The following prompts are found in the assessment for this lesson: "2a. Choose one of these strategies (a or b) and develop a model to illustrate how components in the system would lead to an increase in the reaction rate", and "2b. Briefly explain what your model is showing. Use what you have figured out in this unit about reaction rates to support your explanation" (C.4 Lesson 15 Assessment Ammonia Fertilizer Production, page 2).
- *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 6: The "Supporting Students in Engaging in Developing and Using Models" box states, "The idea of using multiple mental models to make predictions about the same reaction may be new to students. Remind them that the more independent ways we can arrive at the same prediction, the more confident we can be that our prediction is accurate" (Teacher Edition, page 122).
- Lesson 6: Students discuss how a computer simulation may help to provide them with the evidence they need to explain why the color turned back in their investigation. The following statement is provided on the slide used for this discussion: "When scientists and engineers want to explore the mechanisms, interactions, and outcomes in a system at a small scale they sometimes develop a computer simulation of that system" (C.4 Lesson 6 Slides, Slide H). Students engage in a discussion about what parts and interactions would need to be included in the simulation. Students then use the computer simulation to design and carry out an investigation to gather evidence for why the color change occurred. Students then look at bond strength data of acids and bases to further their understanding of why some reactions are more reversible than others. However, it is not clear that this requires the use of a second model and is instead just adding additional data analysis to help explain the results of the initial model. The materials reference the use of multiple mental models. "Also push students to provide as many pieces of evidence as possible, since that can reveal whether they are relying on one mental model or have started to build connections between the different concepts of reversibility, bond strength, pH, weak or strong nomenclature, and stability" (Teacher Edition, page 124). However, it appears as if students are connecting various scientific concepts to explain an idea rather than using multiple models.
- Lesson 10: Students use a marble chips demonstration to simulate what would happen to oyster shells in an ocean. Students are provided with a handout and asked to complete a table with the following headings: "What represents oyster shells in this investigation?", and "What represents ocean water in this investigation?" After carrying out the demonstration, students discuss their observations. After seeing that the marble chips do not change when in the same pH as ocean water, students conduct a reading and then are asked to construct a shell building model. "Integrate key ideas from the reading into a model. Display slide N. Distribute Shell-Building Model to each student. Say, What happens when an oyster is building its shell in an acidified environment? Let's try to model this process. To do this, make sure your model includes the following components: Chemical formation of CaCO; Where materials to build the shell come from; and How increased acidity interferes with the shell-building process. Suggest that students think about the last bullet point from both a matter and forces perspective. Reference the M-E-F triangle. Point out the provided data and list of ions in Shell-Building Model to support students with their modeling. Give students the rest of the class period to work on the model independently, and let them know they will start class the next day by sharing their models" (Teacher Edition, page 188). Students then add this learning to their class consensus model. While students do use multiple models in the lesson, they do not move flexibly between model types based on merits and limitations.

- *Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems.*
  - Lesson 6: "Plan investigations with a partner. Show slide L. Distribute NetLogo Investigation. Give students eight minutes to work with a partner to plan their investigation using prompts #1-4 on NetLogo Investigation. As students plan, ask them

what they expect to happen when they make a change in the simulation. Students who think the CO_2 is coming out of the water should say that they will lower the CO_2 concentration and see that there is less H+. Students who think the reaction is going backward should say that if they start with no or very little CO_2 (because it all reacted), then the reaction will actually go backward and form CO_2 again. Once students have a hypothesis and ideas about what will occur, give them permission to begin their investigation" (Teacher Edition, page 116).

- Lesson 6: The "Supporting Students in Engaging in Developing and Using Models" box states, "The key idea here is that students are using evidence from the simulation (computational model) to explain how the color change occurred. Push students to share this part of their thinking with their peers" (Teacher Edition, page 116).
- Lesson 10: In the **Supporting Students in Engaging in Developing and Using Models** box, "In order to meet high school standards for modeling, students must use mathematical thinking (ratios) to generate data to support their explanation and analyze the changes in the system. In this activity, look for students to physically move around charged particle cards so that the positives and negatives match up differently before and after the water becomes more acidic. Students should use the cards as evidence that the ratio of available calcium is lower because the H ions 'grab' it before it can be made into shells" (Teacher Edition, page 188). While this model is explanatory based upon the data provided, it does not appear to generate data itself which can be used to support explanations.

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.*
    - Lesson 3: The following guidance is provided in the "What to look/listen for in the moment" section of the assessment opportunity box: "Students' investigation plan ensures that variables are controlled so that the empirical evidence collected can be used to evaluate a claim" (Teacher Edition, page 65). In addition, the following prompts are provided to students: "Identify which solution(s) are the: variables and control(s)" (C.4 Lesson 3 Slides, Slide F). However, there is no specific guidance provided to students to ensure confounded variables and effects are considered.
    - Lesson 3: Students collect data from a series of investigations in which the identified phenomenon and sub-phenomena will become progressively better explained and models revised to reflect their knowledge at each point in time. The "Supporting Students in Engaging in Planning and Carrying Out Investigations" box states, "Since models are used to explain a range of phenomena, students will refer back to this list of related phenomena throughout the unit to help them generalize the model(s) they are developing. As students suggest ideas, press them to explain how they are related. This will help students expand their thinking beyond the individual components to the relationships and processes that will be developed in the model" (Teacher Edition, page 64).
    - Lesson 11: The "Supporting Students in Engaging in Planning and Carrying Out Investigations" box states, "Students develop hypotheses in this lesson as a way to make predictions about how their factor will influence reaction rate. They also gain experience with how scientists work to gather evidence for their hypotheses, sometimes figuring

out how something does not work and eliminating those hypotheses. Point this out to students to prevent frustration with the 'extra step' of predicting what will happen and during the investigation if the process is not working as students anticipated" (Teacher Edition, page 209). In addition, guiding questions are provided to assist students with planning the investigation. For example, "How will we control for possible confounding variables? Confounding variables are any other possible factors that you want to keep constant so you know they are not affecting your results. For example, how can you make sure increasing the concentration is not affected by big clumps of reactant?" (C.4 Lesson 11 Handout Shell-Building Lab Planner, page 2).

- *Select appropriate tools to collect, record, analyze, and evaluate data.*
    - Lesson 5: Students annotate [material: **CC.L5.HO1**] using additional investigative tools and develop a data table to appropriately evaluate the data (Lesson 5 Handout Evaluate Investigation Data).
    - Lesson 5: Students evaluate the best way to measure pH of the solution in their small-scale model. Students are also asked to develop a data table for the investigation. "Draft a data table for the investigation. Show slide G. Explain to students that before we conduct the investigation, it is necessary to clarify how we will collect and evaluate our observations. Say, We want to have a data table that outlines the changes we think we will see and gives us a way to record these changes over the course of the investigation. Give groups 4 minutes to draft a data table in their science notebooks. See examples of student data tables" (Teacher Edition, page 95). Students are asked to use this data to connect the results from their small-scale investigation to make data-informed predictions about the extent that the same, observed, mechanisms are also at play in the ocean itself.
- *Manipulate variables and collect data about a complex model of a proposed process or system to identify failure points or improve performance relative to criteria for success or other variables.*
    - Lesson 8: Students begin by conducting an investigation using their working idea that a balanced chemical equation is based upon proportional masses rather than a mole ratio. After collecting data that conflicts with their initial predictions, the teacher will lead students in a discussion about "...the discrepant results. Display slide R. Ask students what ideas they have to explain their unexpected results. Facilitate a Building Understanding discussion using the prompts below to help students realize that the 2:1 ratio must not be a mass ratio" (Teacher Edition, page 151). Following this conversation, students brainstorm ideas to reconsider the relative masses used in their investigation based on a modified understanding of their model of a balanced chemical equation.
    - Lesson 8: After going back to re-attempt the neutralization reactions, "Students should get a final pH close to neutral, but it may not be exactly neutral. If students do not get a neutral pH, this is a good time to discuss possible sources of error in their investigation. Students may bring up that oxalic is a weak acid, which they saw in the previous lesson. If so, ask what they remember about how weak acids behave--they should remember that weak acids do not completely dissociate or ionize in solution the way strong acids do" (Teacher Edition, page 160).

Using Mathematics and Computational Thinking (Focus SEP)

- *Create and/or revise a computational model or simulation of a phenomenon, designed device, process, or system.*
    - This element is claimed as a focus element in the unit but does not appear on the C.4 Teacher Edition or C.4 Elements of NGSS Dimensions documents.

  - In Lessons 8 and 9, students use balanced chemical equations to determine the ratios needed to neutralize an acid as a possible solution to the problem of ocean acidification. Students conduct investigations to determine what the coefficients in the chemical equations mean to revise their thinking. However, students do not create or revise the model itself.
- *Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations.*
  - This element is claimed as a focus element in the unit.
  - Lesson 4: The "Supporting Students in Engaging in Using Mathematics and Computational Thinking" box states, "There are multiple experiences that students have had in the course up to this point that will help them make a reasonable estimate of the quantity of molecules being in the many billions: Students have seen standard notation used to represent the number of H and OH ions in 3mL of water at different pH values and likely will have noted numbers of particles that exceed a billion for many pH values. Students calculated the number of charges (e.g., electrons) they accumulated on a surface in Electrostatics Unit and determined that it was in the billions. And students have worked with scientific notation to represent numbers much larger than a billion in two prior units of study: Polar Ice Unit and Electrostatics Unit". This is initially developed through the introductions of students to the use of Avogadro's Number as a conversion factor that could be used to interpret and analyze experimental data. For example, "Consider quantities in the system. Display slide G. Hold up the container with solution (A) in it. Remind students that you added 60 g of solid acetic acid to the water to make this solution. Read the question on the slide for the poll and the four possible responses. Take the poll. Most students will select option 4) many, many billions. Suggest that we compare the number of molecules of the substance that we added to solution A, to the number of molecules of the same substance that we added to solution B, which had only 6 g of solid acetic acid added to it" (Teacher Edition, page 79).
  - Lesson 8: In the **Supporting Students in Engaging in Using Mathematics and Computational Thinking** box, "Remind students that they have practiced tracking matter through a chemical reaction because they balanced chemical equations to ensure the conservation of matter in Lesson Set 3 of Space Survival Unit." This is further used as students are asked to balance a chemical equation to show the mole ratios for the neutralization of carbonic acid with NaOH as a potential reaction that could be used to solve the issue of increased ocean acidity (Teacher Edition, page 147).
  - Lesson 9: In the **Supporting Students in Engaging in Using Mathematics and Computational Thinking** box, "Mathematical thinking requires not just that students can 'plug and chug' through decontextualized procedures. Students should also be able to compare and evaluate others' ideas. Asking students to share their mathematical thinking and practices builds a culture of figuring out that regards math as a social, 3 dimensional tool, as reflected in A Framework for K–12 Science Education: 'mathematics and computation are fundamental tools for recognizing, expressing, and applying quantitative relationships' (2013, p.51). Avoid using stoichiometry as a rote, decontextualized mathematical task" (Teacher Edition, page 168). Students are asked to calculate moles and molarity of hydrogen ions as a precursor to determining the amount of sodium hydroxide that would need to be added to solve this problem (Teacher Edition, page 170).
  - Lesson 13: Students are asked to quantify their approach to solving the problem of oyster die offs. "They should be as specific and thorough as possible, and quantify their

solutions and impacts where appropriate. For example, if students want to raise the pH of water tanks at an oyster hatchery, they will need to use volume and pH to calculate a specific quantity of the substance to be used. Students need to explain how that substance will help them achieve their goal. Encourage students to use the class consensus model and/or models from individual lessons to help them predict the impacts of their solutions" (Teacher Edition, page 241).

- Lesson 13: Students are asked to quantify their criteria and constraints. As part of their solution design, students are asked the following: "What are the intended effects of the change? Use our class consensus model or individual models you have developed to help think about how your solution will impact people and ecosystems. Use calculations as needed to support your answer" (C.4 Lesson 13 Handout Solution Planning Document, page 3).
- Lesson 15: The following instructions are found on the summative assessment: "3a. A small ammonia plant uses 118,000 g of H gas per day. Determine the mass of CO (in g) that will be released as the H is produced. Show all work", "3b. To produce that much H, the system requires an input of 14,600 mol of CH. What is the mass (in g) of this amount of CH?", "3c. Use any of the information provided so far to determine the mass (in g) of HO required to produce 118,000 g of H", and "3d. Is this a significantly large amount? Explain how your solutions to 3a-3c show how atoms (and therefore mass) are conserved during the chemical reaction CH + 2HO → CO + 4H. Remember that since you are working with fairly large numbers, rounding may have affected how 'exact' your solutions were" (C.4 Lesson 15 Assessment Ammonia Fertilizer Production, page 3).

- *Apply ratios, rates, percentages, and unit conversions in the context of complicated measurement problems involving quantities with derived or compound units (such as mg/mL, kg/m3, acre-feet, etc.).*
  - This element is claimed as a focus element in the unit.
  - Lesson 4: Students are introduced to the idea of concentration. "Emphasize that this mathematical thinking involves scaling up or down the amounts of ingredients used to ensure that the ratios of those ingredients stay the same, and for the examples we considered, that the concentration of molecules in the liquid is the same no matter how much of the mixture is made. Say something like, Scientists have ways of measuring, describing, and keeping track of the concentration of different solutions to ensure fairer comparisons between them, by referring to the number of molecules of a substance they are adding to water when they make a solution. Let's consider the sorts of scales and ratios we will be using when we talk about the numbers of particles in a system, like solutions (a) and (b) that we just made" (Teacher Edition, page 78). Students are then introduced to the concept of a mole and molarity. The following teacher prompt is then provided: "Ask students how the molarities that we see in the fourth row of the table help us determine which solutions have lower concentrations of acetic acid molecules and which solutions have the same concentration" (Teacher Edition, page 79).
  - Lesson 8: The "Supporting Students in Engaging in Using Mathematics and Computational Thinking" box states, "Students may also need support in thinking through ratios to argue that the 2:1 mass ratio is something to try. Have students show their ideas to a partner and ask students to come to the board to show their thinking. Calculating these ratios is a secondary skill compared to being able to understand the mathematical meaning of the value of 'mass ratio' and use of this data as a 'recipe' for neutralization of acids" (Teacher Edition, page 143).

- Lesson 8: Students are asked to "Relate atomic mass to molar mass and reintroduce moles. Tell students, We know from the periodic table that the mass ratio of oxygen to hydrogen is 32 to 2 or 16 to 1. As long as we have the same number of particles of each molecule, we should always have the same mass ratio of 16 to 1. Scientists have a way to use this to 'count' and keep track of the very large numbers of particles found in just a few grams of any substance. It is called a mole." The "Supporting Students in Engaging in Using Mathematics and Computational Thinking" box states, "Unit conversions, especially with moles, are not intuitive for many students. Students may want to work together on these calculations, and students may need to see an extra example or use scaffolds. It is important to emphasize that the conversion factors students are using, such as g/mol, are really fractions equal to one, and students are using equivalent values to get to a unit they can measure" (Teacher Edition, page 155).
- Lesson 9: The "Supporting Students in Engaging in Using Mathematics and Computational Thinking" box states, "Students will use unit conversions to calculate the mass of NaOH needed to neutralize a specific number of moles of H_2. They also need to be able to use and understand the mole ratio, and that acidic hydrogen and basic hydroxide will combine 1:1 to form neutral water. The final calculated mass of NaOH will be very small. If students are confused by this result, a review of scientific notation or encouraging students to convert scientific notation to standard notation should help them understand why. The scaffolding for SEP 5 has been reduced gradually in questions 4 and 5 of Ocean Water Calculations to support students in independent use. This scaffolding is reduced even further in question 6" (Teacher Edition, page 170).
- Lesson 11: "Plan the investigation. Pass out Shell-Building Lab Planner and show slide H. First, groups must do some stoichiometry to figure out the quantities of Na_2CO_3 that they will need." In the **Supporting Students in Engaging in Using Mathematics and Computational Thinking** box, "Students have to use ratio thinking and mathematical tools developed in Lessons 8 & 9 to determine how to proceed with this experiment" (Teacher Edition, page 208).

Constructing Explanations and Designing Solutions

- *Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects.*
  - Lesson 15: "In the assessment, students apply particle-level thinking and how variables affect reversible reactions to develop an explanation for how a strategy would change the rate of reaction of the Haber-Bosch process" (C.4 Elements of NGSS Dimensions). Students do not actively pursue uncovering of unanticipated effects of their solutions nor is this developed throughout this unit, only partially used in this assessment.
- *Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations*.
  - Lesson 13: Students design solutions to help mitigate the impacts of ocean acidification on oysters, using skills and knowledge acquired from previous lessons and agreed-upon quantified criteria and constraints. "Quantify criteria and constraints. As groups work, circulate and check in. Remind students that the more specific their criteria and constraints are, the more useful they will be in developing a solution. Students should quantify criteria and constraints wherever possible" (Teacher Edition, page 240).
  - Lesson 13: "Use the Solution Planning Document to develop the solution. Tell students, Now that we have more specific criteria and constraints and know more about these

locations, let's try to build some solutions and figure out just how we might impact these ecosystems. Display slide G and distribute Solution Planning Document to students. Groups should work together to answer the questions on Solution Planning Document. They should be as specific and thorough as possible, and quantify their solutions and impacts where appropriate. For example, if students want to raise the pH of water tanks at an oyster hatchery, they will need to use volume and pH to calculate a specific quantity of the substance to be used. Students need to explain how that substance will help them achieve their goal. Encourage students to use the class consensus model and/or models from individual lessons to help them predict the impacts of their solutions" (Teacher Edition, page 248).

    - Lesson 14: Students present their solution to another group and receive and provide feedback. Students explore tradeoff considerations when they reflect on how different groups categorized priorities. This feedback is then used to begin thinking about how to refine their solution.

Engaging in Argument From Evidence

- *Compare and evaluate competing arguments or design solutions in light of currently accepted explanations, new evidence, limitations (e.g., trade-offs), constraints, and ethical issues.*
    - Lesson 14: Students evaluate each other's solutions. Guiding questions for feedback are listed in guiding questions for discussion. "Introduce the gallery walk. Display slide M and ask students to make a note-taking guide in their science notebooks. Explain that they will use these notes to identify how the groups used chemistry and Earth science ideas to help the oysters. Display slide N and keep it visible during the gallery walk. Encourage students to pay attention to the different scales of the design solutions by asking them to think about the prompt questions. How are others' solutions based on evidence, criteria, and tradeoffs? How are we engineering chemical interactions in our world's atmosphere and hydrosphere? What is the impact at different orders of magnitude (molecules > earth systems)? How long will these solutions take? Facilitate the gallery walk. Ask students to circulate silently through the room as they view each other's design solution posters. Provide students with approximately ten minutes to view all of the posters and make notes in their science notebook. After students have completed the gallery walk, say, Look at all of the different ways we can use chemistry to help the oysters! Let's think more about how all of these pieces fit together" (Teacher Edition, page 257). However, ethical issues are not necessarily a lens in the comparison of design solutions.
- *Construct, use, and/or present an oral and written argument or counter-arguments based on data and evidence.*
    - Lesson 6: The "Supporting Students in Engaging in Argument from Evidence" box states, "Push students to provide evidence for their ideas using prompts like, What makes you think that? and What can we observe that supports your idea? Encourage students to offer counter-arguments by asking questions like, How does your idea explain the evidence better than the other ideas that have been shared? This should help narrow down the ideas on the table to only those that are supported by what students can see at the visible scale" (Teacher Edition, page 113).
- *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.*
    - Lesson 15: While this SEP element is claimed in the materials for this lesson, there's no evidence that students develop the element. The only use of the element is found in the

assessment in which students use their knowledge to "defend a claim of how to prioritize criteria for a design solution for changing conditions under which a fertilizer plant operates" (C.4 Elements of NGSS Dimensions, page 4).

- *Evaluate competing design solutions to a real-world problem based on scientific ideas and principles, empirical evidence, and/or logical arguments regarding relevant factors (e.g., economic, societal, environmental, ethical considerations).*
    - Lesson 2: Students begin the use of a Progress Tracker to identify the subproblems they have identified as a class. The following teacher guidance is provided: "Progress Tracker is designed to guide students through the engineering design process. It focuses on the main subproblems identified in Lesson 2, and asks students to separately record the science ideas they figure out, how they might apply those ideas, and the criteria and constraints that impact how they apply those ideas. As students return to the Progress Tracker, prompt them to consider the interrelation of these columns, and how all subproblems are important to investigate in order to design solutions that address the large, complex problem identified in the Anchoring Phenomenon Routine. Example Progress Tracker offers some possible ideas students will have added to their Progress Trackers by Lesson 12. This also provides an opportunity to remind students that there are many ways to solve big problems, and that it is important to learn as much as we can about the problem, the people affected by it, and the people working on it, to make sure we can design solutions that do not further harm those who are already marginalized" (Teacher Edition, page 53). Students build initial arguments for which subproblem to focus on next given what they have discussed throughout the lesson. However, the focus is on subproblems and not competing solutions.
    - Lesson 2: "While SEP element 7.6 focuses on evaluating competing design solutions, we use this lesson to evaluate competing larger-scale solutions (meta-strategies) for large-scale earth system problems. These include breaking large problems into subproblems, prioritizing the subproblems that are investigable in our context, and arguing for a dual science and engineering approach to such problems, rather than a science-only or engineering-only approach. This is an important connection to the nature of science as a human endeavor (subsumed within the crosscutting concepts)" (Teacher Edition, page 53). This element is not developed further and does not appear to be sufficiently addressed within this lesson as the focus is on breaking larger problems into sub-problems and not the substance of the claimed criteria itself.

Obtaining, Evaluating, and Communicating Information

- *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 3: Students complete a reading about pH and then analyze ocean pH data. Students use information from both sources to formulate an answer to the question "What do pH values tell us about patterns of H+ ions?" (C.4 Lesson 3 Handout Connect, Extend, Question, page 1). In a class discussion, students then extend the discussion to connect their lab data. "Ask, How do these ideas connect back to our investigation data? What new ideas from the reading or website can help us make sense of some of the differences in pH we measured?" (Teacher Edition, page 68).

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 there are sufficient DCI elements used throughout the materials and there is somewhat of a match between elements claimed and used. However, there is some mismatch between claimed ESS elements and evidence of their development and use.

PS1.B Chemical Reactions (Focus DCI)

- *Substances react chemically in characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants.*
    - Lesson 5: While this Grade 6–8 element is claimed in the materials, evidence of its use is not found in the lesson.
- *Chemical processes, their rates, ~~and whether or not energy is stored or released~~ can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, ~~with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy~~. (**PS1.B.1**)*
    - Lesson 7: The following questions are asked on the assessment: “Question 3a: Use what you know about the properties of acids and the data in the table above to develop a model of the behavior of each acid when dissolved in water. Be sure to include a key for your models”, and “Question 3b: Use your models to briefly explain how the two acids are behaving differently from each other in water” (C.4 Lesson 7 Assessment Acid Behavior Assessment, pages 1–2).
    - Lesson 11: Students develop investigation plans relating to the impact that temperature or concentration have on the rate of reaction. Teachers are reminded that “If student plans do not include measurement of a specific variable, take them back to the original problem of oysters building shells in a short time and ask students to think about how we could measure if the shell is being built fast enough. Encourage students to think about time in particular, as the amount of product must be estimated visually unless a significant amount of time is added to filter and dry products. Also ensure that students are able to make a prediction–if they are able to make a prediction about what they will measure, that means their investigation should be able to get meaningful results that can be applied to the greater problem” (Teacher Edition, page 209). Later, the collected data is analyzed and used to develop an explanation in which teachers might expect students to say, “when the concentration is increased, reactant particles hit each other more often...[or] when particles hit harder or more often, bonds are more likely to break and re-form, which means the reaction is happening more quickly” (Teacher Edition, page 212).
    - Lesson 11: In their notebooks, students are asked to write a draft explanation to the question “What was happening at the particle level that caused our group’s factor (temperature or concentration) to increase the reaction rate?” (C.4 Lesson 11 Slides, Slide L). Students then work together to develop a group explanation.
    - Lesson 11: “Purpose of this discussion: Here students need to think specifically about how particles are interacting in these different situations. Students should progress toward the conclusion that reactions can actually go faster when there are more opportunities for particles to break old bonds and form new ones. Listen for these ideas: When we increased temperature or concentration, more calcium carbonate was formed in less time. When the temperature is increased, particles move faster so they can hit each other harder and more often. When the concentration is increased, reactant particles hit each other more often. When particles hit harder or more often, bonds are

more likely to break and re-form, which means the reaction is happening more quickly" (Teacher Edition, page 212).

- Lesson 15: The following prompts are on the summative assessment: "1. Choose one of these strategies (a or b) and develop a particle-level explanation of how the strategy would lead to a shift in the equilibrium of the reaction so that more NH is produced. Use what you have figured out in this unit about reversible reactions as evidence to support your explanation", and "2a. Choose one of these strategies (a or b) and develop a model to illustrate how components in the system would lead to an increase in the reaction rate", and "2b. Briefly explain what your model is showing. Use what you have figured out in this unit about reaction rates to support your explanation" (C.4 Lesson 15 Assessment Ammonia Fertilizer Production, pages 1 and 2).

- *In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present.*
  - Lesson 3: "Ask, How do these ideas connect back to our investigation data? What new ideas from the reading or website can help us make sense of some of the differences in pH we measured? Look for students to suggest: Because there was a change in the pH of the carbonated water, that means something happened to release a lot of hydrogen ions into the solution. There are fewer hydrogen ions in the 'flat' carbonated water, so something is happening such that as carbon dioxide leaves the solution, the hydrogen ions that were present are no longer there" (Teacher Edition, page 75).
  - Lesson 4: While this DCI element is claimed in the lesson, no evidence of its development or use was found.
  - Lesson 6: "Plan investigations with a partner. Show slide L. Distribute NetLogo Investigation. Give students eight minutes to work with a partner to plan their investigation using prompts #1-4 on NetLogo Investigation. As students plan, ask them what they expect to happen when they make a change in the simulation. Students who think the CO is coming out of the water should say that they will lower the CO concentration and see that there is less H. Students who think the reaction is going backward should say that if they start with no or very little CO (because it all reacted), then the reaction will actually go backward and form CO again. Once students have a hypothesis and ideas about what will occur, give them permission to begin their investigation. Investigate using the simulation. Show slide M. Give groups 10 minutes to investigate using the simulation. Remind students to record observations and data using prompts #5-7 on NetLogo Investigation. Students may also choose to record data in their science notebooks" (Teacher Edition, page 117).
  - Lesson 7: The following directives are on the assessment: "Question 3a: Use what you know about the properties of acids and the data in the table above to develop a model of the behavior of each acid when dissolved in water. Be sure to include a key for your models", and "Question 3b: Use your models to briefly explain how the two acids are behaving differently from each other in water" (C.4 Lesson 7 Assessment Acid Behavior Assessment, pages 1–2).
  - Lesson 10: Students are asked to synthesize their learning about how oysters build their shells using aqueous calcium and carbonate ions. They are asked to "Integrate key ideas from the reading into a model. Display slide N. Distribute Shell-Building Model to each student. Say, What happens when an oyster is building its shell in an acidified environment? Let's try to model this process. To do this, make sure your model includes the following components: Chemical formation of $CaCO_3$; Where materials to build the shell come from; and How increased acidity interferes with the shell-building process.

Suggest that students think about the last bullet point from both a matter and forces perspective. Reference the M-E-F triangle" (Teacher Edition, page 188). Students come to understand that the reverse reaction, influenced by a loss of carbonate ions can also result in a loss of calcium carbonate.

- Lesson 11: Teacher asks students "Adding a substance to one side of a reversible reaction causes the reaction to move the other way. Why is this?" (Teacher Edition, page 218).
- Lesson 15: The following directive is on the summative assessment: "1. Choose one of these strategies (a or b) and develop a particle-level explanation of how the strategy would lead to a shift in the equilibrium of the reaction so that more NH is produced. Use what you have figured out in this unit about reversible reactions as evidence to support your explanation" (C.4 Lesson 15 Assessment Ammonia Fertilizer Production, page 1).

- *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: While this DCI element is claimed in this lesson, evidence of its development or use were not found.
    - Lesson 4: "Use manipulatives to refine ideas. Organize students into groups of five. Motivate how using manipulatives to try to explain this kind of phenomenon might help further refine our ideas. Say something like, It is sometimes hard to picture the results of different force interactions that might be going on between particles without being able to move them around in the system. Let's get ready to use some manipulatives to make our thinking visible. This will help us further refine our ideas with other members of our group. Display slide Q. Distribute the prepared card decks along with an additional copy of Molecule Deck to each group. Give students six more minutes to work with these manipulatives in their group" (Teacher Edition, page 81). As students use the manipulatives, they are expected to illustrate the dissociation of acidic H+ results in the same total number of atoms. For example, students might recognize that "When molecules of an acid dissolve, some of them must break into a H+ ion and a negative ion containing the remaining atoms in the original substance" (Teachers Edition, page 82).
    - Lesson 8: Students work to balance the equation in which Carbonic Acid in the ocean could be neutralized by adding NaOH. "Balance the equation. Say, We know CO in the ocean makes the acid H CO , and we think we can neutralize it with a base such as NaOH. Display slide K and ask, But how much NaOH would we need to neutralize HCO? And does this equation account for conservation of mass? Give students more time to balance the reaction, and tell them that it may help us think about how much base we would need to neutralize an acid. As students realize they have different amounts of some elements on the two sides of the equation, remind them that they can only add coefficients or add an entire second formula to balance and that changing subscripts will change the identity of the compound. Students should realize that they would need to start with two NaOH in order for the equation to be balanced. And this would also impact the amount of water on the products side, so the final balanced equation should be: $H_2CO_3 + 2NaOH \rightarrow 2H_2O + Na_2CO_3$" (Teacher Edition, pages 147–148).
    - Lesson 9: "Calculate the mass of sodium hydroxide needed. Remind students that we are getting the hydroxide from sodium hydroxide, so when we measure it we need to account for all of those atoms in the base. Ask students how we got the molar mass of NaOH last class. Have them recalculate or find the molar mass in their notebooks and then use the molar mass of NaOH as the conversion factor to calculate the mass of

NaOH needed to neutralize the calculated moles of H on question 5 of Ocean Water Calculations. Have them check with a partner as needed" (Teacher Edition, page 176).

- Lesson 9: "Discuss neutralizing the entire ocean. Now that students have calculated the mass of NaOH needed for both an oyster tank and for the entire ocean, ask students how these two systems might differ other than just their size. Display slide O. Encourage students to refer back to what they figured out in Lesson 5 and to think about how the proposed changes would impact the ocean-atmosphere system for a minute before responding" (Teacher Edition, page 181).
- Lesson 15: The following questions are found on the district summative assessment: "3b. To produce that much H, the system requires an input of 14,600 mol of CH . What is the mass (in g) of this amount of CH ?", "3c. Use any of the information provided so far to determine the mass (in g) of H O required to produce 118,000 g of H", and "3d. Is this a significantly large amount? Explain how your solutions to 3a-3c show how atoms (and therefore mass) are conserved during the chemical reaction CH + 2H O → CO + 4H . Remember that since you are working with fairly large numbers, rounding may have affected how 'exact' your solutions were" (C.4 Lesson 15 Assessment Ammonia Fertilizer Production, page 3).

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 5*:* Students conduct an investigation to determine what happens when carbon dioxide gets into water. The following teacher prompts are provided during a discussion of how the carbon dioxide is transferred throughout the ocean: *"*In what part of our small-scale system did we see evidence of increased H ion concentration?", "What mechanisms might cause these ions to be transferred to other parts of an ocean?", and "Could these ions be transferred from one ocean to another? Why or why not?" (Teacher Edition, page 97).

ESS2.D Weather and Climate

- *Changes in the atmosphere due to human activity have increased carbon dioxide concentrations ~~and thus affect climate~~.*
    - Lesson 1: Students analyze data related to carbon dioxide as one of the possible causes of oyster die-offs. While this specific data is only looked at by some students, students engage in discussions about all possible causes as a class. The following sample student response is provided in relation to this discussion: "CO_2 is going up in the atmosphere. It might be a possibility that some gets into the ocean, although there does not seem to be anything special about carbon dioxide in the Pacific Northwest" (Teacher Edition, page 37).
    - Lesson 3: Students conduct an investigation to collect evidence to see that carbon dioxide affects pH levels. Students then analyze data from ocean pH levels to see how they have changed over time. However, at this point a direct connection between rising carbon dioxide levels and the increase in ocean acidity is not made.
    - Lesson 5: Students are asked to reflect on the data provided on the "carbon data" sheet to explain how atmospheric carbon dioxide has changed over time as well as how that's

aligned with changes to the ocean carbon dioxide level. "Purpose of this discussion: Build understanding around what the data represent in terms of the movement of carbon among Earth's spheres. Listen for these ideas: Figure 1 and Figure 2 support our investigation data because they show that an increased concentration of CO2 in the atmosphere can lead to an increased concentration in water. Table 1 shows that CO2 has moved from the atmosphere to the ocean. Figure 1: Atmospheric CO2 levels have always varied throughout Earth's geologic history but never went above 300 ppm until recent history (1960s). Figure 2: Amounts of dissolved CO2 in water off of Hawaii have increased at a similar rate to atmospheric CO2 levels shown in Figure 1. Figure 3: Most of the global greenhouse gas emissions are due to energy production, which includes transportation, industry, and use in buildings. Figure 4: Some countries emit more CO2 than others, and these tend to be the more developed countries. Table 1: CO2 has moved from the atmosphere to the hydrosphere and biosphere. CO has also moved from the geosphere to the atmosphere" (Teacher Edition, page 100).

- Lesson 10: Students discuss where the carbonate in the water must have come from and update their carbon cycle model.
- Lesson 14: Students participate in a class consensus discussion to discuss how their design solutions use knowledge of chemistry and Earth Science. "Purpose of this discussion: To come to a consensus on the chemistry and Earth systems ideas present in the design solutions and to decide on the changes that occur at different timescales. Listen for these ideas: Carbon dioxide reacts with water to form carbonic acid. This is a reversible reaction. We can use our understanding of acids, bases, and neutralization to raise the pH of ocean water. According to stoichiometric calculations, it is reasonable to add compound to a small volume of water, like holding tanks, but not to the entire ocean. Carbon cycles between the geosphere, hydrosphere, biosphere, and atmosphere. When too much carbon is entering the hydrosphere from the atmosphere, we can try to move carbon into the biosphere (i.e., plants) or try to reduce the amount of carbon in the atmosphere. It takes a long time for carbon to move from the hydrosphere to the geosphere through natural processes, so a solution needs to remove carbon more quickly. Shell formation requires calcium carbonate, and adding more calcium and carbonate ions to the water can help strong shells form. We can use what we know about reaction rates to make that reaction happen more quickly or slowly. Different contexts require different engineering design solutions based on the specific needs of local interested parties. Some solutions may affect a small population of oysters, while others may change the conditions in a larger region" (Teacher Edition, page 258). While the movement of carbon is addressed, specific references to human activity are not elicited.

ESS3.C Earth and Human Activity

- *Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation.*
  - Lesson 12: Students develop solutions to address issues of ocean acidification that cause oyster die-offs, some of which can include, "Plant kelp or other aquatic plants to pull carbon dioxide from the water and increase pH. Add limestone or other carbonate sources to the water to increase carbonate ion concentration and support shell building. Add a base to the water to increase pH. Organize for laws or policies that limit the burning of fossil fuels and prevent ocean acidification at its source" (Teacher Edition, page 226). However, these solutions are not focused on producing less pollution or

waste. The DCI from **ETS1.A** included a strike-out of text relating to the production of pollution and its impact on ecosystems, but that strike-out is not present for this DCI.

- Lesson 13: Students develop a solution to the problem of oyster die-off. However, these solutions are not focused on those that produce less pollution and waste and that preclude ecosystem degradation. The following teacher prompt is provided as students develop their posters: "Students create posters of their solutions. Display slide J. Frame the work in terms of science and engineering: Scientists are key to developing contributions through technologies that produce less ecosystem degradation" (Teacher Edition, page 244). While this does inform students of the practice, no further development is provided. However, the assessment opportunity box provides the following: "What to look for", and "Students articulate that the chemistry of the atmosphere & hydrosphere has changed with CO2 production and it can be reduced through human activity" (Teacher Edition, page 259).

ETS1.A Defining and Delimiting Engineering Problems

- *Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them.*
  - Lesson 7: "Display slide F. Say, If we are going to try to develop solutions to the oyster problem, we should probably also consult with people who have already been working on this issue and who are affected by the problem–the interested parties. How might thinking about perspectives and ideas from various interested parties help us develop criteria and constraints? Look for students to mention: If we consult with various interested parties we will have criteria and constraints that cover a wider range of concerns. If our criteria and constraints are more fleshed out by seeing what multiple interested parties have to say, our solutions are more likely to be effective for multiple interested parties, rather than just considering one perspective." Later, the following guidance is provided: "The readings in this jigsaw are strategically written to emphasize varying scale and location, and to motivate the quantification questions that begin Lesson Set 2. Since the readings emphasize different interested parties, it is expected that students will have different initial criteria. When they come together in their home groups, this provides an opportunity to discuss the challenges of trade-offs and prioritizing the needs of multiple interested parties" (Teacher Edition, page 139).
  - Lesson 13: "Use site data to refine criteria and constraints. Ask students, Now that we know a little more about some places where oysters are cultivated, can we refine our criteria and constraints from last class based on these site profiles? Display slide D and distribute Solution Planning Document to students. Have students work in their groups and use the site profiles and their initial solutions to develop a more specific list of criteria and constraints. Students should record their ideas in the first section of Solution Planning Document. The prompts below can be used as a whole-class discussion to get groups started, or as a check-in with individual groups who may be struggling with this step in the lesson. If students are struggling to come up with criteria or constraints, encourage them to think about the specific site they are focusing on. Have them think about what people in that location are already doing and what limitations they may face" (Teacher Edition, page 246).
- *Humanity faces major global challenges today, ~~such as the need for supplies of clean water and food or for energy sources that minimize pollution~~, some of which can be addressed through engineering. These global challenges also may have manifestations in local ~~communities~~.*

- Lesson 2: Students begin looking at the problem of oyster die-off caused by ocean acidification and break it into smaller subproblems that they might be able to address. Ocean acidification is discussed in a local context. However, it's not clear if students are able to connect this local problem to a global challenge as discussed in the element.

ETS1.B Developing Possible Solutions

- *When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts.*
  - Lesson 12: Student discussion is facilitated around criteria and constraints. "This discussion should attend to reliability, safety, and cost. Consider asking about these ideas directly. Students may also bring up aesthetics, which are part of the cultural significance of oyster -- their shells are beautiful and part of many indigenous jewelry and clothing traditions" (Teacher Edition, page 227). The discussion also includes questions about "What criteria and constraints are important to the various interested parties who are most impacted by this problem? Where might there be contradictions or conflict between interested parties' criteria? Whose perspectives are we missing?" (Teacher Edition, page 228).
  - Lesson 12: "If students are struggling to articulate how criteria and constraints might be interrelated, contradictory, or contextual, refer back to the Lesson 7 readings Poultry Farmers, Northwest Indian Fisheries, Oyster Farmers, and Restaurant Personnel and discuss possible examples. For instance, a solution that supports supply-chain issues and cost effectiveness for restaurants in the Pacific Northwest might interfere with ceremonial harvests (aesthetics, values) in Indigenous communities" (Teacher Edition, page 230).

ETS1.C Optimizing the Design Solution

- *Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (tradeoffs) may be needed.*
  - Lesson 12: "Begin to surface ideas about the interrelated nature of criteria, constraints, and tradeoffs. Display slide F. Before moving on to the next step, invite students to consider how there may be variation in those priorities within and across interested parties, as well as perspectives that are missing. There will be more time to develop these ideas in Lessons 12 and 13. The extension opportunity also highlights some options for deepening this discussion" (Teacher Edition, page 228).
  - Lesson 14: Students prioritize the criteria they used to develop their solution. "Prioritize criteria. Display slide E. Say, Each group developed criteria and a solution based on the location and context of their solution. We make decisions based on the science ideas we know and on what is important to us and the people affected by the solution. Ask students to discuss their criteria with their group and rank them from most to least important for deciding if the solution was effective. Also explain that it is important to provide reasons for their rankings during their discussion. Discuss how we prioritize criteria. Display slide F and say, We are not able to address every criterion that we can think of in an engineering design project. How do we decide which criteria are most important for a specific design solution? Facilitate class discussion to build the idea of trade-offs" (Teacher Edition, page 254).

- Lesson 15: Students will make a claim about the effectiveness of the Haber-Bosch process and the tradeoffs associated with the process with regards to its design criteria. (Lesson 15 Assessment Ammonia Fertilizer Production)

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 there are sufficient CCC elements used throughout the materials, but there is some mismatch between CCC elements claimed and used. Additionally, while CCC elements are used by students, many of them are not explicitly developed.

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.*
    - Lesson 2: Students look for patterns in their potential solutions. "Suggest we look for patterns to help decide where to go next. Continue to display slide F. Say, Wow. Look at the many different subproblems and solutions we came up with! Where do we start? It is not always easy to know where to start. We can try to organize our solutions somehow and look for patterns that might help focus us" (Teacher Edition, page 54). Students are encouraged to think about patterns of scale through the following prompt: "Look at our solutions through a lens of proportion and scale. Do any of these require us to think about scale?" (Teacher Edition, page 54). While students do look for patterns in the solutions, there is no evidence of students observing patterns at different scales to provide evidence for causality.

Cause and Effect (Focus CCC)

- *Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.*
    - Lesson 3: "Sample investigation plans are provided in Sample Investigation Plans. If groups' investigation plans differ from those examples, that is okay. It is important that investigation plans are specific, will provide data, and will collect empirical evidence. If plans are not, use probing questions to guide group designs to increase specificity, identify data to collect, and consider how that data can be used as evidence to evaluate a claim. It may be helpful to demonstrate the types of data students can collect when using bromothymol blue and pH strip indicators." (Teacher Edition, page 65). It is not clear that this claimed element is actively being developed by students as the focus of data collection appears to be geared less toward uncovering the difference between correlation and causation and more so aligned with generating evidence to support a claim.
- *Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system.*
    - Lesson 1: The "Supporting Students in Developing and Using Cause and Effect" box states, "Students may be passionate about their potential cause or unsure if any of the potential causes are actually affecting oysters. If so, you may mention to students that all of these potential causes have been harmful to oysters at some place and time. However, it is important to emphasize that we want to keep the focus on what caused the die-offs that happened overnight and began in 2005 in the Pacific Northwest. Ask

students to consider which causes actually meet those space and time restrictions" (Teacher Edition, page 36).

- Lesson 5: Students are asked to use their investigation data to consider "In what part of our small-scale system did we see evidence of increased H ion concentration? What mechanisms might cause these ions to be transferred to other parts of an ocean? Could these ions be transferred from one ocean to another? Why or why not?" (Teacher Edition, page 92).
- Lesson 6: Students use a simulation of what is happening at the molecular level to determine the cause of the color changing back in the investigation completed in the previous lesson. "Look for students to suggest: We want particles to move around like they actually do in the water. We want to be able to control the amount of CO leaving or staying in the water. We want to see all the particles that we know are in the solution (CO , H O, H CO , HCO , CO). We want realistic reactions to happen when particles collide, like we saw in Lesson 3 (formation and dissociation of H CO)" (Teacher Edition, page 114).
- Lesson 7: In the assessment, students develop a model to show the behavior of each acid when dissolved in water at the molecular level. Students then use this model to answer the following questions: "Using your answer from 3a and the model you drew in 2a, would you expect the pH to increase, decrease, or stay the same when $Na_2C_2O_4$ is added?", and "What happened to the pH? Use particle thinking to explain why this occurred. You may want to use a model or diagram to support your explanation" (C.4. Lesson 6 Assessment Acid Behavior Investigation, page 3).
- Lesson 10: The "Supporting Students in Developing and Using Cause and Effect" box states, "This is an opportunity to help students recognize the cause-and-effect relationship between the increased concentration of H in the ocean (cause) and the decrease in CaCO (effect), and consider the mechanistic how or why explanations for this relationship. Use the language of cause and effect introduced in earlier lessons to clarify that these concepts are crosscutting. For example, say, How does this cause-and-effect relationship lead to the trend we learned about at the start of the unit, where oyster larvae are not reaching full maturity?" (Teacher Edition, page 190).
- Lesson 15: The following directives are found on the summative assessment: "1. Choose one of these strategies (a or b) and develop a particle-level explanation of how the strategy would lead to a shift in the equilibrium of the reaction so that more NH is produced. Use what you have figured out in this unit about reversible reactions as evidence to support your explanation", and "2a. Choose one of these strategies (a or b) and develop a model to illustrate how components in the system would lead to an increase in the reaction rate" (Teacher Edition, pages 1–2).

- *Systems can be designed to cause a desired effect.*
  - Lesson 12: "Use the Solution Planning Document to develop the solution. Tell students, Now that we have more specific criteria and constraints and know more about these locations, let's try to build some solutions and figure out just how we might impact these ecosystems. Display slide G and distribute Solution Planning Document to students. Groups should work together to answer the questions on Solution Planning Document. They should be as specific and thorough as possible, and quantify their solutions and impacts where appropriate. For example, if students want to raise the pH of water tanks at an oyster hatchery, they will need to use volume and pH to calculate a specific quantity of the substance to be used. Students need to explain how that substance will help them achieve their goal. Encourage students to use the class

consensus model and/or models from individual lessons to help them predict the impacts of their solutions" (Teacher Edition, page 241).
    - Lesson 13: "See Sample Solution Planning to support students. If students are struggling with calculations, encourage them to refer back to the work they did in Lessons 7 and 8 and use that as a guide. If students are struggling with anticipated effects of solutions, have them look at the models they developed during the unit and identify the specific components they are planning to change. Ask students to predict how those changes will affect other components of that system and connected systems" (Teacher Edition, page 243).

Scale, Proportion, and Quantity (Focus CCC)

- *The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs.*
    - Lesson 2: Students begin looking at the solutions proposed for the subproblems identified. During this discussion the following suggested teacher prompt is provided: "Look at our solutions through a lens of proportion and scale. Are there categories of solutions that emerge when we look through a scale lens?" (Teacher Edition, page 53). While this activity provides students an opportunity to think of potential solutions in terms of scale, it does not directly address its relationship to the significance of the phenomenon. Later in the lesson, students use the idea of scale further to help develop an argument from what to focus on. "Prompt students to consider the categories of solutions through the lens of scale. Display slide I and prompt students to take out their notebooks. Say, Let's sit with these broad categories of solutions for a little bit longer as we work to decide on a direction. Which of these is most important to focus on? Is it enough to act on just one or the other? Why? On what timescales would we see results related to these different approaches to solutions? Where is chemical engineering going to be most useful? Where is engineering or science alone not enough to solve the problem? Jot down your thinking individually first" (Teacher Edition, page 54).
    - Lesson 4: The concept of scale, proportion, and quantity is explored by looking at how the number of H+ ions which dissociate affect the pH of a substance. However, there is no explicit discussion or addressing of how this affects the significance of a phenomenon.
    - Lesson 8: While this CCC element is claimed in this lesson, evidence of its development or use was not found.
    - Lesson 9: The "Supporting Students in Developing and Using Scale, Proportion, and Quantity" box states, "This is an explicit reference to the idea that: The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs" (Teacher Edition, page 175).
    - Lesson 9: The "Supporting Students in Developing and Using Scale, Proportion, and Quantity" box states, "Students may initially think that because they have calculated the masses of base needed to adjust the pH of an oyster tank and the ocean, the solution may be as simple as scaling up. They may need some support in reasoning through this. It is not only that the ocean is much larger and would require significantly larger quantities of base. A tank is a closed system where it is possible to prevent more CO from entering to form more acid, and this is not true of the ocean" (Teacher Edition, page 175).
    - Lesson 15: Students are asked to determine the different masses of reactants and products in the Haber-Bosch process, illustrating its contribution to carbon dioxide

release at various quantities of reactants or products at a realistic scale. The following is found in the summative assessment: "However, the Haber-Bosch process is not necessarily eco-friendly. The reactant nitrogen is drawn from the air while the hydrogen is produced by burning methane gas (CH_4). Is the CO_2 released a significant amount? The series of processes can be simplified as…" (C.4 Lesson 15 Assessment Ammonia Fertilizer Production, page 2).

- *Patterns observable at one scale may not be observable or exist at other scales.*
    - Lesson 2: Students are asked to consider "which aspects of the phenomenon and problem that we explored last time seem to be happening at relatively large scales? [and] which aspects of the phenomenon and problem that we explored last time seem to be happening at relatively small scales?" The "Supporting Students in Developing and Using Scale, Proportion, and Quantity" box states, "It is important at this point in the lesson to have students think about solving problems at different scales. Later, students will break this unit's problem, oyster die-off due to ocean acidification, into smaller scale subproblems. Encourage students to explain the different scales at which we explored problems in prior units." Later, students are asked to consider how they approach solving problems at different scales differently based on what can be observed or measured (Teacher Edition, page 51).
    - Lesson 5: Teachers are asked to "Problematize the need to move to a smaller-scale system as a way to understand the large-scale systems in the models." Later, students are asked to contextualize the small-scale system within the large-scale system as a way to see both sets of patterns within the same model. The "Supporting Students in Developing and Using Scale, Proportion, and Quantity" box states, "While this crosscutting concept is not assessed in this lesson, using scale thinking is important to support student sensemaking when moving to the investigation step. Because the scale of the two systems that interact is too large to observe directly, using a smaller-scale system allows students to study those interactions indirectly. In the next lesson step, students transition to using an investigation to model those large-scale interactions at a small-scale" (Teacher Edition, page 93).
    - Lesson 6: After collecting data from the BTB investigation, students are expected to identify changes in color associated with the investigation, that require more modeling at the particle level to understand more fully. Teachers are asked to "look for students to suggest:...we want to see all the particles that we know are in the solution (CO2, H2O, H2CO4, HCO3-, CO32-)[, and] we want realistic reaction to happen when particles collide, like we saw in Lesson 3". A simulation is offered as a means for students to obtain that type of information they felt was missing after the BTB investigation. The "Supporting Students in Developing and Using Scale, Proportion, and Quantity" box states, "It is important for students to think about how the patterns in the observable data may not provide us enough understanding to develop ideas about what is happening at the particle scale. Using this line of questioning will help students think about the importance of why we need evidence from the particle scale" (Teacher Edition, page 113).
- *Using the concept of orders of magnitude allows one to understand how a model at one scale relates to a model at another scale.*
    - Lesson 1: Students develop an initial model. "Develop initial models. Display slide V. Pass out Initial Modeling and say, It sounds like we have a decent idea now of why oysters are dying, so let's try to put our ideas on paper. We will draw a model that answers the question, 'How is more carbon dioxide in the atmosphere causing problems

for oysters' shells?' We also want to make sure we can zoom in too, so we know what is actually happening to the oyster shell to harm it. Give students time to work on their models individually" (Teacher Edition, page 38). While students are creating models at different scales in order to understand how things at a smaller scale relate to changes on the larger scale, there is no specific guidance provided related to order of magnitude.

- Lesson 3: Students read about how the pH scale works. "As each value in the pH scale changes by 1, the concentrations of = H and = OH ions both change by a factor of 10. Whenever pH decreases by 1 or becomes more acidic, there is an increase by a factor of 10 in the number of = H ions in the substance and a decrease by a factor of 10 in the number of = OH ions. When pH increases by 1 or becomes more basic, the opposite occurs. The table below illustrates this effect" (C.4 Lesson Handout Out Measuring pH, page 2). Students do look at order of magnitude, but not in a way that allows one to understand how a model at one scale relates to a model at another scale.
- Lesson 8: Students are asked to "think about ratios in a water reaction. Suggest that to help us think through how to count molecules in reactions, it could be helpful to visualize the number of particles involved at different scales. Let's try that first with an even simpler reaction." Students later determine the differing masses of small objects such as paper clips or staples relative to their number and compare that to the scale of atoms. The "Supporting Students in Developing and Using Scale, Proportion, and Quantity" box states, "Because atoms and molecules are too small to directly see or measure, students need a way to quantify large numbers of molecules at once. The mole allows students to do this, and molar mass allows students to calculate the relative number of particles in a given mass or the mass of a substance needed to react with a given quantity of another substance" (Teacher Edition, page 153).
- Lesson 9: The "Supporting Students in Developing and Using Scale, Proportion, and Quantity" box states, "The prompts framing foregrounds thinking about scale, proportion and quantity. Students have used conversion factors in prior units to support similar thinking, particularly in OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit). Stoichiometry is just a new instance of this. If students are unfamiliar with the use of scale and proportion, remind them that to 'scale up' means to grow our system out. Bigger systems result in more stuff. Stoichiometry helps us consider the series of proportional relationships we can use to figure it out" (Teacher Edition, page 172).
- Lesson 14: Students participate in a gallery walk to identify similarities and differences in each other's solutions. The following guidance is provided: "Display slide N and keep it visible during the gallery walk. Encourage students to pay attention to the different scales of the design solutions by asking them to think about the prompt questions. How are others' solutions based on evidence, criteria, and tradeoffs? How are we engineering chemical interactions in our world's atmosphere and hydrosphere? What is the impact at different orders of magnitude (molecules > earth systems)? How long will these solutions take?" (Teacher Edition, page 257).
- Lesson 14: The "Supporting Students in Developing and Using Scale, Proportion, and Quantity" box states, "Questions 3 [what is the impact at different orders of magnitude (molecules > earth systems)?] & 4 [How long will these solutions take?] prompt students to think about the different scales at which their solutions are implemented and observed. For example, a solution in which seagrass is planted in order to remove carbon dioxide from the ocean causes several orders of magnitude more CO to be removed compared to removal by wild seagrass. Students should also observe that

some solutions may take longer to implement or have longer-lasting effects depending on what part of the class consensus model they are targeting” (Teacher Edition, page 257).

Systems and System Models

- *Systems can be designed to do specific tasks.*
    - Lesson 12: Students begin to identify and develop a solution to the oyster die-off problem based upon the criteria and constraints identified. “Invite groups to identify a solution of interest. Display slide H. Remind students of the list of possible solutions generated at the beginning of class. Then invite students to decide in groups which solutions seem most promising based on the criteria and constraints. Tell students to record their thinking in their science notebooks. Circulate among the groups to discuss which solution was selected and why. Possible group answers include, but are not limited to: We would like to add old oyster shells to the water to increase carbonate ion concentration and support shell building. This might reduce the supply of oyster shells for poultry farmers at first, but it is less likely to cause negative unintended consequences in the ecosystem or make the oysters unsafe to eat. It will be similar to restoring the ecosystem to what it was like when there were lots of oyster reefs. We would like to add a base to the hatchery water to increase the pH. We know how to perform the calculation to neutralize the acid and have more control in the tanks. This will have an immediate benefit to larvae survival. Prompt groups to begin to develop their solution. Display slide I. Once groups have identified a solution of interest, ask the groups to map out their solution. During the mapping out process they should consider the criteria and constraints, and some of the preliminary calculations for implementing the solution based on what they have learned about the mole. Say, It seems like all of the groups have identified a solution. Let’s use these last few minutes to start mapping out how these solutions will work. As you work, keep a record of any other information you are noticing that you will need to fully build out your plan” (Teacher Edition, page 231).

Energy and Matter

- *Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.*
    - Lesson 15: The following directive is found on the summative assessment: “4a. Use the information in the table to trace how matter flows into and out of the system before, during, and after the Haber-Bosch process. You can choose to use images and/or words” (C.4 Lesson 15 Assessment Ammonia Fertilizer Production, page 4)

Structure and Function

- *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.*
    - Lesson 4: Students relate the strength of acids and bases to the degree of dissociation of different acids. “Purpose of this discussion: Recall ideas about polarization and differences in bonds strengths from Electrostatics Unit and Space Survival Unit. Try to use these ideas to 1) describe different possible force interactions between particles in a solution, and 2) explain differences in the degree of dissociation (differences in H concentrations) for different acids. Key ideas: Water molecules are permanently

polarized. This means that one end has a positive charge and the other has a negative charge. The molecules of acids also are also polarized. Both of these would produce force interactions that either push or pull on other charged parts in other matter around them. The bonds between atoms (elements) in substances vary in strength. Differences in the strength of attractive forces (bonds) between the atoms in a substance, and/or between these atoms and the water molecules, and differences in how they interact with each other, result in a greater concentration of H ions breaking away from some substances more than from others" (Teacher Edition, page 83).

Stability and Change (Focus CCC)

- *Much of science deals with constructing explanations of how things change and how they remain stable.*
    - Lesson 1: "Generate questions. Display slide BB. Say, It seems like we know of some things that are similar to oyster shells being 'eaten away,' but based on our models we are not 100% sure what's happening with oysters. Let's take this opportunity to record our questions so we can think about useful next steps. Direct students to look back at their notebooks and the consensus model and think about discussions they had today to identify relevant questions. Students should write down at least two new questions that they have now about the phenomenon of oyster die-off due to ocean acidification. Remind students to write big so their questions are easier to read. Give students a few minutes to record their questions on 3x3 sticky notes" (Teacher Edition, page 43).
    - Lesson 1: The "Supporting Students in Developing and Using Stability and Change" box states, "In this lesson, students are confronted with a phenomenon that reflects a change over time--relatively recent decreases in oyster populations and mysterious larvae die-offs. Student questions will ideally seek to explain this phenomenon or specific parts of their model and how they are tied to the climate change of ocean acidification" (Teacher Edition, pages 43). This is echoed in the "Where We Are Going" section describing that "The investigation materials in days 2 and 3 of the unit focus on the central cause of ocean acidification: anthropogenic climate change and CO emissions, and seek to explain how the changes in the air can change other systems, such as in aquatic life" (Teacher Edition, page 30). While this guidance is provided to the teacher to tie the questions to the CCC, specific student guidance or teacher prompts to emphasize this connection are not provided beyond the opportunity above describing students adding to the class DQB with questions that hopefully relate to changes observed.
    - Lesson 6: The "Students in Developing and Using Stability and Change" box states, "Reversible reactions are one of many examples in chemistry where a reaction reaches a stable state over time. In this unit, students figure out that reactions can reverse and reach a state of equilibrium. Later, students will figure out mechanistically why some reactions are more likely to reverse than others due to relative bond energies" (Teacher Edition, page 117).
    - Lesson 6: "discussion: To help students establish what happened in the simulation. For example, amounts of CO decreasing if it starts with a high concentration or CO forming if it starts at a low concentration. Students need to relate the simulation evidence to the ideas that 1) dissolved CO can leave water, and 2) reactions can go in reverse or backward. They should be able to describe the reactions that can go backward as 'reversible reactions' and that these reactions will eventually reach a relatively stable state or 'equilibrium'. Listen for these ideas: In the simulation, CO could escape from the

water and CO could form from HCO . In real life, CO was leaking out and because there was not 'enough' CO left in the solution, it somehow formed from HCO . All steps of ocean acidification can go backward (are reversible). The forward and reverse reactions happen at about the same rate, creating a balance. These ideas are complex. If students are struggling with the provided prompts, you may wish to allow them to return to the computer simulation while engaging in whole-class discussion so that students can test ideas in real time if they are unsure" (Teacher Edition, page 117).

- Lesson 11: The **Supporting Students in Developing and Using Stability and Change** side box states, "Push students to have a plan to measure the speed of the reaction quantitatively or semi-quantitatively. Use examples like those discussed above (walking across the room, pouring water) to help students think of different ways to measure these reactions" (Teacher Edition, pages 208–209).
- Lesson 11: "Some students may get confused and think that additional CO ions would actually be a problem, because they would bond with H ions to form HCO and then to form H CO , carbonic acid. Use this as an opportunity to remind students that H CO is not in itself harmful; we figured out in Lesson 9 that free hydrogen ions instead hurt oyster larvae by bonding with free CO that the larvae need" (Teacher Edition, page 215).

- *Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible.*
  - Lesson 11: "Define the idea of reaction rate. Show slide G. Say, Everyday speed is a distance traveled in a certain time, which mathematically is distance divided by time. Reference the equation on the slide and continue, We decided reaction speed is how much product is made in a given time. This is kind of a different idea. What should we call it? Give students a chance to individually brainstorm in their notebooks, then take all student suggestions. Student ideas should focus on the concepts of 'speed' or 'rate'. Connect these ideas to the term scientists generally use, reaction rate, and have students add this term to their personal glossaries. Reaction rate describes how quickly a reaction forms a product" (Teacher Edition, page 214) and later, "Push students to have a plan to measure the speed of the reaction quantitatively or semi-quantitatively. Use examples like those discussed above (walking across the room, pouring water) to help students think of different ways to measure these reactions" (Teacher Edition, pages 208–209).
  - Lesson 11: Teacher leads students in discussion where "Purpose of this discussion: Here students need to think specifically about how particles are interacting in these different situations. Students should progress toward the conclusion that reactions can actually go faster when there are more opportunities for particles to break old bonds and form new ones. Listen for these ideas: When we increased temperature or concentration, more calcium carbonate was formed in less time. When the temperature is increased, particles move faster so they can hit each other harder and more often. When the concentration is increased, reactant particles hit each other more often. When particles hit harder or more often, bonds are more likely to break and re-form, which means the reaction is happening more quickly" (Teacher Edition, page 212).
- *Systems can be designed for greater or lesser stability. (7.4)*
  - Lesson 7: Students brainstorm some potential solutions to the oyster problem which focus around making the ocean pH more stable. In the "What to look/listen for in the moment" section of the Assessment Opportunity box in the Teacher Edition, the following is provided to teachers: "Students explain how those systems have changed

over time, and how a solution might help them gain stability. (CCC: 7.4)" (Teacher Edition, page 136), however, this CCC elements Is claimed for this lesson but evidence of its use or development was not found in the materials.

Suggestions for Improvement

General

- Consider providing a key in the teacher materials so that it is clear to teachers the coding system used for SEP, DCI, or CCC elements (e.g., CCC **7.4** refers to the fourth element of the **Stability and Change** CCC).

Science and Engineering Practices

- Consider providing additional opportunities for the development of identified elements of **Asking Questions and Defining Problems**.

Disciplinary Core Ideas

- As written, **PS1.B** is incorrectly labeled as **PS2.B** in the unit materials.
- As written, **ESS2.D** has strikethrough of the text "…and thus affect climate", which renders the claimed portion of this DCI largely unrepresentative of the intent of **ESS2.D**. Students' development of the climate impact of the changes in carbon dioxide in the atmosphere is essential to this DCI. This could be included in the front matter but given the significant portion of this DCI struck out, it may be wise to consider removing it as a directly claimed focus element. If the stricken portion is developed in other OpenSciEd units, consider stating where this portion is developed and acknowledge that in the front matter.
- Consider providing additional opportunities for the development of claimed DCI elements of **ETS1.A**, **ETS1.B**, and **ETS1.C**.

Crosscutting Concepts

- Consider using specific call-out boxes that include teacher prompts that are designed to elicit student responses related to targeted CCC elements. This would allow for these concepts to be more intentionally integrated into learning experiences.
- Consider providing additional teacher support to help students make connections to CCC element **2.1** throughout Lesson 3 and **7.4** throughout Lesson 7.

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 and/or designing solutions to problems. There are multiple opportunities where students integrate grade-appropriate elements of all three dimensions to design solutions to the anchoring problem.

Students frequently use grade-appropriate elements of all three dimensions together in order to work toward figuring out a phenomenon or solving a problem. Related evidence includes:

- Lesson 1: Students fill out model templates using the patterns observed from the data sets of temperature/carbon dioxide changes on a global scale to show their hypotheses on what might be going on with oyster shells. In this activity, students use the following elements of the three dimensions:
    - DCI: **ESS2.D Weather and Climate**: *Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate.*
    - SEP: **Developing and Using Models**: *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.*
    - CCC: **Scale, Proportion, and Quantity**: *Use the concept of orders to magnitude allows one to understand how a model at one scale relates to a model at another scale.*
- Lesson 3: Students collaboratively plan and then conduct an experiment to test the pH of various substances and then look for patterns in the data as well as the chemical formulas of the substance tested. In this activity, students use the following elements of the three dimensions:
    - DCI: **PS1.B Chemical Reactions**: *In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present.*
    - SEP: **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.*
    - CCC: **Cause and Effect**: *Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.*
- Lesson 5: Students develop a model to show how the movement of carbon changes the atmosphere and ocean. In this activity, students use the following elements of the three dimensions:
    - DCI: **ESS2.D Weather and Climate**: *Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate.*
    - SEP: **Developing and Using Models**: *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.*
    - *SEP:* **Planning and Carrying Out Investigations:** *Select appropriate tools to collect, record, analyze, and evaluate data.*
    - CCC: **Cause and Effect**: *Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system.*
- Lesson 9: Students go through a series of steps to determine how much NaOH would need to be added to the tank to reach the desired pH using conversions and ratios. Students then complete these calculations for the entire ocean and discuss the reasons that might not be an ideal solution. In this activity, students use the following elements of the three dimensions:

  - DCI: **PS1.B Chemical Reactions** *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.*
  - SEP: **Using Mathematics and Computational Thinking**: *Apply ratios, rates, percentages, and unit conversions in the context of complicated measurement problems involving quantities such as derived or compound units (such as mg/L, kg/m3, acre-feet, etc.).*
  - CCC: **Scale, Proportion, and Quantity**: *The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs.*
- Lesson 11: Students plan and conduct an investigation to determine how temperature and concentration affect reaction rates. In this activity, students use the following elements of the three dimensions:
  - DCI: **PS2.B: Chemical Reactions**: *Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy.*
  - SEP: **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.*
  - CCC: **Stability and Change**: *Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible.*

Suggestions for Improvement

None

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 Performance Expectations (PEs) because lessons build on one another using a variety of approaches and support are provided for students to link learning in order to build toward the targeted PEs.

Each lesson builds directly on prior lessons and the links between lessons are made clear to students using a variety of strategies including providing students with opportunities to ask their own questions, using what students figure out as the next question to pursue, and answering questions generated by students in the previous lessons. Related evidence includes:

- Lesson 1: "Generate ideas for investigations. Display slide DD. Say, We have so many ideas to explore! How could we start to investigate the answers to some of these questions? Title the next page in your science notebook 'Ideas for Investigations.' Choose one question or category of questions from our Driving Question Board and talk with a partner or partners near you to consider how we might find the answer—what investigation could we design, what data should we gather, and how could we figure this out in our classroom? Keep track of your ideas in your notebook. After you have discussed one question, move on to another" (Teacher Edition, page 45).
- Lesson 2: "Navigate to today's work. Say, We ended up with a lot of questions and ideas to investigate last class! But let's take a moment to think about the different scales at work in this phenomenon and problem. Display slide A. Give students a couple of minutes to turn and talk with a partner" (Teacher Edition, page 51).
- Lesson 2: "Navigate. Say, You did such a great job building arguments. There are multiple valid arguments for which subproblems and categories of solutions to pursue. That is usually the case with complex problems. Let's pick this up at the beginning of next class and decide on a shared direction" (Teacher Edition, page 58).
- Lesson 3: "Revisit the subproblems identified in Lesson 2. Revisit the list of subproblems at the top of Progress Tracker. Display slide A and say, In the last lesson, we figured out that the big problem of oyster die-off can be broken into more manageable subproblems. Ask students to do an individual quick write to answer the prompts on slide A. After a few minutes, lead a discussion to share student responses. What subproblems did we identify? What types of data do we need to order to address these subproblems?" (Teacher Edition, page 64).
- Lesson 6: "Use the snowball protocol to share ideas and questions. Say, When we left off in the last lesson, we noticed that our water sample with carbon dioxide was no longer acidic. It had changed back in color! At the end of the lesson, you recorded responses to two prompts on a sheet of paper. Display slide A. Read through the directions of the snowball protocol on the slide. Ask if students have any clarifying questions, then carry out the snowball protocol to share student ideas and questions from Lesson 5. As students share questions, tape them to the DQB or have students copy them onto a 3x3 sticky note with a marker and then add them. Some explanations for the color change students may have could include: CO was released from the water back into the atmosphere (air). There wasn't enough CO dissolved in the water to keep it acidic. Maybe there was another chemical reaction that changed the water back to normal. After completing the snowball protocol, point out that there are a lot of different ideas we have about what could be causing the color change. Say, There are a lot of different possibilities here for substances that could be involved in the reverse color change, but we are not sure. Let's think about how these different substances could have been involved in the color change" (Teacher Edition, page 111).
- Lesson 7: Students are asked to relate their learning to the original phenomena of oyster die-offs and consider "what new solutions can we propose using that we have figured out so far?", as well as "what will be the impact of this solution?" (Teacher Edition, page 135).

- Lesson 8: "Discuss what we figured out last class and where we decided to go next. Display slide A. Have students pair up and discuss what we have figured out about acids and pH and how that may be related to potential solutions. Students should recall from the previous lesson that adding something to an acidic solution changed the pH, so maybe adding something to acidic water (or acidifying water) could be a solution. However, at this point they do not know how much would be needed or how exactly to figure that out" (Teacher Edition, page 145).
- Lesson 8: "Discuss how we can use what we have learned today. Display slide MM. Cue students think about how they can apply our new knowledge to helping oysters next class. Give students a few minutes to discuss the prompt with a partner, then ask for volunteers to share what they discussed with their partners" (Teacher Edition, page 161).
- Lesson 9: "Discuss what we figured out last class. Display slide A. Have students turn and talk to discuss what they figured out in Lesson 7. Ask them to list the important ideas, such as what the coefficients in balanced reactions mean, how we can 'count' particles, and any other tools we can use to help oysters. Students should recall: When we balance chemical equations with coefficients, we show the mole ratios of atoms or molecules that are reacting with each other. We can use the atomic masses on the periodic table to determine the mass of one mole of a substance. One mole of anything is the same number of particles or objects. We can use molar mass and mole ratios to calculate an exact amount of base to use to neutralize an acid" (Teacher Edition, page 167).
- Lesson 9: "Discuss neutralizing the entire ocean. Now that students have calculated the mass of NaOH needed for both an oyster tank and for the entire ocean, ask students how these two systems might differ other than just their size. Display slide O. Encourage students to refer back to what they figured out in Lesson 5 and to think about how the proposed changes would impact the ocean-atmosphere system….Once students realize that dumping NaOH into the ocean is probably not the ideal solution, have them think about what else we should do or figure out in order to find solutions that won't harm oysters or other marine life, while working to restore oysters as a food source" (Teacher Edition, page 175).
- Lesson 9: "Motivate a return to the subproblems. Display slide A. Ask students to turn and talk to discuss the solution proposed at the end of our last lesson and why we are uncertain about that particular solution…Emphasize that students' idea of neutralizing the entire ocean with base is a potential solution, but that, given our concerns, we would benefit from considering other solutions as well. Say, Let's take advantage of our Progress Tracker to determine what we have not explored yet; perhaps we will find some inspiration for our investigation. Show slide B and ask students to look back at the subproblems to figure out where we should go next…Show slide C. Say, We know that acidity somehow negatively affects oyster shells but we have not investigated how and why. Point out the Driving Question Board and the ideas for investigations generated throughout the unit." Ask, "Which questions from the Driving Question Board might be useful to investigate this subproblem? What investigations could help us figure out what is going on? Let students know that testing what happens when shells or shell-like substances are placed in acid is a great first step if those materials are available in the classroom or lab setting" (Teacher Edition, pages 181–182).
- Lesson 11: "Reflect on where we came from. Display slide A. Lead students into this lesson by asking what the class had figured out and was wondering at the end of Lesson 10." This is used to connect to the learning in the next lesson by use of the following prompts: "What were we wondering at the end of Lesson 9... What is the key time to help oysters build their shells?" (Teacher Edition, page 205).
- Lesson 11: "Update Progress Trackers. Show slide V. Ask students to work with a partner to update their Progress Trackers with any new ideas from the day's discussion. Say, At this point,

we have come up with a lot of interesting ways to use chemistry to help oysters" (Teacher Edition, page 220).
- Lesson 12: "Navigate. Display slide A. Say, Last class we updated our Progress Trackers, but it has been a while since we have reviewed what we have figured out. What else have we learned that helps us explain the phenomenon of oyster-die off? Direct students to revisit their Progress Trackers and discuss with a partner, then quickly debrief partner discussions…Say, We have figured out a lot in this unit and answered quite a few of our questions. We have already done some thinking about possible solutions to protect oyster larvae, but let's take this opportunity to think more about ways in which we could prevent larvae die-offs" (Teacher Edition, page 225).
- Lesson 12: "Summarize next steps. Say, After listening in on your conversations in groups, it sounds like we need to know more about the specific local contexts in which we will develop our solutions. I will start to dig up some information and bring that to our next class" (Teacher Edition, page 231).
- Lesson 13: "Review what students decided during the previous class. Display slide A. Pair students so they are with someone they did not work with last class. Give students time to turn and talk to share with each other the general solutions their groups came up with, as well as current lists of criteria and constraints" (Teacher Edition, page 237).
- Lesson 13: "Students show their solutions. Display slide K. As students finish their posters, display them in the classroom or in a nearby public space such as a hallway. In the next lesson, students will be presenting their solutions to each other and providing feedback. Tell students that they will have an opportunity to learn from each other in the next class. Have a brief discussion with students about the benefits of peer evaluation and having the opportunity to see each other's solutions" (Teacher Edition, page 247).
- Lesson 15: "Share impressions from the Lesson 14 exit ticket. Thank students for sharing their reflections on the engineering design process at the end of the last lesson. Share a few anonymous student responses or general impressions of responses that you think reflect class thinking, celebrate student accomplishments in the last few lessons, and/or contain insights into how science and engineering differ. Show slide A. Say, What did you figure out from your work using the engineering design process? Give students time to turn and talk before taking responses. Accept all answers. Transition students to a return to the Driving Question Board. Say, Now that we have had a chance to think about solutions to help protect oysters, let's look back at our Driving Question Board. We have actually figured out a lot of things that we were wondering at the start of the unit and can help answer our big question, 'Why are oysters dying, and how can we use chemistry to protect them?'" (Teacher Edition, page 265).

The lessons build coherently to partially develop a targeted set of PEs. Related evidence includes:

- **HS-PS1-5** *Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.*
    - Lesson 8: Students plan and conduct investigations to determine the ratio of substances which would be required to neutralize a reaction and determine that the ratio is determined by molar mass.
    - Lesson 11: Students design and conduct an investigation to test how temperature or concentration affect how much product a reaction makes. Students develop a model to explain how this occurs.
    - The **Patterns** CCC described in this PE is not developed in the materials. See criterion I.B.
- **HS-PS1-6** *Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.*

- Lesson 6: Students use a simulation and data to determine that some reactions are reversible and will eventually stabilize at an equilibrium level.
- Lesson 8: Students plan and conduct investigations to determine the ratio of substances which would be required to neutralize a reaction and determine that the ratio is determined by molar mass.
- Lesson 9: Students figure out how much of a base it would take to neutralize water in an oyster hatchery.
- Lesson 10: Students investigate how pH affects oyster shells and determine oysters build shells by using calcium and carbonate ions from water.
- Lesson 11: Students design and conduct an investigation to test how temperature or concentration affect how much product a reaction makes. Students develop a model to explain how this occurs.

- **HS-PS1-7** *Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.*
  - Lesson 8: "Balance the equation. Say, We know CO in the ocean makes the acid HCO2, and we think we can neutralize it with a base such as NaOH. Display slide K and ask, But how much NaOH would we need to neutralize HCO ? And does this equation account for conservation of mass? Give students more time to balance the reaction, and tell them that it may help us think about how much base we would need to neutralize an acid" (Teacher Edition, page 147).
  - Lesson 9: "Decide what to neutralize. Ask students if they think we should dump NaOH in the ocean and see what happens. Display slide B. After discussing possible benefits and downsides to dumping NaOH in the ocean, ask students if perhaps scaling down our solution might be a better place to start" (Teacher Edition, page 167).
  - The **Energy and Matter** CCC described in this PE is not developed in the materials. See criterion I.B.
- **HS-ESS2-6** *Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.*
  - Lesson 1**:** Students create an initial model which shows how carbon dioxide in the atmosphere enters the ocean. However, at this point a quantitative model is not utilized.
  - Lesson 5: Students analyze data which shows how the amount of carbon dioxide in the atmosphere has changed over time. "Apply the carbon cycle model to oysters. While students are in the Scientists Circle, show slide V. Distribute a whiteboard and dry erase marker to each student. Give students 2 minutes to stop and jot a response to the prompt on the slide. Then have students show their whiteboards. Give students a minute or two to compare their answers with their classmates. Then ask, Where do we see similarities in our ideas? Accept all responses. Summarize areas of agreement, such as: Humans have put more CO in the atmosphere than used to be there. We are getting it from the ground where it was not hurting anybody. More CO gets into the ocean than used to in the past. CO reacts to make the water acidic, which hurts oysters" (Teacher Edition, page 104).
  - Lesson 6: Students update their model to include the idea of carbon dioxide returning to the atmosphere and the reversible reactions. However, at this point a quantitative model is not utilized.
  - Lesson 10: "Update carbon cycle model. Display slide X. Push the students to identify the limitations of the model. It currently does not address where the carbon in limestone came from, and also ask students if the shellfish and limestone should be

incorporated into the model as parts of the biosphere, geosphere, hydrosphere, or atmosphere. If students do not know where to begin, remind them to refer to Oyster Life Cycle" (Teacher Edition, page 193).
  - The **Energy and Matter** CCC described in this PE is not developed in the materials. See criterion I.B.
- **HS-ESS3-4** *Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.* (Across multiple units)
  - Lesson 2: After proposing solutions to subproblems students evaluate the possible solutions with a partner. "Prompt students to consider the categories of solutions through the lens of scale…On what timescales would we see results related to these different approaches to solutions? Where is chemical engineering going to be most useful? Where is engineering or science alone not enough to solve the problem? Jot down your thinking individually first…Affirm that both addressing the root cause and mitigating local impacts are important and urgent, and that science and engineering as well as social and political action are important to help save the oysters, the ecosystems, and the communities connected to oysters" (Teacher Edition, page 55). The following teacher prompts are provided to help guide the discussion: "Which of these (addressing root cause or mitigating local impacts) is most important to focus on? Is it enough to act on just one or the other? Why?", "On what timescales would we see results related to these different approaches to solutions?", and "Where is engineering, and chemical engineering specifically, going to be most useful? Where is engineering or science alone not enough to solve the problem?" (Teacher Edition, pages 56–57).
  - Lesson 12: Students begin to identify and develop a solution to the oyster die-off problem based upon the criteria and constraints identified. "Invite groups to identify a solution of interest…invite students to decide in groups which solutions seem most promising based on the criteria and constraints…Prompt groups to begin to develop their solution. Display slide I. Once groups have identified a solution of interest, ask the groups to map out their solution. During the mapping out process they should consider the criteria and constraints, and some of the preliminary calculations for implementing the solution based on what they have learned about the mole. Say, It seems like all of the groups have identified a solution" (Teacher Edition, page 231).
  - Lesson 13: "Use the Solution Planning Document to develop the solution. Tell students, Now that we have more specific criteria and constraints and know more about these locations, let's try to build some solutions and figure out just how we might impact these ecosystems. Display slide G and distribute Solution Planning Document to students. Groups should work together to answer the questions on Solution Planning Document. They should be as specific and thorough as possible, and quantify their solutions and impacts where appropriate. For example, if students want to raise the pH of water tanks at an oyster hatchery, they will need to use volume and pH to calculate a specific quantity of the substance to be used. Students need to explain how that substance will help them achieve their goal. Encourage students to use the class consensus model and/or models from individual lessons to help them predict the impacts of their solutions" (Teacher Edition, page 241). A Solution Planning Document is provided which contains the following questions: "How will these intended effects benefit oysters and people? Use your calculations from #5 as needed to support your answer", "What scientific/technical barriers are there to implementing the change?", "What social, political, or legal barriers are there to implementing the change?", and

"How might you address those barriers?", (C.4 Lesson 13 Handout Solution Planning Document, page 4).

- The **Stability and Change** CCC described in this PE is not developed in the materials. See criterion I.B.

- **HS-ETS1-1** *Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.*
  - Lesson 7: Students are motivated by their own experiences to consider why they should gather ideas from the community when considering their solutions. Students are asked to discuss the following questions: "Have you ever had someone make a decision that affected you without asking for your input first?", and "What happened?" (C.4 Lesson 7 Slides, Slide C) Students are then prompted to discuss the following questions: "What can we learn from other people who also care about the oysters?", and "Why is it important to listen to people who are already working on this problem?" (C.4 Lesson 7 Slides, Slide D). Students then look at specific interested parties and use these ideas to brainstorm further criteria and constraints. "Display slide F. Say, If we are going to try to develop solutions to the oyster problem, we should probably also consult with people who have already been working on this issue and who are affected by the problem–the interested parties. How might thinking about perspectives and ideas from various interested parties help us develop criteria and constraints? Look for students to mention: If we consult with various interested parties we will have criteria and constraints that cover a wider range of concerns. If our criteria and constraints are more fleshed out by seeing what multiple interested parties have to say, our solutions are more likely to be effective for multiple interested parties, rather than just considering one perspective" (Teacher Edition, page 133). After reading about interested parties, students discuss the following questions: "Why are oysters important to this group of people?", What can we learn about oysters from this group of people?", "Which science concepts that we have figured out help us explain what is going on in the place that they care about?", and "What criteria and constraints are important to this group of people?" (C.4 Lesson 7 Handout Discuss Interested Parties, pages 1–2).
  - Lesson 12: Students engage in a discussion about which solution should be developed. The following prompts are provided: "How should we decide which direction to pursue?", and "What should we prioritize?" The following additional guidance is provided to the teacher: "The DCI is ETS1.B.1: Developing Possible Solutions. When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. This discussion should attend to reliability, safety, and cost. Consider asking about these ideas directly. Students may also bring up aesthetics, which are part of the cultural significance of oyster -- their shells are beautiful and part of many indigenous jewelry and clothing traditions" (Teacher Edition, page 227). Students then discuss the following prompt: "Review the criteria and constraints columns in your Progress Tracker. What criteria and constraints are important to the interested parties who are most impacted by this problem?" (C.4 Lesson 12 Slides, Slide E). This is followed by a class discussion. "Lead the class in a discussion about criteria and constraints important to interested parties. Write a new summary of the criteria and constraints students raise on a whiteboard, a piece of chart paper, or a slide. Ask students to record the list in a T-chart in their science notebooks" (Teacher Edition, page 228).
  - Lesson 13: "Use the Solution Planning Document to develop the solution. Tell students, Now that we have more specific criteria and constraints and know more about these

locations, let's try to build some solutions and figure out just how we might impact these ecosystems…Encourage students to use the class consensus model and/or models from individual lessons to help them predict the impacts of their solutions" (Teacher Edition, page 241). A Solution Planning Document is provided which contains the following questions: "How will these intended effects benefit oysters and people? Use your calculations from #5 as needed to support your answer", "What scientific/technical barriers are there to implementing the change?", "What social, political, or legal barriers are there to implementing the change?", and "How might you address those barriers?" (C.4 Lesson 13 Handout Solution Planning Document, page 4).

- **HS-ETS1-2** *Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.* (Across multiple units)
    - Lesson 2: Students take the larger problem of oyster die-off and break it into smaller subproblems using their class consensus model.
    - Lesson 12: Students begin to identify and develop a solution to the oyster die-off problem based upon the criteria and constraints identified. "Invite groups to identify a solution of interest. Display slide H. Remind students of the list of possible solutions generated at the beginning of class. Then invite students to decide in groups which solutions seem most promising based on the criteria and constraints. Tell students to record their thinking in their science notebooks…Once groups have identified a solution of interest, ask the groups to map out their solution. During the mapping out process they should consider the criteria and constraints…" (Teacher Edition, page 231).
    - Lesson 13: "Use the Solution Planning Document to develop the solution. Tell students, Now that we have more specific criteria and constraints and know more about these locations, let's try to build some solutions and figure out just how we might impact these ecosystems…Encourage students to use the class consensus model and/or models from individual lessons to help them predict the impacts of their solutions" (Teacher Edition, page 241). A Solution Planning Document is provided which contains the following questions: "How will these intended effects benefit oysters and people? Use your calculations from #5 as needed to support your answer", "What scientific/technical barriers are there to implementing the change?", "What social, political, or legal barriers are there to implementing the change?", and "How might you address those barriers?" (C.4 Lesson 13 Handout Solution Planning Document, page 4).

Suggestions for Improvement

Consider providing opportunities for students to build towards all elements of claimed PEs. See criterion I.B for feedback and suggestions for improvements.

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	Extensive *(None, Inadequate, Adequate, Extensive)*

The reviewers found extensive evidence that links are made across the science domains when appropriate because both physical science (PS) and Earth and space science (ESS) domains are used by students to come to understand the phenomenon and to design a potential solution to address the central issue of oyster die-offs. Grade-appropriate elements of CCCs are used to make connections across these science domains.

Grade-appropriate elements of both **PS1.B** and **ESS2.D** are used to make sense of the phenomenon and solve the anchoring problem. Related evidence includes:

- Lesson 3: Students conduct an investigation to collect evidence to see that carbon dioxide affects pH levels. Students then analyze data from ocean pH levels to see how they have changed over time.
- Lesson 5: Students analyze data which shows how the amount of carbon dioxide in the atmosphere has changed over time. "Purpose of this data handout: To identify how carbon has moved throughout Earth's systems and how human activity in different parts of the world may have impacted the amount of carbon that moves among Earth's systems" (Teacher Edition, page 100).
- Lesson 11: Students begin to think about how they could speed up the reaction in which oysters' shells are made. The following teacher prompts are provided as part of a discussion to help students think about this at the
- : PS1.B.2; CCC: 2.2)" (Teacher Edition, page 127).
- Lesson 9: Students learn how oysters build shells and trace the flow of matter. They explore where the carbon in limestone comes from and identify which "sphere" it is a part of. Students compare timescale of carbon from atmosphere to ocean vs. carbon from limestone to ocean to understand the effects of increased fossil fuel use, connecting **PS1.B** with **ESS2.D** (Teacher Edition, page 193).
- Lesson 14: Teachers facilitate discussion around the student solutions and the differing timescales for change, including that "It takes a long time for carbon to move from the hydrosphere to the geosphere through natural processes, so a solution needs to remove carbon more quickly" (Teacher Edition, page 258).
- Lesson 15: "Apply scientific ideas, principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. (SEP: 6.3; DCI: PS1.B.1, PS1.B.2; CCC: 2.2) 15.B Use student-generated sources of evidence and prioritized criteria to refine a solution reversible process that can be made faster by means of increasing collisions to produce larger amounts of products from the cause-effect relationships of small reactions. (SEP: 2.3; DCI: PS1.B.2; CCC: 2.2) 15.C Use

mathematical thinking to describe claims about the conservation of matter and chemical properties of the elements involved can be used to predict the scale and significance of chemical reactions. (SEP: 5.2; DCI: PS1.B.3; CCC: 3.1)" (Teacher Edition, page 261).

Suggestions for Improvement

- Consider making the connection between PS and ESS domains in Lesson 14 more explicit to students as they attempt to design a solution predicated on their new knowledge of the cycling of carbon.
- Consider making a connection to Life Sciences, such as **LS2.C**, as an additional opportunity to support student sense-making by developing understanding of ecosystem dynamics as a result of human activities.

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 the materials explicitly state mathematics and ELA standards which are used throughout the unit and students are provided with a variety of opportunities to engage in reading, writing, speaking, and listening.

Materials explicitly state ELA standards that are used in the unit using "Supporting Students in Making Connections to ELA" call-out boxes at the end of specified units. Related evidence includes:

- **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.*
  - Lesson 1: "As students read about the Billion Oyster Project, they will see that 'acidification' is a cause of die-offs, confirming or disconfirming what they found in the readings. This is in the second half of the article. Consistent with the CCSS standard, students will take note of how the article's discussion of the problems affecting oysters compares to students' conclusions from analyzing data about potential causes of the oyster die-offs. Students are analyzing text and comparing and contrasting it with data" (Teacher Edition, page 46).
- **CCSS.ELA-LITERACY.RST.9-10.2**: *Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.*
  - Lesson 3: "As students read about pH and examine a website, they connect ideas in the two resources to their current knowledge as well as extend their knowledge. Students

use their understandings to develop definitions for acid, base, and pH in their personal glossaries" (Teacher Edition, page 69).

- **CCSS.ELA-LITERACY.RST.9-10.3**: *Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text.*
  - Lesson 5: Students perform a complex investigation using a multistep procedure that they have modified to fit their specifications (Teacher Edition, page 105).
- **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.*
  - Lesson 7: "As students read the interested parties' vignettes, they summarize the information presented in the text to convey the central ideas of the processes to their jigsaw groups" (Teacher Edition, page 138).
- **CCSS.ELA-LITERACY.RST.9-10.5**: *Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., force, friction, energy).*
  - Lesson 10: "Students read about how oyster shells form and later develop a model that visualizes relationships among the terms presented in the text (calcium and carbonate ions, calcium carbonate, limestone)" (Teacher Edition, page 197).
- **CCSS.ELA-LITERACY.RST.9-10.10**: *By the end of grade 10, read and comprehend science/technical texts in the grades 9–10 text complexity band independently and proficiently.*
  - Lesson 13: Students will use reference materials to help them quantify their criteria and constraints. They will also use the information from the reference materials to help them develop site-specific solutions to mitigate the impacts of ocean acidification (Teacher Edition, page 248).

Materials explicitly state mathematics standards that are used in the unit using "Supporting Students in Making Connections to Mathematics" call out boxes at the end of specified units. Related evidence includes:

- **CCSS.MATH.CONTENT.HSN.Q.A.1**: *Use units as a way to understand problems and to guide the solution of multistep problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays*.
  - Lesson 8: Students need to be able to calculate molar mass in order to determine the mass of equivalent amounts (moles) of molecules. And since students are not able to count or measure a specific number of molecules, students need to be able to convert from moles to grams using molar mass (Teacher Edition, page 161).
  - Lesson 9: Students need to be able to calculate molar mass to determine the mass of equivalent amounts (moles) of molecules. Since students are not able to count or measure a specific number of molecules, they need to be able to convert from moles to grams using molar mass (Teacher Edition, page 176).
  - Lesson 11: As students plan their investigation, they have an opportunity to use the stoichiometric tools developed in Lessons 8 and 9 to determine an appropriate amount of sodium carbonate to mix with the given amount of calcium chloride (Teacher Edition, page 220).
  - Lesson 13: Students will use units and unit conversions to determine such quantities as volume of water in a given space, concentration of hydrogen ions, mass of base needed to adjust pH, and mass of CO_2 absorbed, in order to quantify the impacts of a given solution (Teacher Edition, page 248).

- Lesson 15: "In Ammonia Fertilizer Production, students use stoichiometric calculations to determine the masses of reactants and products in hydrogen production and use an understanding of this process to show that atoms and mass are conserved in reactions" (Teacher Edition, page 268).

Students are provided with a number of opportunities to engage in reading, writing, speaking, and listening throughout the unit. Related evidence includes:

- Lesson 1: The "Supporting Students in Engaging in Obtaining, Evaluating, and Communicating Information" margin box states, "The NGSS, as well as Common Core State Standards in English/Language Arts, require students to thoughtfully critique and leverage elements of the text to support a claim. Students should refer to parts of the video or transcript as they share their thinking. Press for the use of text evidence using the talk move, 'What in the video makes you say that?'" (Teacher Edition, page 32).
- Lesson 1: "Discuss data as a class. Display slide P. Bring the class back together and have each representative briefly explain their data and share whether or not they think their potential cause could be affecting oysters. It is not necessary to have multiple groups with the same data re-explaining their piece of data" (Teacher Edition, page 36).
- Lesson 1: Students individually brainstorm what may be causing oyster larvae to die, and then share their ideas with a partner before engaging in a class discussion to generate potential causes.
- Lesson 1: Students read "The Billion Oyster Project" and discuss the following discussion prompts as a class: "What other benefits do oysters have that we did not know about? How does the article fit with the ideas we had yesterday about what might be causing oyster die-offs?, What are communities doing to restore oyster populations and habitats?" (Teacher Edition, pages 37–38).
- Lesson 3: "Read about measuring pH. Say, I have a reading about pH that may help us. Display slide J and distribute Measuring pH and Connect, Extend, Question. Ask students to read Measuring pH and complete the protocol on Connect, Extend, Question. This protocol asks students to relate what they are reading to what they already know and what they are trying to figure out. Prompt students to consider the question they want to test and how what they read might help their investigation. After they have completed the organizer, ask students to compare their responses with a partner and update their responses with any new ideas from their partner" (Teacher Edition, page 67).
- Lesson 5: "Display slide A. Have students meet with a partner and give each pair a whiteboard and dry erase markers. Tell students they should develop an initial model that shows how carbon dioxide in the atmosphere interacts with water in the ocean to make it acidic. Explain that their models should show the movement of carbon dioxide between the atmosphere and ocean systems, and where in the ocean the interaction between carbon dioxide and water occurs. Give partners 5 minutes to develop their initial models" (Teacher Edition, page 93).
- Lesson 6: "Prepare students for the graffiti boards. Distribute the graffiti board chart paper around the room, with one board for each substance on each side of the room. Display slide B. Divide the class into eight groups and show students that there are four boards in their half of the room. Tell them they will have two minutes at each of the four boards and that you will tell them when it is time to move to the next one. Students should work with their group to answer the questions on each board. It is okay if they do not get to all of the questions. Explain to the students that when they move to a new board, they should answer any unanswered questions and add to or comment on the previous group's work. It is fine if they have comments that build

on their classmates' previous statements rather than the original question" (Teacher Edition, page 111)

- Lesson 6: "Discuss individual ideas in groups. Display slide E. Direct the students back into their groups and share their arguments with each other as to what they think caused the color change. Make it clear that the group does not need to reach consensus and that the emphasis should be on listening to each other's differing evidence for their ideas" (Teacher Edition, page 113).
- Lesson 7: Students complete a jigsaw read. "Read about interested parties in expert groups. Arrange students into groups of four. Display slide G. Read through the directions on the slide to have students form and move into expert groups. Ask students to gather in these expert groups. Depending on the number of students in the class, you may choose to divide those expert groups into smaller groups of three to four students. In expert groups, students will read one of four short vignettes about interested parties who are connected to the oyster problem. After they read the vignettes, students discuss questions 1-4 on Discuss Interested Parties. Students should record their responses in the space provided so that they can share those ideas with their home groups" (Teacher Edition, page 133).
- Lesson 10: "Read about interested parties in expert groups. Arrange students into groups of four. Display slide G. Read through the directions on the slide to have students form and move into expert groups. Ask students to gather in these expert groups. Depending on the number of students in the class, you may choose to divide those expert groups into smaller groups of three to four students. In expert groups, students will read one of four short vignettes about interested parties who are connected to the oyster problem. ✱ After they read the vignettes, students discuss questions 1-4 on Discuss Interested Parties. Students should record their responses in the space provided so that they can share those ideas with their home groups" (Teacher Edition, page 187).
- Lesson 10: "Set students up to clarify current thinking. Show slide L. Offer time for students to turn and talk with a partner about what they figured out from the reading" (Teacher Edition, page 187).
- Lesson 13: "Introduce the references. Ask students to look at the references before reading them. Ask, What are some parts these have? Listen for details such as location, the people profiled, and some of the strategies they are using to cultivate oysters in water with decreasing pH. Tell students that each group member is responsible for one site profile (Site Profile 1, Site Profile 2, OR Site Profile 3) and everyone must read Solutions Fact Sheet). As they read the site profiles, students should think about the criteria, constraints, and tradeoffs they have already come up with. Explain to students that the goal of these references is to help them pick a site to focus on so that they can develop more specific criteria and constraints and targeted solutions" (Teacher Edition, page 238).
- Lesson 14: "Review structures for peer feedback. Display slide B and distribute Peer Feedback Guidelines. Give students two minutes to scan Peer Feedback Guidelines. Say, What is one tip from this reference sheet or your own experience that you will focus on during peer feedback today? Have students turn and talk with a neighbor about their ideas" (Teacher Edition, page 253).

Suggestions for Improvement

None

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 experience a relevant and compelling problem and have structured opportunities to relate the problem to their own lives and communities.

The phenomenon and problem presented is one to which students can relate and it is clear to students that the problem is important to others. Additionally, students are supported to experience the phenomenon firsthand. Related evidence includes:

- Lesson 1: "Show Alana Quintasket video. Display slide C. Show https://youtu.be/zKyfbGbRz7c . After the video, say, This connection to food and being able to get your important foods is sometimes called 'food sovereignty.' Have students summarize key points. Display slide E. Ask them to identify 3 key reasons oysters are special to Alana's community. Student examples may include: the time scale of the community's dependence on oysters ('since time immemorial') a sense of sacredness or connection ('more than just our bodies') Focus on restoration efforts. Ask students to identify what Alana said about indigenous efforts to restore oysters. Students should identify that the Swinomish Tribal Community has a 'Swinomish Shellfish company' that is working to help with oysters. If they do not remember this from the video, ask them to consult the transcript or rewatch the video" (Teacher Edition, page 31).
- Lesson 1: "Show a video about oyster die-offs. Display slide F. Say, A scientist working with Alana's community talked to us about oyster die-off events and how scientists are helping restore this special food to the Swinomish Tribal Community. Distribute the Stuart Thomas Transcript. Then play https://youtu.be/UlOSbJD92og. Summarize oyster die-offs. Display slide G and have students collectively explain what a die-off is without interrupting them" (Teacher Edition, page 32).
- Lesson 1: Students read "The Billion Oyster Project" and discuss the following discussion prompts as a class: "What other benefits do oysters have that we did not know about? How does the article fit with the ideas we had yesterday about what might be causing oyster die-offs?, What are communities doing to restore oyster populations and habitats?" (Teacher Edition, page 37).

- Lesson 1: Students watch a video which shows the cleaning abilities of oysters. This is an optional activity and not all students will experience this video even though it appears to be significant for making sense of the problem.
- Lesson 1: “Show the effects of acidity on oyster larvae. Display slide T and say, The images on top show magnified oyster larvae growing in ‘normal’ ocean water at 1, 2, and 4 days of age. On the bottom are the same ages of larvae in more acidic water. Listen for students to note the misshapenness and the ‘trouble forming shells’ in the reading. Students may say shells are being eaten away” (Teacher Edition, page 38). This is an optional activity and not all students will experience this even though it appears to be significant for making sense of the problem.
- Lesson 13: “The site profiles in Lesson 13 also help give students a clearer picture of the experiences of stakeholders in the problem of oyster die-offs, and students are pushed to think deeply about this picture as they develop designs that would be appropriate for these stakeholders” (Teacher Edition, page 22).

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

- Lesson 1: The following prompt is provided for home learning: “Set up home learning. Display slide M. Distribute Traditional Foods. Say, We all have these kinds of ‘first foods’ in our communities. What are some that are important to our community? For example, what would we do without corn? It’s in our candy, our syrups and sweeteners, tortillas, chips, and cereal. Your assignment is to ask 5 people who are not in your grade about foods that are important to them, and what they would do without those foods. Tell students the class will start the next day by discussing the home learning prompt” (Teacher Edition, page 35).
- Lesson 4: “Consider related phenomena. Say, Let’s talk about related experiences where we adjusted the concentration of a drink to make it sweeter or less sweet. This will help us think about how we can prepare our solutions in the lab to make fairer comparisons. Display slide F. Ask, What are examples where you or someone else adjusted how concentrated or how diluted a drink was? What was done to accomplish that?” (Teacher Edition, page 78).
- Lesson 5: The “Attending to Equity” box states, “Engagement and sustained effort and persistence are intentionally developed here as we connect oysters back to issues of food sovereignty. Oysters are not compelling to all students on their own, but reminding students that oysters are an important food source to many people, as they heard about in the videos from Lesson 1 can increase engagement. If needed, reconnect students to the locally-sourced foods they rely on” (Teacher Edition, page 98).
- Lesson 7: The “Attending to Equity” box states, “Engagement and sustained effort and persistence are intentionally developed here as we connect oysters back to issues of food sovereignty. Oysters are not compelling to all students on their own, but reminding students that oysters are an important food source to many people, as they heard about in OP.VID.L1.051 and OP.VID.L1.052 can increase engagement. If needed, reconnect students to the locally-sourced foods they rely on” (Teacher Edition, page 136).
- Lesson 12: The following questions are provided on the handout: “Talk with some members of your family or community. When there is a problem to solve that impacts lots of people, other living things, and the environment, what do they feel is important to consider, and why? How do they think conflicting priorities should be managed?”, and “What are you thinking about now that you weren’t thinking about before reading the article and talking with family and community members?” (C.4 Lesson 12 Handout Extension Opportunity, page 1). This is an optional activity and not all students will experience this.

Suggestions for Improvement

- Consider providing teacher prompts to support the guidance provided for connecting to locally-sourced foods in Lessons 5, 7, 9, and 12.
- Consider revising the optional activities in Lessons 1 and 12 so that all students are encouraged to engage in them in order to experience the phenomenon more directly and connect learning to their homes and communities.
- Consider providing guidance for the teacher to cultivate student questions related to the phenomenon that come from their experience, community, or culture.

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 each lesson provides opportunities for individual and class reflections, small group collaborations, and whole-class discussions using the class consensus model and students' Progress Trackers.

Students are provided with opportunities to share and receive feedback on their thinking. Related evidence includes:

- Lesson 1: Students individually brainstorm what may be causing oyster larvae to die, and then share their ideas with a partner before engaging in a class discussion to generate potential causes.
- Lesson 1: "Generate ideas for investigations. Display slide DD. Say, We have so many ideas to explore! How could we start to investigate the answers to some of these questions? Title the next page in your science notebook 'Ideas for Investigations.' Choose one question or category of questions from our Driving Question Board and talk with a partner or partners near you to consider how we might find the answer—what investigation could we design, what data should we gather, and how could we figure this out in our classroom? Keep track of your ideas in your notebook. After you have discussed one question, move on to another. We will work for about five minutes, then we will share with the group…Thank students for sharing their ideas and tell them that the class will start the next lesson by thinking about how we might break down the study of these large scale system interactions into smaller scale systems to figure out how to tackle this problem" (Teacher Edition, page 45).
- Lesson 1: Students create an initial model individually to explain "How is more carbon dioxide in the atmosphere causing problems for oysters' shells?" (Teacher Edition, page 38). Students are asked to "Develop initial models. Display slide V. Pass out Initial Modeling and say, It sounds like we have a decent idea now of why oysters are dying, so let's try to put our ideas on paper. We

will draw a model that answers the question, 'How is more carbon dioxide in the atmosphere causing problems for oysters' shells?' We also want to make sure we can zoom in too, so we know what is actually happening to the oyster shell to harm it. Give students time to work on their models individually" (Teacher Edition, page 39). Students then engage in a whole group discussion to make a classroom consensus model.

- Lesson 4: "Compare predictions. Display slide D. Prompt students now to compare their predictions with a partner's and then discuss the two questions on the slide for two minutes. Then have students share their responses as a class" (Teacher Edition, page 76).
- Lesson 5: Students use a graffiti board to begin sharing ideas about why the water sample changed back in color. "Prepare students for the graffiti boards. Distribute the graffiti board chart paper around the room, with one board for each substance on each side of the room. Display slide B. Divide the class into eight groups and show students that there are four boards in their half of the room. Tell them they will have two minutes at each of the four boards and that you will tell them when it is time to move to the next one. Students should work with their group to answer the questions on each board. It is okay if they do not get to all of the questions. Explain to the students that when they move to a new board, they should answer any unanswered questions and add to or comment on the previous group's work. It is fine if they have comments that build on their classmates' previous statements rather than the original question. If you did not write the prompts on the chart paper, display slide C. As students work, circulate to ensure that they are focused on the task at hand and that all students are participating. Likely student responses are shown in the table" (Teacher Edition, page 111).
- Lesson 5: Teachers are provided with a section labeled "supporting students in engaging in argument from evidence" which asks teachers to offer prompts to help students compare their explanation to the provided details (e.g., data tables) (Teacher Edition, page 113).
- Lesson 7: Support is provided to guide teacher feedback to students based on student performance. This is done verbally as students do calculations to find mass of hydrogen gas using moles. The teacher materials state, "Give students time to work through the calculation in pairs, and help them reason through how to set up the calculation and what numbers and units need to go where in order to end up with moles of H_2 or grams of H_2. After students complete the calculation, have them add 'mole ratio' to their personal glossaries. You may wish to tell students that the use of mole ratios to solve problems is called 'stoichiometry.' If students struggle to set up and complete the calculation, use the prompts below" (Teacher Edition, page 156).
- Lesson 10: Students individually develop a model to explain what is happening to the oysters' shells under normal and acidified environments. During the next day (still part of Lesson 10), teachers are asked to say, "Begin by looking at peers' models. Display slide O. Have students open their science notebooks to an open page and make a chart with the title 'Compare shell-building models.' Students should follow the example shown in the slide and make two columns: 'Similarities' and 'Differences.' Have students display their models around the room. Then give them about 5 minutes to look at 1 to 2 other models in a gallery walk. Remind students to jot down in their notebook the similarities and differences they see while viewing the models. Discuss the similarities and differences in the shell-building models. Display slide P. Direct students to find a partner to discuss their observations from the gallery walk for five minutes" (Teacher Edition, page 190).

Students are provided with opportunities to show how their thinking has changed over time.

- Lesson 2: Students begin the use of a Progress Tracker to identify the subproblems they have identified as a class. The following teacher guidance is provided: "Progress Tracker is designed to guide students through the engineering design process. It focuses on the main subproblems identified in Lesson 2, and asks students to separately record the science ideas they figure out, how they might apply those ideas, and the criteria and constraints that impact how they apply those ideas. As students return to the Progress Tracker, prompt them to consider the interrelation of these columns, and how all subproblems are important to investigate in order to design solutions that address the large, complex problem identified in the Anchoring Phenomenon Routine. Example Progress Tracker offers some possible ideas students will have added to their Progress Trackers by Lesson 12. This also provides an opportunity to remind students that there are many ways to solve big problems, and that it is important to learn as much as we can about the problem, the people affected by it, and the people working on it, to make sure we can design solutions that do not further harm those who are already marginalized" (Teacher Edition, page 53). Students use and update this Progress Tracker in subsequent lessons throughout the unit.

- Throughout the unit, students work as a class to build and revise a class consensus model which displays the class thinking over time. For example:
    - Lesson 5: Students update the classroom consensus model with the information they have gained from the carbon dioxide data they have analyzed and "focus on the carbon cycle" (Teacher Edition, page 103).
    - Lesson 6: Students conduct simulations to determine that reactions are reversible and move in both directions. Students add this idea to the classroom consensus model.
    - Lesson 10: "Update carbon cycle model. Display slide X. Push the students to identify the limitations of the model. It currently does not address where the carbon in limestone came from, and also ask students if the shellfish and limestone should be incorporated into the model as parts of the biosphere, geosphere, hydrosphere, or atmosphere. If students do not know where to begin, remind them to refer to Oyster Life Cycle" (Teacher Edition, page 193).
    - Lesson 11: "Add agreed-upon ideas to the class consensus model. Point to the list of consensus ideas and say, We have figured out a lot of interesting things in this lesson! Do we still think that adding calcium carbonate to the water would help oysters? After students express agreement, direct students to the class consensus model and lead a discussion about how to add these ideas" (Teacher Edition, page 218).
    - Lesson 12: "Refer back to the class consensus model. Say, We want to make sure we are being thorough and bringing in everything we have figured out in this unit. Display slide C. Ask students to examine the class consensus model of the phenomenon. Ask them to consider if there is any other place within the system where it might be useful to intervene to prevent oyster die-off and related impacts. Update the class list of solutions with any new ideas shared. The final list should include, but not be limited to: Plant kelp or other aquatic plants to pull carbon dioxide from the water and increase pH. Add limestone or other carbonate sources to the water to increase carbonate ion concentration and support shell building. Add a base to the water to increase pH. Organize for laws or policies that limit the burning of fossil fuels and prevent ocean acidification at its source" (Teacher Edition, page 226).

Suggestions for Improvement

None

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	Adequate *(None, Inadequate, Adequate, Extensive)*

The reviewers found adequate evidence that the materials identify and build on students' prior learning in all three dimensions because while the progression of prior learning is outlined for all dimensions and expected prior learning is explicitly stated for DCI elements, expected prior learning is not provided for SEP or CCC elements in a manner that would reasonably allow teachers to fully understand the prior proficiency expected of students beginning this unit.

The unit materials clearly outline expected prior learning students should have with DCI elements as well as supports for clarifying potential alternate concepts. However, the expected prior learning is not outlined for SEP and CCC elements with the same level of specificity as they are with the DCIs. Related evidence includes:

- The "What elements of the NGSS three dimensions developed in this unit?" section of the Teacher Edition outlines how DCIs are developed over the course of the unit. For example, "In the first lesson set (Lessons 1-6), students learn that oyster die-offs occur in the Pacific Northwest due to ocean acidification, develop initial models of how this might occur, and build a Driving Question Board. They decide they want to design solutions to help oysters and break the problem of oyster die-offs due to ocean acidification into smaller sub-problems. They investigate acids and bases to build a model of how increased atmospheric carbon dioxide causes ocean acidification. They investigate how carbon dioxide gets into the ocean and how carbon moves through some of Earth's systems. They use a computational model to figure out how acidification and other processes can naturally reverse due to shifts in chemical equilibrium. Finally, they think about the interest different groups of people have in solving the problem of oyster die-offs and engage in a mid-unit transfer task. This lesson set builds toward the DCI elements associated with the following performance expectations: HS-ESS2-6, HS-ETS1-2, HS-PS1-6, and HS-ETS-1-1" (Teacher Edition, page 15).
- The "How does the unit build three-dimensional progressions across the course and program?" section (Teacher Edition, page 18) outlines the elements of each dimension students should be familiar with. For example:
  - *"*This unit uses and builds upon Disciplinary Core Ideas (DCIs) and other science ideas that students should have previously developed in the OpenSciEd High School Biology and Chemistry courses. Carbon moves from the atmosphere to the biosphere through photosynthesis and from the biosphere to atmosphere through respiration. When

organisms die, decomposers break them down, transferring carbon to the geosphere. (B.2 Ecosystems: Matter & Energy) Engineers break problems down into smaller parts in order to more easily solve them. (B.2 Ecosystems: Matter & Energy) We can specify criteria and constraints based on societal needs and wants. (B.4 Natural Selection & Evolution of Populations) Certain quantities can be used as conversion factors to move between amounts of one measure and comparable amounts of another measure for a substance. (C.1 Thermodynamics in Earth Systems) An ion is formed when an atom loses or gains electrons. Ionic compounds dissolve into their constituent ions in water. (C.2 Structure & Properties of Matter) The polarity of a molecule is determined by its structure. Water molecules are polar. (C.3 Molecular Processes) Chemical reactions can and should be balanced to show that atoms are conserved. (C.3 Molecular Processes)" (Teacher Edition, page 18).

  - "This unit reinforces and builds from the following science ideas from the OpenSciEd Middle School sequence. Particle motion in a substance changes as thermal energy is added or removed. (6.2 Thermal Energy and 6.3 Weather, Climate & Water Cycling) Atoms make up molecules. Atoms rearrange in chemical reactions. (7.1 Chemical Reactions & Matter)" (Teacher Edition, page 18).
  - "This unit uses and builds upon high school level Science and Engineering Practices (SEPs) and Crosscutting Concepts (CCCs) that students should have previously developed in OpenSciEd High School Biology and will continue to build in future units in OpenSciEd High School Chemistry and Physics. The progression of these practices and concepts across the program are as follows: [two tables show alignment as described]" (Teacher Edition, page 19). Information is not provided for the expected level of proficiency for individual SEP and CCC elements.
- The "What are some common ideas that students might have?" outlines some ideas students might have coming into the unit. In addition to listing possible ideas students may have, the following teacher guidance is provided: "Students will come into the unit with many ideas about acidity and related chemical processes derived from previous classroom experiences, intuitive understandings of the way the world works, everyday experiences with movement, and the conversations they have had with parents, friends, and family members. Some relevant ideas that students may come into the unit with include the following: 1. Ocean acidification means that the ocean is becoming acidic, rather than increasing in acidity or decreasing in pH; 2. Increased atmospheric carbon dioxide due to human activity primarily causes global climate change without other negative effects; 3. Acids are always dangerous and corrosive; 4. All corrosive substances are acids; 5. A base is a part of an acid; 6. A solution with a higher pH is more acidic; 7. Only solids can dissolve in liquids; 8. All acids or solutions of the same acid are the same in their 'strength'; 9. All reactions are irreversible; 10. Irreversible processes are chemical while reversible processes are physical; 11. Equilibrium means that no reaction is occurring; 12. Neutralization breaks down an acid into something safe; 13. The coefficients in a chemical equation can describe the mass ratios of the substances in the reaction" (Teacher Edition, page 20).

Learning generally progresses logically throughout the materials. This is often clearly outlined in the "Where We Are Going/Where We are Not Going" or "Supporting Students In…" sections of the materials. There are some mismatches between prior SEP or CCC elements claimed as prior learning and that which is described as being developed in the unit. Related evidence includes:

- Lesson 1: "Students will leave this lesson without a clear particle-level explanation for how carbon dioxide gets into the ocean from the atmosphere, how carbon dioxide causes ocean acidification, or why increased acidity makes it difficult for oysters to build shells. Students explore these ideas throughout the unit, starting in Lesson 3. Partial understandings are perfectly acceptable here. The term 'pH' is also intentionally downplayed in this lesson so students can leverage the more familiar-sounding and evocative 'acidity'. Relevant chemical equations will also be discovered throughout the unit as students seek to answer questions asked in this lesson" (Teacher Edition, page 30).

- Lesson 1: The "Supporting Students in Developing and Using Patterns" section states, "Students are first trying to identify potential cause-and-effect relationships between the microscopic and macroscopic worlds so that they can then test them using the simulation in the next step. Remind students that we spend time on argumentation and developing a hypothesis to clarify our ideas so that we can obtain evidence for or against their accuracy" (Teacher Edition, page 35).
- Lesson 2: "Students break down engineering problems that are large and global, such as ocean acidification, into smaller problems that can be investigated in class (SEP: 7.6; DCI: ETS1.A.2). This relationship of large problems to smaller subproblems brings into play interrelated issues of scale and patterns (CCC: 1.1, 3.1). Students brainstorm initial ideas about what is happening with oysters and look across each others' ideas to find patterns (CCC: 1.1). Finally, students build an argument about the focus of their initial search for solutions to ocean acidification (SEP: 7.6). They evaluate proposals by comparing scale and patterns, and prioritize counteracting negative human impacts on oyster systems (SEP: 7.6; DCI: ETS1.A.2; CCC: 1.1, 3.1). One argument is that students are well positioned to design solutions for local mitigation in chemistry class (SEP: 7.6; DCI: ETS1.A.2). This motivates future investigations centered around chemical engineering" (Teacher Edition, page 50).
- Lesson 3: "At this point, students know that the ocean is becoming more acidic which is causing problems for oysters. This lesson addresses how carbon dioxide lowers the pH of water through a series of chemical reactions, which builds on the data students saw in Lesson 1 and prepares students to investigate the particle model of the process in Lesson 4. Students identify data needed to make progress on addressing subproblems they identified in Lesson 2 (SEP: 3.1). They work with a partner to brainstorm examples of substances that contain both carbon dioxide and water. Students use some of the substances on the list, as well as additional substances, to design investigation plans in small groups to test whether substances that contain carbon dioxide and water are acidic (SEP: 3.1; DCI: PS1.B.2). After completing their investigations, students discuss the evidence they gathered to come to the conclusion that carbon dioxide in water causes water to become acidic (SEP: 3.1; DCI: PS1.B.2, ESS2.D.3; CCC: 2.1). Students evaluate the usefulness of the types of evidence gathered and determine what tools are best to use moving forward (SEP: 3.1). Students wonder about what pH measures. They are given a reading and website to gather information to help them answer questions about pH values (SEP: 8.2; DCI: PS1.B.2). They are able to integrate information from their investigation data, the reading, and the website to determine how a slight change in pH represents a larger magnitude change in the concentration of hydrogen ($H+$) ions in the solution (SEP: 8.2; DCI: PS1.B.2; CCC: 3.4)" (Teacher Edition, page 63).
- Lesson 6: The "Supporting Students in Engaging in Argument from Evidence" section states, "Students are first trying to identify potential cause-and-effect relationships between the microscopic and macroscopic worlds so that they can then test them using the simulation in the next step. Remind students that we spend time on argumentation and developing a hypothesis to clarify our ideas so that we can obtain evidence for or against their accuracy" (Teacher Edition, page 113).

- Lesson 6: The “Supporting Students in Developing and Using Cause and Effect” section states, “Students are first trying to identify potential cause-and-effect relationships between the microscopic and macroscopic worlds so that they can then test them using the simulation in the next step. Remind students that we spend time on argumentation and developing a hypothesis to clarify our ideas so that we can obtain evidence for or against their accuracy” (Teacher Edition, page 116).
- Lesson 9: “The targeted disciplinary core idea that we are beginning to develop is: PS1.B.3: Chemical Reactions. 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. Explanation of Crossouts: The primary concern of this lesson is stoichiometry, which relies on balanced chemical equations. Other lessons in this unit address the rest of this DCI, especially when students account for the differences in the degree to which different acids and bases will dissociate. This lesson focuses on applying what students figured out about mole ratios and molar mass to figure out how to raise the pH of water within the oyster tank. Students use mole ratios and mass to calculate the amount of base that would need to be added to oyster hatchery tanks to return the pH to safe levels. This is one step in helping students use stoichiometry to define engineering problems and develop solutions in Lesson Set 3 (PS1.B.3; CCC: 3.1). This lesson comprises several opportunities for students to practice with stoichiometry, unit conversions, and applying contextual information in the pursuit of predicting chemical reactions. Because these are complex, multi-step mathematical calculations, this lesson provides ample opportunities for support and practice (SEP: 5.5; CCC: 3.1). On Day 1, students work with a partner in a more scaffolded way to practice with Ocean Water Calculations by calculating how much base would need to be added to a small oyster hatchery operation with only 1000 L of water (DCI: PS1.B.3). On Day 2, students can choose to work with a partner or to work alone, with or without the scaffolds from the prior day, as they scale up the calculation of the amount of NaOH that would be needed to neutralize the added hydrogen ions in the ocean (SEP: 5.5; DCI: PS1.B.3; CCC: 3.1)” (Teacher Edition, page 166).
- Lesson 12: “This lesson is designed to coherently build new ideas related to the following disciplinary core ideas: ETS1.B.1: Developing Possible Solutions. When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. ESS3.C.2: Human Impact on Earth Systems. Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation. This lesson requires ‘putting the pieces together’ for several previous lessons in order to do engineering thinking about the unit problem: oyster die-offs. Students begin by returning to their progress trackers and consider the earth systems where they can consider societal requirements and reduce environmental degradation. The lesson begins with students revisiting the oyster die-off prevention system they are developing that has interacting components, and they redefine the interacting social, technical, and environmental criteria and constraints they first visited in Lesson 7 (SEP: 1.8; CCC: 4.1). At the high-school level, students should generate their own criteria and constraints rather than be provided a list. In this lesson, students revisit emerging ideas about technical and social requirements and limitations for design, developed in Lesson 7. Students update their list of criteria and constraints based on what they have figured out since then. They bring out their lists of interested parties to understand the perspectives of those most impacted by oyster die-offs to improve the depth of engineering design thinking by including broader, more complex elements of the system. Students also consider how criteria and constraints are interrelated, are sometimes contradictory, and may need to be quantified to implement a particular solution, motivating the idea that solutions must be developed in

context. In the final activity, students brainstorm possible locations in the system that they can impact with their engineering design. When evaluating these solutions, students take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts (DCI: ETS1.B.1; CCC: 4.1). These considerations are addressed contextually throughout the lesson: cost and reliability are addressed with slide D, and aesthetics, cultural impacts, and safety are addressed in slide E. In this final activity, students engage with the design problem as engineers, who make major contributions by developing technologies such as oyster die-off prevention systems that produce less pollution and waste and that preclude ecosystem degradation (DCI: ESS3.C.2)" (Teacher Edition, page 224).

- Lesson 14: "The targeted disciplinary core ideas developed in this lesson are: ETS1.C.1: Optimizing the Design Solution. Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (tradeoffs) may be needed. ESS2.D.3 Weather and Climate. Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate. In the first half of this lesson, students build on the initial criteria that they developed in Lessons 7 and 12 in order to evaluate competing design solutions in light of the complete set of evidence, explanations, limitations and trade-offs of relevant criteria and constraints, and ethical issues they have encountered (SEP: 7.1; DCI: ETS1.C.1). They have to build the tool they will use to evaluate each others' ideas (CCC: 3.4). They share solutions and discuss the decisions they made to prioritize certain criteria over others as they addressed a specific subproblem in a specific context (DCI: ETS1.C.1). Students will use their criteria and constraints to evaluate the engineering design solutions they developed in Lesson 12 (SEP: 7.1). Students will continue to highlight the importance of context and orders of magnitude to a design solution as they provide feedback on another group's design (CCC: 3.4). Students will synthesize the key science ideas from this unit as they compare design solutions and consider the different options for preventing oyster die-offs (SEP: 6.5). They encounter the root cause of oyster die-off events: the production of atmospheric CO2 by humans that impacts climate, which they have already investigated and modeled in Polar Ice Unit (DCI: ESS2.D.3)" (Teacher Edition, page 252).
- Lesson 5: "Students previously used SEP: 3.4: Select appropriate tools to collect, record, analyze, and evaluate data in Polar Ice Unit. Students build new understanding of this SEP element as they evaluate an investigation plan to include additional tools to collect data" (Teacher Edition, page 96). This same SEP is claimed as a focus element developed throughout the C4 unit, but also acknowledged as previously developed in an earlier unit.
- Lesson 5: "Students build on CCC: 2.2 developed in Electrostatics Unit. In this lesson they connect small scale systems back to a large-scale system. Later in the unit students develop a new use of the CCC as they predict relationships of human designed, small-scale systems and scale those up to natural large-scale systems (Lesson 6, 7, 10, and 15)" (Teacher Edition, page 96). This same CCC is claimed as a focus element developed throughout the C4 unit, but also acknowledged as previously developed in an earlier unit.

Suggestions for Improvement

- Consider explicitly identifying the expected prior learning for CCC and SEP elements in the same manner in which it is done for DCI elements in the Teacher Edition. As currently constructed, teachers must look through other OpenSciEd units to piece together prior learning.
- Expected prior student learning is described in terms of prior units' learning rather than clearly stating what expected levels of proficiency are required to engage with this unit. Without strong knowledge of prior units' learning progressions, it would be challenging for teachers to

meaningfully understand what students are expected to come into the unit able to do. Consider providing concise descriptions of expected prior knowledge for each of the targeted SEPs and CCCs at the element level.

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.

All scientific information in the materials is accurate. Specific teacher guidance is provided to clarify aspects of what students are learning and what may be missing, as well as to provide important information regarding scientific accuracy. Related evidence includes:

- Lesson 6: "The goal is to help students figure out a piece of the puzzle of why reversible reactions might occur. The picture they build here is incomplete, as it does not account for the bond strength (or strength of intermolecular forces) in the products, but these pieces may be added as students explore bond strength and energy more deeply in OpenSciEd Unit C.5 Which fuels should we design our next generation vehicles to use? (fuels unit)" (Teacher Edition, page 122).
- Lesson 8: "Oxalic acid is used here because it is diprotic, so it does not react with NaOH in a 1:1 ratio. Additionally, it is solid, making it easier for students to measure masses to combine. In this unit, oxalic acid is written as $H_2C_2O_4$ to help students focus on the diprotic nature of the acid when they are predicting the ratio to result in a neutral solution. You may want to point out to students that, since it is an organic acid, oxalic acid is most often written as HOOC-COOH. If they are curious about why that is, it may be helpful to explain to students that the hydrogen in each 'COOH' group is the acidic hydrogen that will separate as H^+ in aqueous solutions" (Teacher Edition, page 149).
- Lesson 9: "Note that students have not yet learned that oyster shells are made of calcium carbonate and thus will likely have models which only show H^+ ions reacting with the 'shell particles.' Also use this opportunity to point out that if their models were accurate, both oyster larvae and adults would experience die-offs at equal rates, but in reality larvae are much more strongly impacted" (Teacher Edition, page 186).
- Lesson 12: "When developing engineering solutions, it can be helpful to learn about how others have attempted to solve the problem. The two articles below detail real-world attempts to use seawater to reduce CO in the atmosphere and enhance ocean alkalinity. https://newsroom.ucla.edu/releases/using-seawater-to-reduce-co2-in-atmosphere https://www.ceaconsulting.com/wp-content/uploads/Ocean-Alkalinity-Enhancement-CEA-proceedi ngs-doc..pdf" (Teacher Edition, page 226).

In addition, teacher notes are provided when additional science concepts not in the lesson are relevant and may help with scientific understanding. Related evidence includes:

- Lesson 5: "Chemical equilibrium is also influenced by temperature. This idea is not directly addressed in the NGSS. It is not addressed in this unit, either, as the mechanism requires a more complete understanding of bond energies that will be developed in Unit 5" (Teacher Edition, page 110).
- Lesson 10: "There are several additional factors at play in ecosystems that are outside the scope of the NGSS but may occur to the teacher. Do not pursue these ideas with students unless they have already suggested the concepts based on evidence. 1. Carbon dioxide, like many gasses, dissolves more easily in lower-temperature water, as the gas molecules do not escape as easily when the particles around them are moving relatively slowly. 2. This will not show up in students' investigations, but calcium carbonate formation from dissolved ions is actually favored in the long run at lower temperatures. This occurs because of the relative bond energy of the intermolecular forces that water forms with the dissolved ions compared to the bond energy of the calcium carbonate bond. 3. Other compounds that do not contain carbonate may also support marine ecosystems" (Teacher Edition, page 214).

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 numerous differentiation strategies focusing on a myriad of potential student needs, including multilingual learners, and struggling readers.

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

- Lesson 1: The "Attending to Equity" section states, "It is important to encourage students to represent their ideas in a way that is meaningful to them. This may include using any languages they can to best think through their ideas. As they continue to express their ideas and hear others' ideas, their linguistic repertoires in science will deepen. This practice of encouraging translagnaging[sic] should be encouraged in all OpenSciEd HS Units" (Teacher Edition, pages 31–32).
- Lesson 3: The "Attending to Equity" section states, "Supporting Emergent Multilinguals: Before students engage in whole-class discussions, it can be helpful to first provide them with the opportunity to work in pairs, triads, or small groups on ideas related to their reasoning. Smaller groups can be especially helpful to emerging multilingual students because they offer a chance to engage in sensemaking with their peers. They also offer students a comfortable space to use their linguistic and nonlinguistic resources to express their ideas as well as learn from other students" (Teacher Edition, page 64).
- Lesson 9: The "Attending to Equity" section states, "Students often benefit from a sentence starter in short writing exercises because it can orient them to the task of writing their ideas. Once the first idea is out, a second idea or more details can flow more easily. The basis of this cognitive science is rooted in schema-setting, whereby activating a base of knowledge and language can result in deeper thinking over time" (Teacher Edition, pages 170–171).
- Lesson 10: The "Attending to Equity" section states, "Encourage students to express the new ideas from the Consensus Discussion using a model that makes sense for them. For some emergent multilingual students, encourage them to use space to express ideas in the language that they feel most comfortable with. Remind students that the model they build from the Consensus Discussion is a low-stakes opportunity to make sense of what they are learning without the worry or anxiety that comes with graded work" (Teacher Edition, page 191).
- Lesson 13: The "Attending to Equity" section states, "You may encourage students to use a translator device if the text is not in their home language" (Teacher Edition, page 238). While this may provide support for some multilingual learners, additional support about which translation tools may be valuable and what to do if translator tools are not available may be needed.

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

- Lesson 1: The "Attending to Equity" section states, "If reading aloud to the whole class is not preferred, form choice reading groups where students can choose to 1) listen to you read in a small group, 2) read with a partner, or 3) read silently. This reading structure can give students choice in engagement" (Teacher Edition, page 37).
- Lesson 10: The "Attending to Equity" section states, "Students benefit from options for reading. You may read the text aloud to the class or provide options such as having students read aloud with a partner or in a small group. The prosody or pace of a reading, with pauses and inflection, is more obvious when read aloud for many students and it can support meaning-making" (Teacher Edition, page 187).
- Lesson 13: The "Attending to Equity" section states, "You can have students read individually or aloud with a partner. Allowing students a choice in how the information is represented (hearing it read aloud or individual reading time) can support comprehension for a wider range of learners" (Teacher Edition, page 238).
- Lesson 14: The "Attending to Equity" section states, "The introduction to this assessment is text heavy. This is necessary to provide students with important background information, but it may

also cause some students to worry or 'lock up.' Consider reading the introduction aloud to students to help them feel more comfortable" (Teacher Edition, page 266).

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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 4: "Extension Opportunity: The Electronic Exit Ticket introduced three types of living things that need certain pH ranges to survive. This reading, pH and Organisms, will explore these phenomena in greater detail. Because the reading will not be discussed in the next lesson, the recommendation is to provide it as an optional extension opportunity for interested students. If many of your students did not see the anchor as directly relevant to their lives or communities, consider using this reading to support an increased sense of relevance for them. It may help motivate the need to continue to figure out how acids and bases interact with living things. If you do this, also consider allocating additional time at the start of the next lesson to have students select a new question the reading raised for them, share it with others, and add it to the Driving Question Board" (Teacher Edition, page 85).
- Lesson 10: "Extension Opportunity: Model the reaction between vinegar and marble chips. If students are motivated to investigate the particle-level dissolution of calcium carbonate in acid, prompt them to add a model to their science notebook with their ideas of how H+ ions from acid may chemically react with the shell. Note that students have not yet learned that oyster shells are made of calcium carbonate and thus will likely have models which only show H+ ions reacting with the 'shell particles.' Also use this opportunity to point out that if their models were accurate, both oyster larvae and adults would experience die-offs at equal rates, but in reality larvae are much more strongly impacted" (Teacher Edition, page 186).
- Lesson 12: "Extension Opportunity: To seed the dilemma of how to develop solutions when there are conflicting priorities, consider guiding the class through the attached Extension Opportunity. You might make time in class to read the linked article, suggest that students complete part 2 for home learning, and then revisit the reflective questions during the next class. If you read the article during class, consider offering guidance for how students might annotate the text. The Iowa Public Radio article https://www.iowapublicradio.org/ipr-news/2021-04-22/des-moines-water-works -advances-plans-to-build-new-wells-in-light-of-river-pollutants linked in Extension Opportunity discusses how Des Moines, Iowa, is dealing with nitrate pollution in drinking water. There are many other communities around the world that are dealing with nitrate pollution from agriculture and the exacerbated impacts of climate change. If you would like to substitute this article with another, we suggest finding a piece that highlights social, technical, and scientific dimensions of the problem, as well as tensions in the priorities of various interested parties. Local public radio affiliates and environment-focused publications often report on such issues" (Teacher Edition, page 229).
- Lesson 15: "Extension Opportunity: Students may finish the assessment at different times, so you may wish to utilize an extension activity. This activity is ideal for students who complete the assessment early on day 2. As students finish, have them read The Legacy of Haber and Bosch and respond to the prompt in their science notebooks. Students should recognize that the technology developed by Haber and Bosch has been used to provide great benefits to the world, but also to commit serious violence against human beings. The information in this reading may be surprising and even disturbing to some students, so prepare for a range of reactions. Allow and encourage those who are interested to conduct further research. Do not engage in a class discussion around this reading unless you have sufficient time and a strong classroom community where students can have a respectful and thoughtful discussion after the mental challenge of an assessment. Another extension opportunity is to have students research the

ways in which engineers are trying to make the Haber-Bosch process more environmentally friendly" (Teacher Edition, page 267).

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

- Lesson 1: Students are assigned one of four data sets to analyze. The following teacher guidance is provided: "The four data sources differ in complexity. Pollution Data is easiest to analyze, followed by Carbon Dioxide Maps. Ocean Temperature Map and Ocean Acidity Maps have more challenging maps embedded in them. You may wish to distribute these materials to students so that each student can be successful with the data they are given" (Teacher Edition, page 34).
- Lesson 6: "If students are unsure whether the simulation showed these ideas, demonstrate it for the whole class at once. What is happening in the reaction can be viewed most easily by slowing the simulation down with dissociation off and pausing the model after a CO_2 molecule is formed where there previously was no CO_2. This should be accompanied by the disappearance of H_2CO_3, visible both in the container and on the graph" (Teacher Edition, page 118).
- Lesson 5: "If students are having trouble getting to the idea that the forward and reverse reactions must be happening at the same rate, walk the class through this using the simulation. Run it slowly and point out places where 'products' are forming and where 'reactants' are forming. Say, Both these events happen, but the overall concentrations stay about the same. Let's think about a town of 1000 people. If the town's population has been exactly 1000 for 50 years, what could that mean? Students will say that either nothing is happening or that every time a person dies or leaves town, a baby is born or someone new comes into town. Then return to the prompt about keeping a stable concentration" (Teacher Edition, page 120).
- Lesson 6: "If students are stuck on other aspects of reactions besides bonds breaking and forming, try to have them make relevant connections. For example, if students emphasize different elements involved in reactions rather than bonds, ask them to tell you, or demonstrate how to draw a particle model of the reaction on the whiteboard. Have students highlight in their model where atoms are breaking apart and coming together. Make sure they connect that to bonds are breaking and reforming. If students are focused on 'types' of bonding (covalent, ionic, metallic) rather than strengths, ask them how the differences between bonds show themselves in real life--for example, How do covalent and ionic compounds behave differently in water?" (Teacher Edition, page 121).
- Lesson 8: "The mole concept was introduced in Lesson 4. A mole is not intuitive for many students. If they are struggling with the ideas of a term to represent a large quantity, give them the examples of a dozen or a century, then ask them to think about how many donuts are in a dozen, how many cookies, etc. Emphasize that a dozen is always 12 things, and likewise a mole is always 6.02×10^{23} things. Like a dozen, a mole provides a shortcut to counting and comparing large numbers of particles. Molar mass can also be challenging, and using the example of a dozen can help here too. Ask students to think about a dozen ping pong balls and a dozen bowling balls (or pick anything with a small mass and a large mass). Ask them if they would weigh the same—the obvious answer is no. Explain that the same number of two objects can have very different masses if one object has a larger mass than the other" (Teacher Edition, page 156).
- Lesson 9: Additional practice is provided for completing calculations. "We recommend that any additional practice in this or other units be contextualized within the unit, or at least in support of figuring out another phenomenon that is interesting to students. Stoichiometry Practice is designed to help students practice using the mathematical tools from the last two lessons using the phenomenon of carbon sequestration. Carbon sequestration is also a notable, if imperfect,

technology to help slow ocean acidification and climate change. See Stoichiometry Practice Key for solutions" (Teacher Edition, page 176).

- Lesson 10: The "Attending to Equity" box states, "You may wish to tape some of the cards from Reaction Cards on the board to help show speakers' thinking throughout this discussion. This can help students track their peers' ideas more easily. You may additionally wish to leave decks with any students who want them to use throughout the discussion so that students can engage with the ideas in the way that is most meaningful to them" (Teacher Edition, page 216).
- Lesson 13: "If students are struggling to complete parts of their planning documents, direct them to the relevant information in the reference materials. If they are still struggling to find information on their own, help them come up with some useful search terms. If Internet access is available, talk with students about prioritizing the criteria for which they already have information. There are several different solutions that students may want to develop, depending on the criteria, constraints, and site they choose. There is not one list of 'correct' or 'acceptable' solutions, and the goal in this activity is not that students select a particular solution. The important part is that students engage with the engineering process and work to use the science ideas and mathematical models they have developed" (Teacher Edition, page 242).
- Lesson 13: "Students remain with a partner from their original group so that they have someone to evaluate the poster with. They can decide together on what feedback to leave in the next step. This allows students who may feel less comfortable asking questions or evaluating another group's design solution on their own to have the social support of a partner as they explain their design solution and provide feedback to another group. This activity gives students the opportunity to learn about one other design solution in detail. Students will have the opportunity to view all posters during the gallery walk on Day 2. If time permits, you could have students find a second set of partners and repeat the sharing and feedback steps" (Teacher Edition, page 255).

Suggestions for Improvement

- Consider providing explicit guidance for students with disabilities who may be unable to participate in some of the data collection activities beyond the use of group work.
- Consider providing more explicit suggestions for when it might be appropriate to offer translation tools for multilingual students as well as what types of tools might best support the chosen task. Translation tools often lack accuracy in areas of scientific language and not all languages have well-developed translation tools readily available.

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. Frequent guidance is provided for teachers to see links in engagement across lessons. These strategies provide links to ensure that students see how their learning is connected to their progress as they figure out the phenomenon and attempt to solve the problem.

Teacher guidance is provided for linking learning across lessons to ensure that students see learning as coherent. Related evidence includes:

- Lesson 2: "Navigate to today's work. Say, we ended up with a lot of questions and ideas to investigate last class! But let's take a moment to think about the different scales at work in this phenomenon and problem. Display slide A. Give students a couple of minutes to turn and talk with a partner" (Teacher Edition, page 51).
- Lesson 3: "Revisit the subproblems identified in Lesson 2. Revisit the list of subproblems at the top of Progress Tracker. Display slide A and say, In the last lesson, we figured out that the big problem of oyster die-off can be broken into more manageable subproblems. Ask students to do an individual quick write to answer the prompts on slide A. After a few minutes, lead a discussion to share student responses" (Teacher Edition, page 64).
- Lesson 3: "Discuss investigation results. Make sure that each group's investigation data poster is visible to everyone in the class. Display slide H." Ask questions such as: "what patterns are you noticing in the class data? How do the data either support or refute the claim that increasing atmospheric CO_2 levels cause ocean water to become more acidic? What indicator, the pH strips or bromothymol blue, provided more useful data? Why? Based on your group's measurements and/or class data, what other water that was tested could be considered a control? Why? What implications does using distilled water as a control and pH strip indicators have on future investigations?" (Teacher Edition, page 66).
- Lesson 5: "Model initial ideas for how CO interacts with water to make it acidic. Display the class consensus model from Lesson 1 for students to examine. Remind students that we were wondering about how carbon dioxide moves from the atmosphere into the ocean and what interactions between carbon dioxide and water result in an increase in H ions in the water" (Teacher Edition, page 93).
- Lesson 4: "Revisit the lab setup from Day 1. Show slide X. Suggest that the class look back at the Dissolving Carbon Dioxide Lab from Day 1. If students have proposed possible solutions for taking CO out of the ocean, direct them to the lab as a way to test their ideas on a familiar model. If students did not suggest many ideas, say, If we used that lab to study how CO got into the water, maybe we can use it to see if we can take the CO back out. Discover that the

dissolved CO from Day 1 is no longer in the water. Give students some time to mention this on their own, as they will notice that the colors look different than on the previous day. Use this noticing as a way to problematize and motivate students to investigate what happened in the next lesson" (Teacher Edition, page 102).

- Lesson 8: "Discuss what we figured out last class and where we decided to go next. Display slide A. Have students turn and talk about the questions on the slide and then share their ideas as a class. Students should recall from the previous lesson that adding something to an acidic solution changed the pH, making it less acidic, so maybe adding something to acidic water could be a solution. However, at this point they do not know how much would be needed or how exactly to figure that out" (Teacher Edition, page 151).
- Lesson 8: "Discuss how we can use what we have learned today. Display slide MM. Cue students to think about how they can apply our new knowledge to helping oysters next class. Give students a few minutes to discuss the prompt with a partner, then ask for volunteers to share what they discussed with their partners" (Teacher Edition, page 160).
- Lesson 9: "Discuss what we figured out last class. Display slide A. Have students share what they figured out in Lesson 7. Ask them to list the important ideas, such as what the coefficients in balanced reactions mean, how we can 'count' particles, and any other tools we can use to help oysters. Students should recall: When we balance chemical equations with coefficients, we show the mole ratios of atoms or molecules that are reacting with each other. We can use the atomic masses on the periodic table to determine the mass of one mole of a substance. One mole of anything is the same number of particles or objects. We can use molar mass and mole ratios to calculate an exact amount of base to use to neutralize an acid" (Teacher Edition, page 167).
- Lesson 9: "Discuss neutralizing the entire ocean. Now that students have calculated the mass of NaOH needed for both an oyster tank and for the entire ocean, ask students how these two systems might differ other than just their size. Display slide O. Encourage students to refer back to what they figured out in Lesson 5 and to think about how the proposed changes would impact the ocean-atmosphere system", and later, "Once students realize that dumping NaOH into the ocean may have unintended consequences or might not be feasible, or at least might not be the ideal solution, have them think about what else we should do or figure out in order to find solutions that won't harm oysters or other marine life, while working to restore oysters as a food source" (Teacher Edition, page 175).
- Lesson 10: "Encourage students to focus on solutions within a workable time scale. Display slide A. Ask students to turn and talk to discuss the solution proposed at the end of our last lesson and why we are uncertain about that particular solution" (Teacher Edition, page 181).
- Lesson 11: "Reflect on where we came from. Display slide A. Lead students into this lesson by asking what the class had figured out and was wondering at the end of Lesson 10" (Teacher Edition, page 205).
- Lesson 11: "Update Progress Trackers. Show slide V. Ask students to work with a partner to update their Progress Trackers with any new ideas from the day's discussion. Say, At this point, we have come up with a lot of interesting ways to use chemistry to help oysters. In order to determine if any of those solution(s) are ones that we would recommend for helping protect oysters, we will need to evaluate them in light of the different criteria and constraints we need to keep in mind. Let us plan to do that tomorrow" (Teacher Edition, page 220).
- Lesson 12: "Navigate. Display slide A. Say, Last class we updated our Progress Trackers, but it has been a while since we have reviewed what we have figured out. What else have we learned that helps us explain the phenomenon of oyster-die off to restore this important food? Direct students to revisit their Progress Trackers and discuss with a partner, then quickly debrief partner discussions", and later, "Say, We have figured out a lot in this unit and answered quite a

few of our questions. We have already done some thinking about possible solutions to protect oyster larvae, but let's take this opportunity to think more about ways in which we could prevent larvae die-offs" (Teacher Edition, page 225).

- Lesson 12: "Summarize next steps. Say, After listening in on your conversations in groups, it sounds like we need to know more about the specific local contexts in which we will develop our solutions. I will start to dig up some information and bring that to our next class" (Teacher Edition, page 231).
- Lesson 13: "Review what students decided during the previous class. Display slide A. Pair students so they are with someone they did not work with last class. Give students time to turn and talk to share with each other the general solutions their groups came up with, as well as current lists of criteria and constraints" (Teacher Edition, page 237).
- Lesson 13: "Students show their solutions. Display slide K. As students finish their posters, display them in the classroom or in a nearby public space such as a hallway. In the next lesson, students will be presenting their solutions to each other and providing feedback. Tell students that they will have an opportunity to learn from each other in the next class. Have a brief discussion with students about the benefits of peer evaluation and having the opportunity to see each other's solutions" (Teacher Edition, page 247).
- Lesson 15: "Share impressions from the Lesson 14 exit ticket. Thank students for sharing their reflections on the engineering design process at the end of the last lesson. Share a few anonymous student responses or general impressions of responses that you think reflect class thinking, celebrate student accomplishments in the last few lessons, and/or contain insights into how science and engineering differ. Show slide A. Say, What did you figure out from your work using the engineering design process? Give students time to turn and talk before taking responses. Accept all answers. Transition students to a return to the Driving Question Board. Say, Now that we have had a chance to think about solutions to help protect oysters, let's look back at our Driving Question Board. We have actually figured out a lot of things that we were wondering at the start of the unit and can help answer our big question, 'Why are oysters dying, and how can we use chemistry to protect them?'" (Teacher Edition, page 265).
- The teacher materials explicitly call out SEPs and CCCs support on the right-hand side of the teacher guide for each lesson. For example, in Lesson 6, "Students are first trying to identify potential cause-and-effect relationships between the microscopic and macroscopic worlds so that they can then test them using the simulation in the next step. Remind students that we spend time on argumentation and developing a hypothesis to clarify our ideas so that we can obtain evidence for or against their accuracy" (Teacher Edition, page 116).

Suggestions for Improvement

Consider providing teacher prompts to link students learning of the CCC of **Stability and Change** across lessons. While this CCC is explored throughout the unit, it is not used to explicitly link ideas.

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	Extensive *(None, Inadequate, Adequate, Extensive)*

The reviewers found extensive evidence that the materials support teachers in helping students engage in the practices as needed and gradually adjusts supports over time because students develop independence in several SEPs through gradual reduction of teacher supports.

Scaffolding is reduced over time for most but not all of the targeted SEP elements.

- **Asking Questions and Defining Problems:** *Ask questions that arise from examining models or a theory, to clarify and/or seek additional information and relationships*.
    - Lesson 1: "Generate questions. Display slide BB. Say, It seems like we know of some things that are similar to oyster shells being 'eaten away,' but based on our models we are not 100% sure what's happening with oysters. Let's take this opportunity to record our questions so we can think about useful next steps. Direct students to look back at their notebooks and the consensus model and think about discussions they had today to identify relevant questions. Students should write down at least two new questions that they have now about the phenomenon of oyster die-off due to ocean acidification. Remind students to write big so their questions are easier to read. Give students a few minutes to record their questions on 3x3 sticky notes" (Teacher Edition, page 43). Because this is the only lesson in which this SEP element is used, there is no evidence of removal of scaffolding.
- **Asking Questions and Defining Problems**: *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.*
    - Lesson 7: "Return to our unit question. Display slide B. Remind students of the overarching question we are trying to figure out: Why are oysters dying, and how can we use chemistry to protect them? Say, We want to think about how we can use chemistry to protect the oysters. Based on what we have figured out so far, what are some ideas that we have for how we can do that? Call on several students for responses...What can we learn from other people who also care about oysters? Why is it important to listen to people who are already working on this problem?" (Teachers Edition, page 132). Students later connect the initial questions they generated to potential solutions needed to address these issues they have come to begin to understand during Lessons 1–6.
    - Lesson 7: "Introduce criteria and constraints. Display slide F. Say, We will want to know if the engineering solution we come up with is good or not. How do we decide if an engineering design solution is effective or not? Call on several students for responses, then introduce the terms criteria and constraints. Some students may already be familiar with these terms from previous units focused on engineering design. Criteria are the guidelines that are used to judge the success of a solution, while constraints are the limits on a solution. Say, If we are going to try to develop solutions to the oyster problem, we should probably also consult with people who have already been working on this issue and who are affected by the problem–the stakeholders. How might

thinking about perspectives and ideas from various stakeholders help us develop criteria and constraints?" (Teacher Edition, page 132). This provides specific directed teacher support in building an understanding of criteria and constraints.

- Lesson 11: "Link the ideas shared to the criteria and constraints columns of the Progress Tracker. Say, It sounds like we need to compare our ideas to the requirements for our design, and also to the limitations that our design needs to work within. These criteria and constraints are closely connected with the effects on people and the environment. Let's take some time to revisit our ideas about criteria and constraints that we recorded in our Progress Trackers. Give students a minute to do so and take a few suggestions from the class of ideas they found in the Progress Trackers. Revisit priorities of impacted communities. Display slide E. Say, We have talked before about the importance of consulting with multiple stakeholders. Let's start with what we know about criteria and constraints from the perspectives of those most impacted. Direct students to review the initial ideas they wrote in Learning from Stakeholders in Lesson 7 about criteria and constraints related to stakeholder priorities, and have students discuss these ideas in groups" (Teacher Edition, page 227).

- **Developing and Using Models**: *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 7: The following questions are asked on the assessment: "Use what you know about the properties of acids and the data in the table above to develop a model of the behavior of each acid when dissolved in water. Be sure to include a key for your model", and "Use your models to briefly explain how the two acids are behaving differently from each other in water" (C.4 Lesson 7 Assessment Acid Behavior Assessment, pages 1–2). Students are provided with an opportunity to develop their model individually.
  - Lesson 10: Students independently develop a model of vinegar and marble chips and use that as the basis for predicting relationships between the amount of hydrogen ions present in the ocean and the development of an oyster's shell. "Model the reaction between vinegar and marble chips. If students are motivated to investigate the particle-level dissolution of calcium carbonate in acid, prompt them to add a model to their science notebook with their ideas of how H ions from acid may chemically react with the shell. Note that students have not yet learned that oyster shells are made of calcium carbonate and thus will likely have models which only show H ions reacting with the 'shell particles.' Also use this opportunity to point out that if their models were accurate, both oyster larvae and adults would experience die-offs at equal rates, but in reality larvae are much more strongly impacted" (Teacher Edition, page 186). Support for students to use the SEP remains the same as previous lessons.
  - Lesson 10: Building upon their models of hydrogen ion concentration and shell formation, quantitative reasoning is used to further refine the model to reflect their learning around the concept of the Law of Conservation of Mass. "In order to meet high school standards for modeling, students must use mathematical thinking (ratios) to generate data to support their explanation and analyze the changes in the system. In this activity, look for students to physically move around charged particle cards so that the positives and negatives match up differently before and after the water becomes more acidic. Students should use the cards as evidence that the ratio of available calcium is lower because the H ions 'grab' it before it can be made into shells" (Teacher Edition, page 188). Support for students to use the SEP remains the same as previous lessons.

  - In the examples above, students use of the SEP element remains the same throughout the unit and it is not clear that students are moving toward independence in its use.
- **Using Mathematics and Computational Thinking** *Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations*.
  - Lesson 8: Students use balanced chemical equations to determine the ratios needed to neutralize an acid as a possible solution to the problem of ocean acidification. Students conduct investigations to determine what the coefficients in the chemical equations mean in order to revise their thinking. Students use these balanced chemical equations to begin describing what quantities of NaOH may be needed to neutralize an acid. These activities are constructed in groups and are followed up on through large group discussion.
  - Lesson 13: Students are asked to quantify their criteria and constraints. As part of their solution design, students are asked the following: "What are the intended effects of the change? Use our class consensus model or individual models you have developed to help think about how your solution will impact people and ecosystems. Use calculations as needed to support your answer" (C.4 Lesson 13 Handout Solution Planning Document, page 3). While students complete this activity in groups, specific guidance is not provided through whole group discussion, indicating removal of a scaffold.
  - Lesson 15: The following directives are found on the summative assessment: "3a. A small ammonia plant uses 118,000 g of H gas per day. Determine the mass of CO (in g) that will be released as the H is produced. Show all work", "3b. To produce that much H , the system requires an input of 14,600 mol of CH . What is the mass (in g) of this amount of CH ?", "3c. Use any of the information provided so far to determine the mass (in g) of H O required to produce 118,000 g of H", and "3d. Is this a significantly large amount? Explain how your solutions to 3a-3c show how atoms (and therefore mass) are conserved during the chemical reaction CH + 2H O → CO + 4H . Remember that since you are working with fairly large numbers, rounding may have affected how 'exact' your solutions were" (C.4 Lesson 15 Assessment Ammonia Fertilizer Production, page 3). Students complete this assessment individually.
- **Using Mathematics and Computational Thinking**: *Apply ratios, rates, percentages, and unit conversions in the context of complicated measurement problems involving quantities with derived or compound units (such as mg/mL, kg/m3, acre-feet, etc.).*
  - Lesson 8: Students work to balance chemical equations by determining proper ratios between components of the reaction. Students work with a partner using the balancing equation cards to accomplish this.
  - Lesson 9: "Students will use unit conversions to calculate the mass of NaOH needed to neutralize a specific number of moles of H . They also need to be able to use and understand the mole ratio, and that acidic hydrogen and basic hydroxide will combine 1:1 to form neutral water. The final calculated mass of NaOH will be very small. If students are confused by this result, a review of scientific notation or encouraging students to convert scientific notation to standard notation should help them understand why. The scaffolding for SEP 5 has been reduced gradually in questions 4 and 5 of Ocean Water Calculations to support students in independent use. This scaffolding is reduced even further in question 6" (Teacher Edition, page 170).
  - Lesson 8: Students perform individual calculations to determine whether adding NaOH into oceans could be a viable solution for ocean acidification (C.4 Neutralization Investigation #2)

- Lesson 11: Students are asked to complete the following while designing their investigation: “Each trial you will use approximately 50 mL of 0.1 M CaCl at a cold temperature as the control. Use this information and the molar mass to determine the mass of Na CO you would need to react with all of the CaCl . This will help you determine a range of about how much Na CO you should add (you will need to vary the amount somewhat if you want to test concentration)” (C.4 Lesson 11 Handout Shell-Building Lab Planner, page 1). The following additional guidance is provided: “If students struggle with stoichiometry, break it into these steps. 1. Calculate the amount of moles in 50 mL of the .1 M NaCl solute. (.002 mol) 2. Calculate the ratio of Na CO they will need to react with the NaCl (given in the reaction equation as 1-1). 3. Calculate the molar mass of Na CO (105.988 g) 4. Calculate the mass in grams needed (105.988 * .002 mol = .212 g)” (Teacher Edition, page 209). The calculations are completed in groups. Because students completed similar calculations independently in Lesson 8, they move away from gaining independence in this SEP element by reintroducing the use of group calculations in lesson 11.
- Lesson 15: In the summative assessment, students are asked to individually perform calculations involving stoichiometry.

Some teacher supports are provided to help students in building toward SEPs. Related evidence includes:

- Lesson 1: “Initial questions about a phenomenon are intended to clarify what information is known and not known and, as is often the case, there are more questions than answers when scientists begin their investigations. Develop a safe and supportive space for students’ uncertainty, and focus on the need to ask and answer questions to help address and resolve their uncertainty over the course of the unit” (Teacher Edition, page 33).
- Lesson 6: “Push students to provide evidence for their ideas using prompts like, What makes you think that? and What can we observe that supports your idea? Encourage students to offer counter-arguments by asking questions like, How does your idea explain the evidence better than the other ideas that have been shared? This should help narrow down the ideas on the table to only those that are supported by what students can see at the visible scale. (SEP: 7.4)” (Teacher Edition, page 113).
- Lesson 9: “Students will use unit conversions to calculate the mass of NaOH needed to neutralize a specific number of moles of H. They also need to be able to use and understand the mole ratio, and that acidic hydrogen and basic hydroxide will combine 1:1 to form neutral water. The final calculated mass of NaOH will be very small. If students are confused by this result, a review of scientific notation or encouraging students to convert scientific notation to standard notation should help them understand why. The scaffolding for SEP 5 has been reduced gradually in questions 4 and 5 of Ocean Water Calculations to support students in independent use. This scaffolding is reduced even further in question 6” (Teacher Edition, page 176).
- Lesson 10: “In order to meet high school standards for modeling, students must use mathematical thinking (ratios) to generate data to support their explanation and analyze the changes in the system. In this activity, look for students to physically move around charged particle cards so that the positives and negatives match up differently before and after the water becomes more acidic. Students should use the cards as evidence that the ratio of available calcium is lower because the H ions ‘grab’ it before it can be made into shells” (Teacher Edition, page 188).

Suggestions for Improvement

- Consider providing clear teacher guidance or create a document or table outlining the specific ways in which scaffolding is intended to be reduced in this unit.
- Consider providing more explicit scaffolding for all SEPs with a clear description about how those supports are reduced over time.

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 and/or design solutions because there are numerous opportunities where students integrate all three dimensions in service of sense-making around a central problem.

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 1: In the assessment, students fill out model templates using information from the data sets of temperature/carbon dioxide changes on a global scale to show their hypotheses on what might be going on with oyster shells. This lesson provides pre-assessment information on where students are with their understanding of SEP modeling. The question on the handout includes: "How is more carbon dioxide in the atmosphere causing ocean acidification?" (Initial Modeling Handout, page 1). Students integrate the following three dimensions in the task:
    - SEP: **Developing and Using Models**: *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.*
    - CCC: **Scale, Proportion, and Quantity**: *Using the concept of orders of magnitude allows one to understand how a model at one scale relates to a model at another scale.*
    - CCC: **Stability and Change**: *Much of science deals with constructing explanations of how things change and how they remain stable.*
    - DCI: **ESS2.D Weather and Climate**: *Changes in the atmosphere ~~due to human activity~~ have increased carbon dioxide concentrations ~~and thus affect climate~~.*
- Lesson 4: Students are provided with a template to create a model showing how different acids dissociate in water. The following teacher guidance is provided: "Develop an initial explanation. Display slide P. Problematize something we cannot yet explain about the results by reading the top of the slide. Say, Even when we made solutions with the same concentration of substances added to them, different substances produced a different concentration of H+ or OH ions when they dissolved in the water. Suggest that we try to make sense of this outcome by developing a model. Distribute Modeling H+ Concentrations. Direct students to use the prompts on the handout to help them model what could be happening to the molecules of two different acids to account for our results. Give students five minutes for this. Collect the handout before the end of the period" (Teacher Edition, page 87). Students integrate the following three dimensions in the task:
    - DCI: **PS1.B Chemical Reactions**: *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.*

  - SEP: **Developing and Using Models**: *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.*
  - CCC: **Structure and Function**: *The ~~functions and~~ properties of natural ~~and designed~~ systems can be inferred from ~~their overall structure, the way their components are shaped and used, and~~ the molecular substructures of their various materials.*
- Lesson 9: Students individually "…calculate the mass of NaOH needed for the whole ocean. Display slide K. Give students time to complete the calculation on the last page of Ocean Water Calculations" (Teacher Edition, pages 172–173). Students contrast calculations at the scale of a small oyster tank with that of the entire ocean, considering different scales of NaOH that would be required to solve the same problem at each scale. Students integrate the following three dimensions in the task:
  - DCI: **PS1.B Chemical Reactions**: *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.*
  - SEP: **Using Mathematics and Computational Thinking**: *Apply ratios, rates, percentages, and unit conversions in the context of complicated measurement problems involving quantities with derived or compound units (such as mg/mL, kg/m^3, acre-feet, etc.).*
  - CCC: **Scale, Proportion, and Quantity**: *The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs.*
- Lesson 15: Students engage in the final unit assessment which asks students to consider Ammonia Fertilizer Production. Several three-dimensional directives are given. For example: "1. Choose one of these strategies (a or b) and develop a particle-level explanation of how the strategy would lead to a shift in the equilibrium of the reaction so that more NH_3 is produced. Use what you have figured out in this unit about reversible reactions as evidence to support your explanation", "2a. Choose one of these strategies (a or b) and develop a model that shows how the strategy would lead to an increase in the reaction rate so that NH_3 is produced more quickly", and "3d. Explain how your solutions to 3a-3c show how atoms (and therefore mass) are conserved during the chemical reaction $CH_4 + 2H_2O \rightarrow CO_2 + 4H_2$. Remember that since you are working with fairly large numbers, rounding may have affected how 'exact' your solutions were" (Ammonia Fertilizer Production, pages 2–4). Students integrate the following three dimensions in the task:
  - DCI:
    - **PS1.B.1: Chemical Reactions**: *Chemical processes, their rates, ~~and whether or not energy is stored or released~~ can be understood in terms of the collisions of molecules, and the rearrangements of atoms into new molecules, ~~with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy~~.*
    - **PS1.B.3: Chemical Reactions**: *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.*
    - **ETS1.C.1: Optimizing the Design Solution**: *Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (tradeoffs) may be needed.*
  - SEP:
    - **Constructive Explanations and Designing Solutions**: *Students apply scientific ideas, principles, and evidence to provide an explanation of phenomena ~~and solve design problems, taking into account possible unanticipated effects.~~*

- **Developing and Using Models**: *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.*
- **Using Mathematics and Computational Thinking**: *Use mathematical~~,~~ ~~computational, and/or algorithmic~~ representations of phenomena ~~or design solutions~~ to describe and/or support claims ~~and/or explanations~~.*
- **Engaging in Argument from Evidence**: *Make and defend a claim based on evidence about the effectiveness of a design solution that reflects scientific knowledge and student-generated evidence.*

- CCC:
  - **Energy and Matter**: *Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.*
  - **Cause and Effect**: *Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system.*
  - **Scale, Proportion, and Quantity**: *The significance of phenomenon is dependent on the scale, proportion, and quantity at which it occurs.*

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

- Lesson 7: In the “Acid Behavior Assessment”, the handout starts with the following: “Can we just dump any substance into the hatchery environment to help the baby oysters? Could adding a different substance to the ocean water reverse the acidification process?” (Acid Behavior Assessment, page 1). This phenomenon is referenced again in “Question 7a: How could the model you developed to explain the observations from this investigation be used to help the oysters and the people who depend on them? Question 7b: What are some possible unintended effects that we would need to consider when thinking about potential design solutions?” (C.4 Lesson 7 Assessment Acid Behavior Assessment, page 4). However, other questions are not used for students to further explore the phenomenon provided.
- Lesson 15: While a scenario is presented to students in the “Ammonia Fertilizer Assessment,” it is not used to drive this task. The teacher states as a transition “Navigate into the assessment. Show slide D. Say, We have figured out a lot of great chemistry ideas in this unit, but we have really only applied these ideas to oysters. Today you will have a chance to look at a different problem that has a lot in common with ocean acidification. This problem involves producing ammonia fertilizer to help crops grow. You will have about 20 minutes today and plenty of time when we see each other again to work through this problem on your own. Distribute Ammonia Fertilizer Production and ask students to take out Our DQB Questions. Continue, All the information you need to complete this assessment is given here or can be found on the periodic table. Take your time. I will collect your work at the end of the day for safekeeping until next time. Allow students to work until class is almost over, then collect assessments before students leave” (Teacher Edition, page 266). However, in the handout, a problem isn’t introduced until the last question rather than introduced at the beginning to drive sense-making.

Suggestions for Improvement

- Consider scaffolding questions and directives in such a way that it is clear to students that answering questions and following directives is in service of making sense of a phenomenon or solving a problem.

- For the summative assessment in Lesson 15, consider moving the problem from the end of the assessment to the beginning and allow that to drive student movement throughout to scaffold sense-making tasks.

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 formative assessments for all three dimensions are embedded frequently throughout the unit with teacher guidance provided to help support students' emergent needs.

The materials include opportunities for formative assessment of all three dimensions that are called out explicitly throughout the lessons. Related evidence includes:

- Lesson 3: Students are provided with an Exit Ticket. They answer the following question: "When a substance is added to water, what do you think determines whether the solution will become acidic or basic?" (C.4 Lesson 3 Slides, Slide O).
- Lesson 4: Students are provided with a template to create a model showing hydrogen ion concentration differs for different types of acids. The following teacher guidance is provided: "Suggest that we try to make sense of this outcome by developing a model. Distribute Modeling H+ Concentrations. Direct students to use the prompts on the handout to help them model what could be happening to the molecules of two different acids to account for our results. Give students five minutes for this. Collect the handout before the end of the period" (Teacher Edition, page 87). Students examine each other's work and teachers are told "if you have time, allow students to revise their chosen acids on Modeling H+ Concentrations before collecting them" (Teacher Edition, page 83).
- Lesson 5: Students use a graffiti board to begin sharing ideas about why the water sample changed back in color. "Prepare students for the graffiti boards. Distribute the graffiti board chart paper around the room, with one board for each substance on each side of the room. Display slide B. Divide the class into eight groups and show students that there are four boards in their half of the room. Tell them they will have two minutes at each of the four boards and that you will tell them when it is time to move to the next one. Students should work with their group to answer the questions on each board. It is okay if they do not get to all of the questions. Explain to the students that when they move to a new board, they should answer any unanswered questions and add to or comment on the previous group's work. It is fine if they have comments that build on their classmates' previous statements rather than the original

question" (Teacher Edition, page 117). A sample student response is provided. After reviewing what other students wrote on their own board, students individually respond to the following prompt: "Review the graffiti boards and record thinking in science notebooks. Thank the students for all of the interesting ideas they recorded on their graffiti boards. Display slide D. Say, You have generated a lot of great ideas, but you have not had a chance to look at what other people said about your first board. Direct students to individually view the first two boards they had written on with their groups. Then instruct students to write an answer to the prompt on the slide in their notebook" (Teacher Edition, page 112).

- Lesson 6: Students complete the "Bond Data" handout which asks them to recognize patterns in the strength of bonds in order to determine what reversible and irreversible reactions have in common and how that relates to the strengths of acids and bases. A key for the activity is provided. In addition, the following teacher guidance is provided: "Collect Bond Data as a formative assessment" (Teacher Edition, page 124).
- Lesson 9: Students complete an electronic Exit Ticket.
- Lesson 10: Students individually develop a model to explain what is happening to the oysters. A handout is provided with a diagram to guide the model and the following guidance: "Use what we have gathered from the reading and investigation to draw a model that helps answer the question, What happens when an oyster is building its shell in an acidified environment?" Also included is "Include the following components in your model: Chemical formation of $CaCO_3$, Where materials to build the shell come from. How increased acidity interferes with the shell-building process. Be sure to think about changes at the particle level, and include a key. The table below shows some data and a list of ions that you may wish to incorporate into your model" (C.4. Lesson 10 Handout Shell-Building Model, page 1). Students then look at each other's models in a gallery walk and note similarities and differences. After making a class consensus model, students are provided with an opportunity to revise their model.
- Lesson 13: Students complete an Exit Ticket. "Complete exit tickets. Display slide P and distribute Exit Ticket. Ask students to reflect on the engineering design process that they used in this unit and record their reflections on the exit ticket. Collect exit tickets before students leave the classroom" (Teacher Edition, page 266).
- Lesson 13: In addition, the following teacher guidance is provided: "The two exit ticket prompts ask students to reflect on the process of using engineering ideas to develop a design solution. Some students may be new to this process, while others may have used engineering design in a previous unit or lesson. Question 1 engages students in self-reflection by asking how they contributed to the design process. Question 2 asks students to compare the engineering design process to other scientific processes, which prepares them to think about what they have learned about engineering in this unit. Before Lesson 15, read through student responses to Question 2 and select a few responses or patterns to share during the opening navigation" (Teacher Edition, page 260).

Formative assessment opportunities are aligned to three-dimensional learning outcomes derived from grade-appropriate elements from all three dimensions. However, only a single sample student response is provided for most assessments. Related evidence includes:

- Assessment callout boxes are found throughout the unit. Each of these boxes contains sections titled "What to look/listen for" and "What to Do." Guidance is labeled to indicate which DCI, CCC, and SEP elements are assessed. However, an accompanying key is not provided to ensure teachers know what each code (e.g., SEP: **1.8**) indicates. Some samples are below:
  - Lesson 3: "Building towards: 3.A.1 Plan and conduct an investigation to produce empirical evidence that supports the claim that increased atmospheric carbon dioxide

levels causes ocean water to become more acidic. What to look for/listen for: Students collaboratively plan an investigation to produce data to support a scientific claim. Students' investigation plan ensures that variables are controlled so that the empirical evidence collected can be used to evaluate a claim. What to do: Sample investigation plans are provided in Sample Investigation Plans. If groups' investigation plans differ from those examples, that is okay. It is important that investigation plans are specific, will provide data, and will collect empirical evidence. If plans are not, use probing questions to guide group designs to increase specificity, identify data to collect, and consider how that data can be used as evidence to evaluate a claim. It may be helpful to demonstrate the types of data students can collect when using bromothymol blue and pH strip indicators" (Teacher Edition, page 65). While guidance is provided to the teacher for responding to students who are struggling, the guidance provided is specific to helping students complete the specified task rather than a modification in instruction intended to address students struggling with the concept.

- Lesson 4: "Building towards: 4.A.1: Apply ratio thinking in the context of complicated measurement problems involving quantities with compound units (moles/L) to predict how the concentration of an acid or base dissolved n(sic) water will affect the pH of the solution. (SEP: 5.5; CCC: 3.1; DCI: PS1.B.2) What to look for/listen for: Students explain that the concentrations of solutions are equal because the ratios of moles/L are equal, even though the quantities of moles (molecules) and water are different. What to do: Have students calculate the ratio of moles or molecules to liters, as a unit rate, using a calculator" (Teacher Editions, page 79).
- Lesson 8: "Building towards: 8.A.2. Plan and carry out an investigation of a neutralization reaction by predicting and manipulating the amounts using mass and mole proportions and collecting data to identify failure points to improve the reaction outcome (SEP: 2.2, 3.6; DCI: PS1.B.3; CCC: 3.1). What to look for/listen for: Students describe observations of a failure point in the system design or other qualitative and quantitative data they gathered. What to do: If students do not immediately see a problem with the pH, ask them what pH a neutral substance should have and what color the pH paper should be for a neutral solution. Help them reason through why the pH would be so high: Which substance must we have used too much of? Also see: 1) supporting the practice of developing and using models and 2) on the purpose and prompts to use for this Building Understanding discussion" (Teacher Edition, page 158).

While numerous opportunities for formative assessment are found throughout the materials, the assessment processes do not frequently call out aspects of student responses that might be driven by students' preferred response formats. For example, most assessments do not provide multiple ways for students to express their thinking, and support is not provided for teachers to attend to a student's individual needs level. Related evidence includes:

- Lesson 7: Teacher support is provided for responding to students who are struggling. "If students do not immediately see a problem with the pH, ask them what pH a neutral substance should have and what color the pH paper should be for a neutral solution. Help them reason through why the pH would be so high: Which substance must we have used too much of?" (Teacher Edition, page 151). The "Building Understanding" discussion describes prompts that teachers can use to support students. Examples include: "water[sic] can we conclude?" or "how did you arrive at the conclusion?" (Teacher Edition, page 123).
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- Lesson 8: "Support for Universal Design for Learning: Physical cards make this activity more accessible for learners who can move them around on their desktop to think about reactants and products. You can continue to improve access by asking students to use the card to represent what is shown in the chemical equation on subsequent slides (through slide N). This supports representation" (Teacher Edition, page 147).
- Lesson 9: "Supporting Multilingual Learners: Students often benefit from a sentence starter in short writing exercises because it can orient them to the task of writing their ideas. Once the first idea is out, a second idea or more details can flow more easily The basis of this cognitive science is rooted in schema-setting, whereby activating a base of knowledge and language can result in deeper thinking over time" (Teacher Edition, pages 170–171)
- Lesson 10: "Supporting Emerging Multilingual Learners. Encourage students to express the new ideas from the Consensus Discussion using a mode that makes sense for them. For some emergent multilingual students, encourage them to use space to express ideas in the language that they feel most comfortable with. Remind students that the model they built from the Consensus Discussion is a low-stakes opportunity to make sense of what they are learning without the worry or anxiety that comes with graded work" (Teacher Edition, page 191).
- Lesson 12: Students fill out solutions worksheets. "If students are struggling with calculations, encourage them to refer back to the work they did in Lessons 7 and 8 and use that as a guide" (Teacher Edition, page 243). Guidance for supporting students is found in the Sample Solution Planning document. (Teacher Edition, page 347).

Suggestions for Improvement

- Consider providing additional guidance for how individual students could be provided feedback throughout the materials.
- The call out box on page 173 of the Teacher Edition appears to have an incomplete sentence at the very end of the "what to do" section.

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 included aligned rubrics and scoring guidelines that help the teacher interpret student performance for all three dimensions because sample student responses and look-fors are provided for key assessments throughout the materials along with guidance to interpret scores. However, explicit guidance to support students in interpreting their own progress toward most of the targeted standards is not provided.

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:

- Assessment callout boxes are found throughout the unit. Each of these contains sections titled "What to look/listen for:" and "What to Do" as well as what specific three-dimensional learning target the assessment is aligned to. For example:
    - Lesson 1
        - "Building towards: 1.A.1 Develop a model using evidence that compares large scale carbon dioxide changes to explain small scale oyster die-offs using particle-level interactions. What to look for/listen for:
            - Student's models use evidence to show how large scale ocean system changes result in ocean acidification at a particle level.
            - Student models use evidence to show how ocean acidification at a particle level affects small scale oyster structures (systems).
            - Student's trace the flow of carbon dioxide from human activities to the atmosphere, and into the ocean" (Teacher Edition, page 39).
        - "What to do: Students' models will be incomplete since this is the first lesson of the unit. It may be used as a pre-assessment opportunity to check in on students' modeling and use of patterns noted in the data analysis. If students do not agree on the idea that carbon dioxide somehow causes ocean acidification which causes oyster die-off use the crosscutting concept of scale, proportion, and quantity to push them to use the evidence they examined to consider what might be happening at a particle level" (Teacher Edition, page 39).
    - Lesson 13
        - "Building towards: 13.A Use computational thinking to quantify criteria for a solution that will positively affect oysters. What to look for/listen for:
            - Students use stoichiometric (mathematical) and other calculations to quantify design solution impacts of pH, carbonate, and CO_2.
            - Students quantitatively represent criteria and constraints.
            - Students articulate the importance of criteria and constraints in ensuring positive outcomes for oysters" (Teacher Edition, page 241).
        - "What to do: If students are having difficulty quantifying criteria and constraints, have them review their original lists alongside the site data. Questions such as 'how much/many?', 'when?', or 'how long?' may help students refine their criteria and constraints" (Teacher Edition, page 241).
- Lesson 9: Students complete the "Ocean Water Calculations Handout." A key is provided along with only a single sample student response, rather than a range of student responses showing varying levels of student proficiency. The following teacher guidance is provided: "Collect Ocean Water Calculations to review and redistribute for the second day of this lesson" (Teacher Edition, page 170).
- Lesson 9: Students complete an Exit Ticket that includes teacher guidance for handling student responses that are not correct in the section entitled "what to do". For example, Question 3 says, "students should select all of the responses except 'leave out your units'. Ocean Water Calculations encourages them to follow these steps. They should be paying close attention to units in the context of using mathematical thinking to predict outcomes from chemical equations. Review the sub-steps that students went through in Ocean Water Calculations" (C.4 Exit Ticket Key, page 3).

- The unit assessments in Lessons 7 and 15 contain a table aligning questions to specific SEP, CCC, and DCI elements, as well as sample student responses for each question. Rubrics include a range of student responses organized as "Foundational Pieces", "Linked Understanding", and "Organized Understanding" designed to support the scoring of student work. Additional ideas for instruction are provided for students scoring at each of the levels.
- The rubric provided for Lesson 13's poster model of acid behavior when dissolved in water breaks down "key elements" for each of the lesson level PEs (**13.A** and **13.B**), which specifically call out the elements of the model that should be looked for when providing students with feedback as well as suggestions for how the teacher could support students that have not yet met those lesson level PEs in the "what to do" section (C.4 Poster Feedback Guide, pages 1–2).

Students are provided with ways of tracking their own progress; however, these opportunities are not always aligned to three-dimensional learning outcomes or SEP, CCC, or DCI elements. Related evidence includes:

- Lesson 1: "Keeping a science notebook allows students a space in which to reflect and communicate their developing understandings about science ideas and to track changes in their understandings. Each student should have a binder that will serve as their 'science notebook' for the course. Students can use large dividers to indicate the start of a new unit. They can use additional smaller dividers or sticky notes to create three sections within the unit, corresponding to the three lesson sets" (Teacher Edition, page 33).
- Lesson 2: Students begin the use of a Progress Tracker to identify the subproblems they have identified as a class. The following teacher guidance is provided: "Progress Tracker is designed to guide students through the engineering design process. It focuses on the main subproblems identified in Lesson 2, and asks students to separately record the science ideas they figure out, how they might apply those ideas, and the criteria and constraints that impact how they apply those ideas. As students return to the Progress Tracker, prompt them to consider the interrelation of these columns, and how all subproblems are important to investigate in order to design solutions that address the large, complex problem identified in the Anchoring Phenomenon Routine. Example Progress Tracker offers some possible ideas students will have added to their Progress Trackers by Lesson 12. This also provides an opportunity to remind students that there are many ways to solve big problems, and that it is important to learn as much as we can about the problem, the people affected by it, and the people working on it, to make sure we can design solutions that do not further harm those who are already marginalized" (Teacher Edition, page 59).
- Students frequently update their Progress Trackers throughout the unit. For example, in Lesson 3: "Refer students to the list of subproblems at the top of Progress Tracker. Display slide A and say, In the last lesson, we figured out that the big problem of oyster die-off can be broken into more manageable subproblems. Ask students to do an individual quick write to answer the prompts on slide A. After a few minutes, lead a discussion to share student responses" (Teacher Edition, page 70).
- Lesson 4: Students complete an electronic Exit Ticket. Question 7 of the assessment provides an opportunity to for students to self-assess their contribution to the class. Question 5 prompts students to specifically think about their use of **Scale, Proportion, and Quantity** in the unit. "How did comparing the scale, proportion, and quantity of particles in different solutions during this lesson help you make sense of why different substances might have different pH values?" (C.4 Lesson 4 Answer Key Exit Ticket Key, page 5). However, this connection is not at the element level.

- Lesson 5: "Update Progress Trackers. Present slide X. Say, Let's take a moment to record our ideas about how the carbon cycle model helps us understand oyster die-offs and improve access to them as an important food source. Say, Update your Progress Trackers for a second time this lesson. Give students enough time to update their Progress Trackers while ensuring that you have 10 minutes to complete the next lesson activity. See Progress Tracker Key for a sample Progress Tracker entry" (Teacher Edition, page 104).
- Lesson 11: Students update their Progress Tracker. "Update Progress Trackers. Say, These are really interesting ideas! Let's add them to our Progress Trackers. Give students time to update their Progress Trackers. Encourage them to work with a partner and add thinking to all the columns. Use Progress Tracker Key for teacher guidance" (Teacher Edition, page 213).
- While students are able to use tools, such as the Progress Tracker, to measure their progress, these are not directly related to specified learning outcomes or targeted elements in the lesson, and guidance is not provided for how students can use these tools to measure progress toward learning.

Suggestions for Improvement

- Consider providing students with additional guidance for how they can use their Progress Tracker to measure progress toward learning beyond initial reflection and organization. Consider including a range of what acceptable student Progress Trackers could look like and could they serve as a potential formative assessment tool for teachers at varying points in the unit.
- Consider providing students with self-assessment tools (such as rubrics) that could be used to track their progress relating to the SEP and CCC goals in the form of an Exit Ticket with an opportunity for self-rating after each lesson or lesson segments to monitor progress or understanding.

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	Adequate *(None, Inadequate, Adequate, Extensive)*

The reviewers found adequate evidence that the materials assess student proficiency using accessible and unbiased methods, vocabulary, representations, and examples because the unit offers numerous opportunities to measure student learning in a variety of ways as students write, draw, discuss, and verbally present their learning and ideas. However, multiple modalities for presenting tasks are not always provided to students and they are not given multiple opportunities to choose a modality for expression of their ideas and provide evidence of their learning.

Vocabulary and text volume in student assessments are grade level appropriate. Support is provided for students to access tasks when needed, however limited non-text supports are provided to help students access task information. Non-text resources are often used in place of text, but infrequently paired with text as a support. Related evidence includes:

- All integral vocabulary is developed intentionally through the use of a student generated glossary in science notebooks. There is also guidance present for teachers on how to use vocabulary such as having students generate their own understanding of the word prior to the definition.
- Lesson 1: "Swinomish = SWIN-uh-mish; It's good to use the proper names for people and groups. The Swinomish Trival Community is known as such because 'tribe' and 'nation' are inaccurate—many tribes and nations make up the Swinomish Tribal Community" (Teacher Edition, page 31).
- Lesson 1: "It is important to encourage students to represent their ideas in a way that is meaningful to them. This may include using any languages they can to best think through their ideas. As they continue to express their ideas and hear others' ideas, their linguistic repertoires in science will deepen. This practice of encouraging all translanguaging should be encouraged in all OpenSciEd units" (Teacher Edition, page 31).
- Lesson 6: "These ideas are complex. If students are struggling with the provided prompts, you may wish to allow them to return to the computer simulation while engaging in whole-class discussion so that students can test ideas in real time if they are unsure" (Teacher Edition, page 117).
- Lesson 7: Instructions for the assessment, as well as the description of the phenomenon are provided in words. However, no additional modalities are used to convey information.
- Lesson 10: The "Attending to Equity: box states, "You may wish to tape some of the cards from Reaction Cards on the board to help show speakers' thinking throughout this discussion. This can help students track their peers' ideas more easily. You may additionally wish to leave decks with any students who want them to use throughout the discussion so that students can engage with the ideas in the way that is most meaningful to them" (Teacher Edition, page 216).
- Lesson 11: "Individual time gives students an opportunity to synthesize evidence and formulate their ideas. This is important so students are prepared to defend their ideas and evaluate others' ideas when they share their ideas in small groups and with the whole class. As students work, circulate among them prompting them to defend their model (or part of their model) using evidence collected during investigations. This can help students think through where their model may have a hole prior to the collaborative group sharing" (Teacher Edition, page 215).
- Lesson 12: Students plan solutions for specific site profiles: The readings are bulleted, and pictures are provided. New vocabulary is defined as needed (e.g., intensive cultivation vs. extensive cultivation) (C.4 Lesson 12 Reference Site Profile 3, page 1).
- Lesson 15: Support is provided for students who may have difficulty with the amount of text on the final assessment. "The introduction to this assessment is text heavy. This is necessary to provide students with important background information, but it may also cause some students to worry or 'lock up.' Consider reading the introduction aloud to students to help them feel more comfortable" (Teacher Edition, page 266).

Multiple modalities for presenting and providing information are available throughout the unit. However, students are only offered one opportunity in which they can choose the modality they would prefer to use in responding to a prompt.

- Lesson 1: Students create an initial model individually to explain "How is more carbon dioxide in the atmosphere causing problems for oysters' shells?" (C.4 Lesson 1: Handout Initial Modeling, page 1). Students are provided a handout to make their model which contains a picture to guide their model.

- Lesson 6: Students use a graffiti board to begin sharing ideas about why the water sample changed back in color. “Discuss individual ideas in groups. Display slide E. Direct the students back into their groups and share their arguments with each other as to what they think caused the color change. Make it clear that the group does not need to reach consensus and that the emphasis should be on listening to each others’ differing evidence for their ideas” (Teacher Edition, page 112).
- Lesson 8: “Display slide M. Tell students we can try balancing this equation, which involves two solids, making it easier to ensure an accurate measurement of the two substances. Give students time to balance the equation using the cards from Balancing Equations Cards. Then after balancing, display slide N and use the prompts on the slide to discuss what these reactions tell us and how testing one of them might help us determine if we have a way to predict how much base is needed to neutralize an acid” (Teacher Edition, page 149).
- Lesson 9: The “Attending to Equity” box states, “Encourage students to express the new ideas from the Consensus Discussion using a mode that makes sense for them. For some emergent multilingual students, encourage them to use space to express ideas in the language that they feel most comfortable with. Remind students that the model they built from the Consensus Discussion is a low-stakes opportunity to make sense of what they are learning without the worry or anxiety that comes with graded work” (Teacher Edition, page 191). While this does address some issues of equity and access, this example is the only moment in this unit where students are offered a specific opportunity to choose the mode that they would prefer to respond in.
- Lesson 10: “Supporting Emerging Multilingual Learners. Encourage students to express the new ideas from the Consensus Discussion using a mode that makes sense for them. For some emergent multilingual students, encourage them to use space to express ideas in the language that they feel most comfortable with. Remind students that the model they built from the Consensus Discussion is a low-stakes opportunity to make sense of what they are learning without the worry or anxiety that comes with graded work” (Teacher Edition, page 191).
- Lesson 13: “Universal Design for Learning & Literacy. Representation. You can have students read individually or aloud with a partner. Allowing students a choice in how the information is represented (hearing it read aloud or individual reading time) can support comprehension for a wider range of learners. Multilingual Learners. You may encourage students to use a translator device if the text is not in their home language” (Teacher Edition, page 238).
- Lesson 15: Ammonia Fertilizer Production is used as the scenario to drive the summative assessment. The following question is posed in the introductory reading: “How can we use what we know about reactions to build enough fertilizer for worldwide agriculture?” (C.4 Lesson 15 Assessment Ammonia Fertilizer Production, page 1). The scenario is presented entirely through text. While a picture is provided, it does not clarify or add additional context. Questions are directly related to the scenario but are not necessarily designed in a way that is moving toward students figuring something out or solving a problem.
- While students are provided with opportunities to show their learning in a variety of ways throughout the unit, key assessments in Lessons 7 and 15 are made up of primarily written responses and no student choice is explicitly provided in modality.

Suggestions for Improvement

- Consider providing additional opportunities for students to choose modalities for the same task to show their thinking throughout the unit. In the same way that students are encouraged to use language comfortable to them throughout the unit, the mode in which they describe or represent their learning may be beneficial.
- Consider providing labeled pictures, diagrams, etc. to assessment prompts in Lessons 7 and 15 to provide multiple ways for students to access scenario information in the assessment.

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 all types of assessment are present in the unit and the materials within connect to the stated learning goals for all three dimensions.

The materials contain pre-assessments. Related evidence includes:

- Lesson 1: Students create an initial model individually to explain “How is more carbon dioxide in the atmosphere causing problems for oysters’ shells?” and described in the assessment call out body as being able to be “…used as a pre-assessment opportunity to check in on students’ modeling and use of patterns noted in the data analysis” (Teacher Edition, page 39).

The materials contain formative assessments that measure three-dimensional learning. Related evidence includes:

- Lesson 1: “Set up home learning. Display slide M. Distribute Traditional Foods. Say, We all have these kinds of ‘first foods’ in our communities. What are some that are important to our community? For example, what would we do without corn? It’s in our candy, our syrups and sweeteners, tortillas, chips, and cereal. Your assignment is to ask 5 people who are not in your grade about foods that are important to them, and what they would do without those foods. Tell students the class will start the next day by discussing the home learning prompt. ‘Home learning is an important to do cultural formative assessment…’” (Teacher Edition, page 35).
- Lesson 3: “Collect Evaluative Investigation Data and use that, along with students’ participation in the Building Understandings Discussion, as a formative assessment opportunity” (Teacher Edition, page 104).
- Lesson 3: Students are provided with an Exit Ticket. They answer the following question: “When a substance is added to water, what do you think determines whether the solution will become acidic or basic?” (C.4 Lesson 3 Slides, Slide O).

- Lesson 4: Students complete an electronic Exit Ticket. A key is provided which outlines how each question aligns to specific SEP, CCC, and DCI elements.
- Lesson 6: "Collect Bond Data as a formative assessment" which includes opportunities for students to "…correctly predict unknown information about reversibility, bond strength, substance type, and stability", as well as "…cite other model types as evidence" and build toward using "multiple types of models to make predictions about the relative stability of substances in reversible reactions" (Teacher Edition, page 124).

The materials contain summative assessments that measure three-dimensional learning. Related evidence includes:

- Lesson 7: Students take the "Acid Behavior Assessment" which requires them to use what they have learned about acids and bases to explain the results of an investigation.
- Lesson 14: Students take a final assessment on "Ammonia Fertilizer Production" which addresses the focus DCIs, SEPs, and CCCs in the unit.

The materials contain self-assessment opportunities. Related evidence includes:

- Lesson 4: A student self-assessment is provided. "Complete the electronic exit ticket. Display slide U. Share the related link with students and have them individually complete the electronic exit ticket. Some of the questions require self-assessment on classroom community norms in addition to science ideas" (Teacher Edition, page 84).
- Lesson 14: "Two prompts on this Exit Ticket gives[sic] students opportunities to reflect on their own engineering design solution, their role in its development, and how the engineering design process differs from approaching purely scientific problems. These artifacts can provide evidence as to students' individual contributions to and understanding of the group's work in Lesson Set 3, as well as a deeper understanding of how students view engineering. On an exit ticket, students are asked to address how their ideas contributed to their group's proposed solution as well as how their group's process '…similar to or different from how you have approached other scientific problems?'" (Teacher Edition, page 273).

The assessment purpose and rationale are coherent across the materials and is explicitly described for all three dimensions.

- The "Assessment System Overview" document provides information regarding each assessment in the materials, as well as which CCC and SEP they are aligned to. Specific elements for each DCI, SEP, and CCC are provided using a code. While one can assume how this code aligns with specific elements, a key is not provided in the materials. For example:
    - Lesson 1: "1.A Develop a model using evidence that compares large scale carbon dioxide changes to explain small scale oyster die-offs using particle-level interactions. (SEP:2.3; DCI: ESS2.D.3; CCC: 3.4) 1.B Ask questions to clarify how oyster populations and changes in climate due to atmospheric carbon dioxide are connected. (SEP: 1.2; DCI: ESS2.D.3; CCC: 7.1)" and elaborated upon in the column for "Assessment Guidance" (Teacher Edition, page 275).
    - Lesson 4: "4.A When to check for understanding: 1. As students use mathematical thinking to relate moles and molecules. (Slides H-K) 2. As students complete questions 1 and 3 on Modeling H+ Concentrations. (Slide P) 3. During the Scientists Circle discussion to identify interactions between different acids and water molecules. (Slide R) What to look/listen for across opportunities 1-3: Students explain that the concentrations of solutions are equal because the ratios of moles/L are equal, even though the quantities of moles (molecules) and water are different. (SEP: 5.5; CCC: 3.1) Students explain that

different acids dissociate unequally to account for differences in the amounts of H ions in solution as measured by pH values. (DCI: PS1.B.2; CCC: 3.1)" (Teacher Edition, page 276).
  - Lesson 11: "11.A When to check for understanding: On day 1 as students plan their investigations. (Slide H) What to look/listen for in the moment: Student investigation plans allow for measurement of a dependent variable (amount of product produced or time) that helps provide some quantification of the rate of change in the reaction. (SEP: 3.1; DCI: PS1.B.1) Students plan to investigate how a specific change in their factor will influence how the reaction proceeds and can describe what they expect to see, providing evidence that they will be able to answer the investigative question. (SEP: 3.1; CCC: 7.2) 11.B When to check for understanding: 1. On day 2 as students explain their experimental results in groups. (Slide N) 2. As students individually model how the addition of calcium carbonate can help ocean acidification. (Slide S) 3. During the consensus discussion. (Slide U)" (Teacher Edition, page 261).

Suggestions for Improvement
Consider providing a key so that it is clear for teachers to know which SEP, CCC, and DCI elements are being used in the assessments that align with the current coding system (e.g., **3.1** or **7.2**).

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 because students are provided with numerous opportunities to demonstrate their learning and receive feedback from their peers and the teachers relating to their performance in each of the three dimensions in the unit.

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

- Lesson 3: Students are provided with an Exit Ticket. They answer the following question: "When a substance is added to water, what do you think determines whether the solution will become acidic or basic?" (C.4 Lesson 3 Slides, Slide O). While the teacher is instructed to collect the responses and use some of them the next day, no suggestions for providing feedback are provided.

- Lesson 5: Students complete an "Evaluate Investigation Data" handout in which they answer questions related to the lab they have completed and the data collected. Students are provided with an opportunity to discuss their answers with a partner. "Share Evaluate Investigation Data responses with a peer. Display slide K. Give students 3 minutes to turn and talk with a partner to share their responses to Evaluate Investigation Data. Tell students that as they share, they should add to their responses based on new ideas their partner may have" (Teacher Edition, page 97). Students then use the results to engage in a class conversation. The following teacher guidance is provided in relation to the handout: "Collect Evaluate Investigation Data and use that, along with students' participation in the Building Understandings Discussion, as a formative assessment opportunity" (Teacher Edition, page 98).
- Lesson 6: Students use a graffiti board to begin sharing ideas about why the water sample changed back in color. "Discuss individual ideas in groups. Display slide E. Direct the students back into their groups and share their arguments with each other as to what they think caused the color change. Make it clear that the group does not need to reach consensus and that the emphasis should be on listening to each others' differing evidence for their ideas" (Teacher Edition, page 112).
- Lesson 10: "Integrate key ideas from the reading into a model. Display slide N. Distribute Shell-Building Model to each student. Say, What happens when an oyster is building its shell in an acidified environment? Let's try to model this process. To do this, make sure your model includes the following components:
    - Chemical formation of CaCO
    - Where materials to build the shell come from
    - How increased acidity interferes with the shell-building process

  Suggest that students think about the last bullet point from both a matter and forces perspective. Reference the M-E-F triangle. Point out the provided data and list of ions in Shell-Building Model to support students with their modeling. Give students the rest of the class period to work on the model independently, and let them know they will start class the next day by sharing their models" (Teacher Edition, page 188).
- Lesson 11: "Your model should show how the ions move and how bonds break and form at different points in the process. Model how adding calcium carbonate can help. Give students time to model on their own using the cards. Emphasize to students that their model should be interactive, meaning it should show ion movement and interactions over time. After 3 minutes, show slide S. Have students join a partner and come to a consensus" (Teacher Edition, page 215).
- Lesson 12: "Provide peer feedback. Once students have explained their design solutions to each other, separate groups back into pairs from the same design solution group. Display slide I. Ask partners to discuss the design solution that they learned about, using the questions on Peer Discussions Guide as a guide. Then, have students use 3x3 sticky notes to leave feedback on the other pair's design solution poster. Suggest that students write one idea on each sticky note, balancing praise and constructive critique. Once all students have finished providing feedback, give students a few minutes to return to their own design solution posters to read the 3x3 sticky notes. Say, Now that you have had the chance to learn about another design solution and receive peer feedback on yours, let's take some time to reflect on what we have learned" (Teacher Edition, page 240).
- Lesson 12: "Use the Solution Planning Document to develop the solution. Tell students, Now that we have more specific criteria and constraints and know more about these locations, let's try to build some solutions and figure out just how we might impact these ecosystems. Display slide G and distribute Solution Planning Document to students. Groups should work together to

answer the questions on Solution Planning Document. They should be as specific and thorough as possible, and quantify their solutions and impacts where appropriate. For example, if students want to raise the pH of water tanks at an oyster hatchery, they will need to use volume and pH to calculate a specific quantity of the substance to be used. Students need to explain how that substance will help them achieve their goal. Encourage students to use the class consensus model and/or models from individual lessons to help them predict the impacts of their solutions" (Teacher Edition, page 241).

- Lesson 12: "If students are struggling to complete parts of their planning documents, direct them to the relevant information in the reference materials. If they are still struggling to find information on their own, help them come up with some useful search terms. If Internet access is available, talk with students about prioritizing the criteria for which they already have information" (Teacher Edition, page 242).
- Lesson 13: "Provide peer feedback. Once students have explained their design solutions to each other, separate groups back into pairs from the same design solution group. Display slide I. Ask partners to discuss the design solution that they learned about, using the questions on Peer Discussions Guide as a guide. Then, have students use 3x3 sticky notes to leave feedback on the other pair's design solution poster. Suggest that students write one idea on each sticky note, balancing praise and constructive critique. Once all students have finished providing feedback, give students a few minutes to return to their own design solution posters to read the 3x3 sticky notes. Say, Now that you have had the chance to learn about another design solution and receive peer feedback on yours, let's take some time to reflect on what we have learned" (Teacher Edition, page 255).
- Throughout the unit, guidance is provided in Assessment Opportunity boxes which provide guidance for teacher feedback. For example:
    - Lesson 1: "What to do: Students' models will be incomplete since this is the first lesson of the unit. It may be used as a pre-assessment opportunity to check in on students' modeling and use of patterns noted in the data analysis. If students do not agree on the idea that carbon dioxide somehow causes ocean acidification which causes oyster die-off use the crosscutting concept of scale, proportion, and quantity to push them to use the evidence they examined to consider what might be happening at a particle level" (Teacher Edition, page 39).
    - Lesson 4: "See Exit Ticket Key. Provide students with feedback in a timely manner. One way to do this is by using the 'show results' feature of the Form in order to show with graphs how the class is thinking as you begin the next portion of the lesson. Do not skip the self-assessment questions; they are important for continuing to build community" (Teacher Edition, page 84).
    - Lesson 7: "While the answers in Acid Behavior Investigation show the expected responses and calculations, keep in mind that student thinking may be valuable even if their answers are conventionally incorrect. Use the 'ideas to look for' in the key to help provide positive feedback and partial credit to students based on their responses. They[sic] key is designed to help you keep track of students' use of all three dimensions of the NGSS, rather than just whether or not their statement of science ideas is correct" (Teacher Edition, page 137).
    - Lesson 13: "Use Poster Feedback Guide to guide feedback to students. If students are struggling with anticipated effects of solutions, have them look at the models they have developed and identify the specific components they are planning to change. Ask students to predict how those changes will affect other components of that system and connected systems. If students are struggling with representing these ideas on their

posters, have them talk through the ideas first. Students should discuss with their group the best way to show those ideas-textually, with images, mathematical models, or some other appropriate representation" (Teacher Edition, page 247).
    - Lesson 13: "What to do: If students are having difficulty quantifying criteria and constraints, have them review their original lists alongside the site data. Questions such as 'how much/many?', 'when?', or 'how long?' may help students refine their criteria and constraints" (Teacher Edition, page 241).

For the claimed learning in the unit, there are multiple opportunities for students to demonstrate their growth in proficiency over time. Related evidence includes:

- For key claimed learning in the DCI of **PS2.B**, SEP of **Using Mathematics and Computational Thinking**, and CCC of **Scale Proportion and Quantity**:
    - Lesson 9: Students are provided with the Ocean Water Calculations, which asks them to calculate the moles of H+ in an oyster tank at two different points in time. Students work with a partner, and scaffolds are provided to students on the handout to help them setup and complete the calculations. Students then work with their partners to calculate the moles of excess H+ needed to raise the pH of the tank. Students use this information to calculate the amount of NaOH which needs to be added. Students work individually on these calculations.
    - Lesson 11: Students are asked to complete the following while designing their investigation: "Each trial you will use approximately 50 mL of 0.1 M CaCl at a cold temperature as the control. Use this information and the molar mass to determine the mass of Na CO you would need to react with all of the CaCl. This will help you determine a range of about how much NaCO you should add (you will need to vary the amount somewhat if you want to test concentration)" (C.4 Lesson 11 Handout Shell-Building Lab Planner, page 1). The following additional guidance is provided: "If students struggle with stoichiometry, break it into these steps. 1. Calculate the amount of moles in 50 mL of the .1 M NaCl solute. (.002 mol) 2. Calculate the ratio of Na CO they will need to react with the NaCl (given in the reaction equation as 1-1). 3. Calculate the molar mass of Na CO (105.988 g) 4. Calculate the mass in grams needed (105.988 * .002 mol = .212 g)" (Teacher Edition, page 209).
    - Lesson 15: The following questions are found on the district summative assessment: "3b. To produce that much H , the system requires an input of 14,600 mol of CH. What is the mass (in g) of this amount of CH ?", "3c. Use any of the information provided so far to determine the mass (in g) of H O required to produce 118,000 g of H.", and "3d. Is this a significantly large amount? Explain how your solutions to 3a-3c show how atoms (and therefore mass) are conserved during the chemical reaction CH + 2H O → CO + 4H . Remember that since you are working with fairly large numbers, rounding may have affected how 'exact' your solutions were" (C.4 Lesson 15 Assessment Ammonia Fertilizer Production, page 3).
- For key claimed learning in the DCI of **PS2.B** and **ESS3.C**, SEP of **Developing and Using Models**, and CCC of **Cause and Effect**:
    - Lesson 1: "Develop initial models. Display slide V. Pass out Initial Modeling and say, It sounds like we have a decent idea now of why oysters are dying, so let's try to put our ideas on paper. We will draw a model that answers the question, 'How is more carbon dioxide in the atmosphere causing problems for oysters' shells?' We also want to make sure we can zoom in too, so we know what is actually happening to the oyster shell to

harm it. Give students time to work on their models individually" (Teacher Edition, page 38).
  - Lesson 6: "Suggest that we try to make sense of this outcome by developing a model. Distribute Modeling H+ Concentrations. Direct students to use the prompts on the handout to help them model what could be happening to the molecules of two different acids to account for our results" (Teacher Edition, page 81).
  - Lesson 7: On the lesson 7 assessment, students develop a model to show the behavior of each acid when dissolved in water at the molecular level. Students then use this model to answer the following question: "Use the dissociation models in the first table and your models from 3a to make predictions…?" (C.4. Lesson 7 Assessment Acid Behavior Assessment, pages 2–3).
  - Lesson 10: "Revise individual models based on class consensus ideas. Direct students to revise their own models in Shell-Building Model to add any key ideas from the class consensus model that were not included. Say, You do not need to completely alter your model to copy the class consensus model. What is important is that you incorporate key ideas that we all agree on into your model if they are not represented yet" (Teacher Edition, page 192).
  - Lesson 11: "Prepare students to model. Display slide R. Pass out the cards from Reaction Cards and say, Now that we have agreed on a potential solution, we need to model it to help us decide if it could really help oysters build their shells. These cards include the ions that oysters need to build their shells and the hydrogen ions that we figured out can interfere with the process. You will use these cards to model what happens when we add calcium carbonate to the water. You will have a few minutes to think on your own first, then you will work with a partner to come up with an interactive model that you will share with classmates. Your model should show how the ions move and how bonds break and form at different points in the process. Model how adding calcium carbonate can help. Give students time to model on their own using the cards. Emphasize to students that their model should be interactive, meaning it should show ion movement and interactions over time. After 3 minutes, show slide S. Have students join a partner and come to a consensus" (Teacher Edition, page 215).
  - Lesson 12: "Use the Solution Planning Document to develop the solution. Tell students, Now that we have more specific criteria and constraints and know more about these locations, let's try to build some solutions and figure out just how we might impact these ecosystems. Display slide G and distribute Solution Planning Document to students. Groups should work together to answer the questions on Solution Planning Document. They should be as specific and thorough as possible, and quantify their solutions and impacts where appropriate. For example, if students want to raise the pH of water tanks at an oyster hatchery, they will need to use volume and pH to calculate a specific quantity of the substance to be used. Students need to explain how that substance will help them achieve their goal. Encourage students to use the class consensus model and/or models from individual lessons to help them predict the impacts of their solutions" (Teacher Edition, page 234).
  - Lesson 14: Students engage in a transfer task assessment regarding fertilizer which provides students an opportunity to develop models to explain a related phenomenon.
- For key claimed learning in DCIs **ETS1.A**, **ETS1.B**, **ETS1.C**, and the SEP of **Asking Questions and Defining Problems** and the CCC of **Stability and Change:**
  - Lesson 13: Students complete the Solution Planning Document which asks them to outline and prioritize criteria and constraints based upon the site they have selected and

develop a solution. Students then share their criteria and constraints with peers and receive feedback and use their feedback to create solution posters.

- Lesson 13: Students share their design solutions with another group and receive feedback. "Provide peer feedback. Once students have explained their design solutions to each other, separate groups back into pairs from the same design solution group. Display slide I. Ask partners to discuss the design solution that they learned about, using the questions on Peer Discussions Guide as a guide. Then, have students use 3x3 sticky notes to leave feedback on the other pair's design solution poster. Suggest that students write one idea on each sticky note, balancing praise and constructive critique. Once all students have finished providing feedback, give students a few minutes to return to their own design solution posters to read the 3x3 sticky notes. Say, Now that you have had the chance to learn about another design solution and receive peer feedback on yours, let's take some time to reflect on what we have learned." (Teacher Edition, page 255).
- Lesson 14: "Individually reflect on design solutions. Display slide J. Ask students to refer back to their notes on Peer Discussions Guide as well as the peer feedback that they received on their design solution poster. Give students time to write a response to the first question on Design Solution Reflection: After learning from other groups and discussing potential trade-offs, what would you change about your own engineering design solution? Use the following to evaluate your solution. Let's think about how we could use the peer feedback we received to make our design solutions stronger" (Teacher Edition, pages 256–257).
- The Lesson 14 assessment presents the following instruction: "4b. A chemical engineer approaches the decision between the bolded strategies presented in questions 1 and 2 with these three criteria: maximize production of NH_3, minimize monetary cost, and minimize negative environmental impact. Due to droughts in the area, water access is decreasing. Given this scenario, make a claim about which criteria should be prioritized. 4c. Explain your reasoning in 4b" (Ammonia Fertilizer Production, page 4).

Suggestions for Improvement

Consider providing additional opportunities for students to demonstrate their growth in the claimed elements of **Asking Questions and Defining Problems**.

Chemical Reactions in Our World

EQuIP RUBRIC FOR SCIENCE EVALUATION

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

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)