Lithium-Based Batteries

DEVELOPER: Carolina

GRADE: High School **|** **DATE OF REVIEW:** Sept 2023

NextGen Science
WestEd

Lithium-Based Batteries
EQuIP RUBRIC FOR SCIENCE EVALUATION

OVERALL RATING: E

TOTAL SCORE: 9

CATEGORY I: NGSS 3D Design Score	CATEGORY II: NGSS Instructional Supports Score	CATEGORY III: Monitoring NGSS Student Progress Score
3 (0, 1, **2**, 3)	**3** (0, 1, **2**, 3)	**3** (0, 1, 2, **3**)

Click here to see the scoring guidelines.

This review was conducted by NextGenScience 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	Adequate	**A.**	Monitoring 3D Student Performances	Extensive
B.	Three Dimensions	Adequate	**B.**	Student Ideas	Extensive	**B.**	Formative	Adequate
C.	Integrating the Three Dimensions	Extensive	**C.**	Building Progressions	Adequate	**C.**	Scoring Guidance	Adequate
			D.	Scientific Accuracy	Adequate	**D.**	Unbiased Tasks/Items	Adequate
			E.	Differentiated Instruction	Adequate			

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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. This lesson is strong in several areas, including the integration of the three dimensions, lesson coherence, and explicit support to help teachers understand the focal Disciplinary Core Idea (DCI) elements.

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

- **Feedback:** Consider providing teachers with additional teacher support to provide students with individualized feedback and suggestions for how to revise instruction based on students' demonstrated understanding and use of elements of all three dimensions.
- **Progressions**: Consider providing additional guidance on how and when students are expected to progress in their use and understanding of the targeted elements of all three dimensions.

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

CATEGORY I

NGSS 3D DESIGN

I.A. EXPLAINING PHENOMENA/DESIGNING SOLUTIONS

I.B. THREE DIMENSIONS

I.C. INTEGRATING THE THREE DIMENSIONS

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I.A. EXPLAINING PHENOMENA/DESIGNING SOLUTIONS

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

i. Student questions and prior experiences related to the phenomenon or problem motivate sense-making and/or problem solving.
ii. The focus of the lesson is to support students in making sense of phenomena and/or designing solutions to problems.
iii. When engineering is a learning focus, it is integrated with developing disciplinary core ideas from physical, life, and/or earth and space sciences.

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

The reviewers found extensive evidence that learning is driven by students making sense of phenomena or designing solutions to a problem. The materials are organized so students figure out how lithium-based batteries work. The lesson includes three investigations, sequenced to help students answer the question: “Why have lithium-based batteries gained widespread use in electronics over other types of batteries?” The materials also support teachers’ elicitation of students’ questions and prior experiences.

The lesson sequence is focused on lithium batteries. For example:

- Launching the Phenomenon, (Engage): “Students engage in the phenomenon of lithium batteries by compiling a class list of devices that use lithium batteries and discussing a video that shows a fast car powered by lithium batteries. Next, students generate questions to investigate the chemistry of lithium batteries and make an initial claim as to why lithium is a good battery material” (Teacher Edition, page 30).
- Investigation 1, (Explore/Explain): How Do Batteries Work?
    - The teacher is told, “Students build an aluminum-air battery from simple materials and use it to power a small electric motor. They examine the half-reactions of the electrochemical cell and use that information to trace the flow of charge through the system. Then they use the evidence they gathered to create a model that illustrates the relationship between components of the battery system, including the flow of matter and energy due to chemical reactions and the flow of energy into and out of the battery’s external circuits. Finally, students apply what they have learned about batteries in general to develop, draw, and label a model of a lithium metal battery that illustrates the relationship between battery components and the flow of matter and energy through the battery” (Teacher Edition, page 30).

  - Introduction to Investigation 1: "Previously, you brainstormed a list of devices that are powered by lithium batteries and made an initial claim about why lithium makes such a good battery material. In this investigation, you will develop and build an aluminum-air battery to explore how the components and chemicals in a battery work together to transport energy to power electrical devices" (Teacher Edition, page 40; Student Edition, page S-6).
- Investigation 2: In the beginning of the lesson, the class revisits the Driving Question Board (DQB), and students are told, "The lithium batteries phenomenon and the aluminum–air battery you built in Investigation 1 depend on chemical reactions." In the Explore/Explain section "How Can You Describe and Predict Chemical Reactions?" the teacher is told, "Students make predictions about reactions between metals and dissolved metal salts. Then they perform reactions between three different metals and dissolved metal salts and observe whether a chemical reaction has occurred. Within their group, they use the evidence they gathered to develop a model of metal reactivity. Each group presents their activity series model and reasoning to the class. Students revise and expand their model, working to integrate all the class data into a class consensus model. Next, students view videos of additional metal and dissolved metal salt reactions and use their observations to place aluminum, lead, and silver into the consensus metal activity series. Finally, they make claims as to where lithium fits into the activity series, and update their initial claim (made during the Engage phase of the lesson) as to why lithium makes a great battery material" (Teacher Edition, page 30).
- Investigation 3: During the launch, it is explained that "to drive their sense-making, students should make connections between the phenomenon and the investigation" (Teacher Edition, page 99).
- Investigation 3, (Explore/Explain): Which Pair of Electrodes Makes the Best Battery? "Given four pairs of metals for use as electrode pairs in a simple battery, students determine which should be the anode and cathode in each pair. They make a prediction about which of the four pairs of electrodes will make the best battery. Then students build a simple battery, using one of the four pairs of metal electrodes, and use the battery to power the mini motor. They use the evidence they collect to identify patterns in metal reactivity and make a claim as to the pair of metal electrodes that makes the best and worst battery. Finally, students apply what they learn to predict which of three metals would make the best primary battery when paired with a lithium electrode."
- Final Lesson Performance, (Explain): "Students use a starting template to develop a model to show how a lithium-ion battery uses a flow of matter and energy to power a device. Then they use the model to construct an explanation for how the lithium-ion battery can be recharged."
- Final Lesson Reflection, (Evaluate): "Students reflect on the development and use of models in the lesson and evaluate how their thinking about the importance of chemical reactions to battery technology has changed as a result of the lesson" (Teacher Edition, page 31).

Teachers are supported to elicit student questions and prior experiences. For example:

- Introduction: "Also, give students time to share stories about their experiences with lithium batteries. Some students may have heard stories about lithium batteries catching fire or getting hot. Encourage students to share stories about their own experiences or what they have heard from others about using lithium batteries" (Teacher Edition, page 32).

- Launching the Phenomenon: Students are given a short reading introducing them to a lithium battery-powered car and are tasked to, "work with your group to complete a list of all the devices that you think use lithium batteries." Students complete a table related to what they already understand about batteries and what questions they have about batteries (Teacher Edition, page 34).
- Launching the Phenomenon: The teacher is directed to, "create a class driving question board (DQB)" (Teacher Edition, page 33). Additionally, the Teacher's Edition, on page 18, explains that "While the DQB can be revisited informally at any point during the lesson, it should be explicitly revisited after each investigation in the lesson sequence so that unanswered or new questions can serve as the transition into the next investigation."
- Investigation 1: The material states that "the goal of the investigation launch is to guide students to select driving questions on the DQB that can be addressed directly through the investigation and reading. Before class, review Investigation 1. Identify questions on the DQB that can be answered with data and information students will be able to obtain from the investigation" (Teacher Edition, page 41).
- Investigation 1: During Investigation 1, students are instructed to, "Identify and list any questions from the driving question board that you will explore in the investigation" (Teacher Edition, page 40).
- Investigation 1: The material states that students "will connect evidence they have gathered about battery systems with their ideas about the lithium battery phenomenon and their understanding of the flow of matter and energy through a lithium metal battery" (Teacher Edition, page 65).
- Investigation 2: During the launching of the second investigation, it is explained that "the goal of the investigation launch is for students to select driving questions on the DQB that can be addressed directly through the investigation and reading. Before class, review Investigation 2 in the Student Guide. Identify questions on the DQB that can be answered with the data and information students will be able to obtain from the investigation" (Teacher Edition, page 73).
- Investigation 2: The student is told, "The phenomenon for this lesson is lithium-based batteries. How is the metal activity series model you developed important to battery design? Respond to the following prompts as you think through this question." Several questions follow to elicit student ideas (Teacher Edition, page 91).
- Investigation 3: During the launching of the third investigation, it is explained that "the goal of the investigation launch is for students to select driving questions on the DQB that can be addressed directly through the investigation. Before class, review Investigation 3, the digital investigation resources, and the Lithium-Based Batteries article in the Student Guide. Identify questions on the DQB that can be answered with the data and information students will be able to obtain from the Investigation" (Teacher Edition, page 99).
- Investigation 3: The material states that "students read the article 'Lithium-Based Batteries' to help them connect their work on reactivity and electrodes back to the Phenomenon in questions 9-12" (Teacher Edition, page 115).

The materials support students to see how their questions are related to the activities, and teachers are supported to engage students in choosing which questions to answer next. For example:

- Launching the Phenomenon: Teachers are told to, "Have students share and discuss question 3 with a partner" (Teacher Edition, page 33). Students are told, "Work together to develop two questions to help you investigate lithium batteries and how they use chemical reactions to power devices. Your questions, combined with those from other pairs of students, will be posted on a driving question board. Throughout this lesson, you will be able to obtain information and gather evidence that will help you answer these questions" (Student Edition, page S-4). Teachers then tell students "With a partner, share and discuss your understandings about batteries and what you wonder about them. Work together to develop two questions to help you investigate batteries and how they use chemical reactions to power device" (Teacher Edition, page 39 / Student Edition, page S04). Teachers are then directed to, "provide each pair of students with sticky notes and have them write one question on each note" and told, "In this part of Launching the Phenomenon, you will create a class driving question board (DQB)" (Teacher Edition, page 33). Teachers are told to, "Review the questions and talk to students about grouping the questions according to similarities. Work with the class to move the sticky notes around and organize the questions into major categories." They are advised, "As this lesson progresses, students will be able to answer questions related to how batteries work, the parts of a battery, the chemical reactions that drive batteries, how to select the best materials to make a battery, the movement of matter and energy inside and outside a battery, and what makes lithium so useful in batteries" (Teacher Edition, page 33). The teacher is then told to, "Ask the class to identify questions on the DQB related to lithium" (Teacher Edition, page 33).
- Launching Investigation 1: The teacher is told, "The goal of the investigation launch is to guide students to select driving questions on the DQB that can be addressed directly through the investigation and reading. Before class, review Investigation 1. Identify questions on the DQB that can be answered with the data and information students will be able to obtain from the investigation. Taking the time to identify these questions for yourself will prepare you to facilitate the use of the driving question board as a tool to help students understand that they are driving their own learning, creating a need to know within the classroom. Examples of questions directly related to this investigation are provided in the sample answers. 1. Revisit the DQB and guide students toward identifying questions related to how a battery works, the chemical reactions that take place, and how the energy from those reactions transforms into electrical energy that powers a device" (Teacher Edition, page 41).
- Launching Investigation 2: The teacher is told to, "1. Revisit the DQB and ask students, 'Which questions still need to be answered in order to make sense of the phenomenon?' Then, guide them toward identifying questions related to the chemical reactions that take place in a battery and questions about chemical reactions in general. 2. List or mark the questions students have identified so they can record them when you hand out the investigation. It is important not to hand out the investigation until after the questions have been identified." (Teacher Edition, page 73).

- Launching Investigation 3: 1. “Revisit the DQB and ask students, ‘Which questions do we still need to answer to help make sense of the phenomenon?’ Then, guide them toward identifying questions that are related to the chemistry of battery design and how different battery components could affect the performance of a battery. 2. List or mark the questions students have identified so they can record them when you hand out the investigation. It is important not to hand out the investigation until after the questions have been identified” (Teacher Edition, page 101).

Suggestions for Improvement

Consider ensuring clarity on the anchoring question presented to the students and used throughout the materials. The question “how do lithium batteries work?” is very different from the question “why do so many people use lithium batteries?” Answering the latter involves sociology and marketing.

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 an understanding of grade-appropriate elements of the three dimensions because there is a close match between the claimed Science and Engineering Practice (SEP) elements and the evidence of SEP development in the materials. Students use grade-appropriate elements in service of making sense of the phenomenon. Additionally, students are supported in developing their competence in the SEP elements throughout the materials as they work toward their Final Performance Task. However, there is a mismatch between some of the claims and the evidence of students’ use of the SEPs and Crosscutting Concepts (CCCs).

Science and Engineering Practices (SEPs) | Rating: Adequate

The reviewers found adequate evidence that students have the opportunity to use or develop the SEPs in this lesson because students engage in grade-level elements of **Asking and Defining Problems**,

Developing and Using Models, and **Engaging in Argument from Evidence**. However, there is a mismatch between some of the claims and the evidence of students' use of the SEPs.

Asking Questions and Defining Problems

- *Ask questions that arise from careful observation of phenomena, or unexpected results, to clarify and/or seek additional information.*
    - Launching the Phenomenon: After watching the phenomenon launch video students are instructed to complete a t-chart where they record their current understandings about batteries and they are told to, "record questions you have about batteries" (Teacher Edition, page 32). However, students are only required to engage with this element at the K–2 level, using the following element: *Ask questions based on observations to find more information about the natural and/or designed world(s)*.
    - Launching the Phenomenon: The teacher is instructed to create a DQB with student-generated questions that have been created from pairs of students based on earlier questions. Students are prompted on S–4 to, "work together to develop two questions to help you investigate batteries and how they use chemical reactions to power devices" (Teacher Edition, page 33).
    - Investigation 1: After developing their initial model of the aluminum-air battery system, students are asked, "What questions do you still have about how the aluminum-air battery system works?" (Teacher Edition, page 62). However, students are only required to engage with this element at the K–2 level, using the following element: *Ask questions based on observations to find more information about the natural and/or designed world(s)*.
    - Investigation 1: After completing Investigation 1, the teacher is instructed to lead a class discussion to, "evaluate how well the evidence you gathered so far supports answers to the questions from the driving question board." One of the prompts provided for the teacher is to tell the students to, "write any additional questions you would like to add to the driving question board" (Teacher Edition, page 69).

Developing and Using Models

- *Develop, revise, and/or use a model based on evidence to illustrate the relationships between components of a system.*
    - Investigation 1: Students develop a model to show how components in an aluminum-air battery work together to transport energy. Students "apply what they have learned about batteries in general to develop, draw, and label a model of a lithium metal battery that illustrates the relationship between battery components and the flow of matter and energy through the battery" (Teacher Edition, page 41).
    - Investigation 1: Students are asked to use the class consensus model to consider what would happen if components were missing. "Once you have achieved a class consensus as to how matter and energy flows, encourage students to use the model to consider what would happen if individual system components were missing. For example, ask students, 'How would removing the separator affect the system?' (The cathode and

anode would be able to come in contact, and electrons would flow from one to the other instead of through the load). As students consider how a missing component impacts the flow of energy and matter in the system, help students understand how useful the model is at illustrating the relationships between components in the system" (Teacher Edition, page 43).

- Investigation 1: Students are encouraged to add to or revise a system model based on new learning. "Give students time to add to or revise their battery-load system models based on the class consensus model" (Teacher Edition, page 43).
- Investigation 1, Part A: Students design a battery. "Record an initial drawing and a plan to serve as a model that shows how you will build a battery to power the electric motor" (Teacher Edition, page 49).
- Investigation 2: Students develop and revise a metal activity series model.
- Investigation 3: Students refine a model of how a battery works.
- Lesson Performance: At the end of the lesson, students develop a model of "how a secondary lithium-ion battery uses changes in the flow of matter and energy from chemical reactions to supply energy to a device." "Then they use the model to explain how it is possible to recharge the secondary battery" (Teacher Edition, page 4).
- Final Reflection: Students reflect on the components they included in their model of a lithium-ion battery and are asked, "How could you improve your model of the lithium-ion battery?" (Teacher Edition, page 128 / Student Edition, page S-50).

Engaging in Argument from Evidence

- *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.*
    - Launching the Phenomenon: Students make an initial claim about "why lithium makes such a good battery." Students are asked to explain, "what scientific reasoning supports" their claim (Teacher Edition, page 36).
    - Investigation 1: During the Investigation 1 Performance Task students are instructed to, "make and defend a claim based on evidence you gathered in this investigation and your understanding of matter and energy flow in a battery-load system as to what the chemical makeup of the anode and the cathode is for this lithium metal battery." Students are provided with a graphic organizer which includes prompts for "make a claim," "support your claim with related scientific knowledge," and "provide scientific reasoning for how or why the evidence supports the claim" (Teacher Edition, page 64).
    - Investigation 2: During the second investigation students are instructed to, "use the prompts below to construct an evidence based argument" to respond to the question, "where does lithium belong in the metal activity series?" Students are provided with a graphic organizer, which includes prompts for "make a claim," "support your claim with at least two empirical evidence patterns and related scientific knowledge," and "provide scientific reasoning for how or why the evidence supports the claim." Additionally, students defend their claim with a partner and then revise the claim based on partner feedback (Teacher Edition, page 90).

  - Investigation 2: During the Investigation 2 Performance Task students are instructed to, "use patterns in evidence you gathered from experiments, the video, the periodic table, your metal activity series model, and class discussions, along with scientific knowledge and scientific reasoning to construct an argument in support of a claim as to why lithium makes a great candidate for supplying energy in a battery." Students are provided with a graphic organizer, which includes prompts for, "make a claim," "support your claim with at least two empirical evidence patterns and related scientific knowledge," and "provide scientific reasoning for how or why the evidence supports the claim" (Teacher Edition, page 96).
  - Investigation 3: During the Investigation 3 Performance Task students are instructed to, "make and defend a claim based on patterns in evidence as to which of these three metals would make the best cathode for a primary lithium metal battery." Students are provided with a graphic organizer, which includes prompts for, "make a claim," "support your claim with at least two empirical evidence patterns and related scientific knowledge," and "provide scientific reasoning for how or why the evidence supports the claim" (Teacher Edition, page 118).
  - Investigation 3: While reflecting on the third investigation, students are given the opportunity to "review the evidence-based claim you constructed for this investigation's performance task" and are provided with a graphic organizer to explain the evidence used to support their claim. Students are also given an opportunity to add evidence to their claim from Investigation 2 (Teacher Edition, page 122). Students are told that "valid and reliable evidence comes from a variety of sources" and are asked, "Which of the following sources of evidence did you use to support your arguments? For each source of evidence, give a brief description of that evidence." A list of evidence sources is provided, for example: "Evidence from a model," "evidence from a theory," and "evidence from information obtained from a teacher's direct instruction" (Teacher Edition, page 123 / Student Edition, page S-46).

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

The reviewers found extensive evidence that students have the opportunity to use or develop the DCIs in this lesson because students test and build an understanding of chemical properties of metals in battery systems and apply and develop an understanding about what metals would make the best anode and cathodes in a battery system.

PS1.B Chemical Reactions

- *The fact that atoms are conserved, together with the knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.*
  - Launching the Phenomenon: Students read that "to understand the chemistry of batteries, it is helpful to consider the chemical and physical properties of the elements used in batteries. Why do you think the element lithium makes such a great battery, as opposed to other elements such as hydrogen or neon? Complete steps a-c to answer this question. A) Gather information about the element lithium using the periodic table

and your prior knowledge of the physical and chemical properties of elements" (Teacher Edition, page 36). Students are not expected to use this element in this section of the lesson.

- Investigation 1: Students read that "the following half-reactions, together, make up the full chemical reaction in the battery. Each half-reaction takes place at one of the electrodes. Remember, the reaction that produces electrons occurs at the anode, and the reaction that accepts electrons occurs at the cathode." Students are then shown the half-reactions in an aluminum-air battery and informed that "the half-reactions will be balanced once you put the whole chemical equations together later in this investigation" (Teacher Edition, page 52). The students read "Notice that the activated charcoal (C) is not a reactant or product in either of the half-reactions. The charcoal conducts electricity but is not chemically reactive itself. It acts as a catalyst to help speed up the reaction" (Teacher Edition, page 54). Students provide explanations for the following prompts: "Given the half-reactions, and your knowledge of chemistry and battery systems, write the complete balanced chemical equation for the reaction that drives the aluminum-air battery. Explain what the complete balanced chemical equation reveals about how the aluminum-air battery system works. The aluminum-air battery system cannot power the motor forever. Explain, referring to the complete balanced chemical reaction, why this is so" (Teacher Edition, page 62). During the Investigation 1 Performance Task students are given the half-reactions for electrodes found in lithium metal batteries. They are then tasked to, "write the complete balanced chemical equation that represents the chemical reaction that takes place in this lithium metal battery" (Teacher Edition, page 64).
- Investigation 2: During the Stop and Think activity students respond to the following prompts: "How will you know if a chemical reaction is taking place? Describe at least three different pieces of evidence that show a reaction is taking place. What properties of the reactants do you think determine whether a reaction will occur?" (Teacher Edition, page 72). Students make predictions about the possibility of reactions and possible products between several reactants. These predictions are then tested through student investigations. A similar activity is conducted for S–22 (Teacher Edition, pages 74 and 76). The teacher is told to, "Facilitate a brief discussion to apply prior learning about single-replacement reactions. A single-replacement reaction is a reaction in which a more reactive element is substituted for a less reactive element in a compound. All the reactions that students will conduct are potentially metal displacement reactions, of the following form: **A + BC(aq) → AC(aq) + B** The starting materials are a pure metal, A, and an aqueous solution of a metallic salt, **BC**. When a displacement reaction occurs, a new aqueous metallic salt, **AC**, and a different pure element, **B**, are generated as products" (Teacher Edition, page 78). The teacher is told to, "Then lead a brief whole-class discussion of how knowledge of the chemical properties of the elements that are involved as reactants can be used to predict whether a chemical reaction occurs and what the products of that reaction would be. All the reactions that will be conducted are between metals and aqueous metal salts,

so it will be helpful to focus on properties of metals. Metals differ in their tendencies to give up valence electrons. In the case of single-replacement reactions, the more readily the solid metal gives up an electron, the more likely the reaction will occur" (Teacher Edition, page 78). Students explain their response to the following question: "How does the placement of elements in your metal activity series model relate to patterns of the periodic table?" (Teacher Edition, page 88). Students write the complete balanced equations for reactions that took place in three different test tubes (Teacher Edition, page 92).

- Investigation 3: Students are asked, "if two metals from your metal activity series were chosen as electrodes in a simple battery, how would you decide which would be the anode and which the cathode?" Sample student responses indicate that anticipated answers would demonstrate student understanding of the reactivity levels of each metal (Teacher Edition, page 104). During a class-wide discussion the teacher is instructed to ask, "Do the electrodes in the batteries change during the reactions? How does the model show that? Did you see evidence of it in the battery you built?" The sample student response is, "The electrodes are part of the chemical reaction, so there must be changes to them. The anode loses electrons and positive ions, so it must get smaller. The cathode gains electrons and solid metal is formed, so it must get bigger" (Teacher Edition, page 113). Students are asked, "if two metals from your metal activity series were chosen as electrodes in a simple battery, how would you decide which would be the anode and which the cathode?" Sample student responses indicate that anticipated answers would demonstrate student understanding of the reactivity levels of each metal (Teacher Edition, page 104). During a class-wide discussion the teacher is instructed to ask, "Do the electrodes in the batteries change during the reactions? How does the model show that? Did you see evidence of it in the battery you built?" The sample student response is, "The electrodes are part of the chemical reaction, so there must be changes to them. The anode loses electrons and positive ions, so it must get smaller. The cathode gains electrons and solid metal is formed, so it must get bigger" (Teacher Edition, page 113).

Crosscutting Concepts (CCCs) | **Rating: Adequate**

The reviewers found adequate evidence that students have the opportunity to use or develop the CCCs in this lesson because students are regularly expected to apply and build an understanding of energy and matter flows within a battery system. The CCC of **Patterns** is claimed and referenced, but it is not developed.

CCC Categories addressed (or not addressed):

Patterns

- *Empirical evidence is needed to identify patterns.*
  - Investigation 2:
    - How Can You Describe and Predict Chemical Reactions?: Students "perform reactions between three different metals and dissolved metal salts and

observe whether a chemical reaction has occurred." They rank the metals by reactivity "use the evidence they gathered to develop a model of metal reactivity, ranking the metals from most reactive to least reactive." Students then "use their metal activity series to find patterns in the performance of different pairs of battery electrodes and predict which pair of electrode metals will make the best battery" (Teacher Edition, page 71). In the Student Edition "Empirical evidence is the evidence that you directly observe and get from your senses. Look for patterns in the empirical evidence you gathered for the three chemical reactions. What patterns can you identify?" (Teacher Edition, page 76 / Student Edition, page S-22). Students are therefore supported to build toward an understanding of this element. Student Edition, Explain: Students are asked, "How does the placement of elements in your metal activity series model relate to patterns of the periodic table?" (Teacher Edition, page 87 / Student Edition, page S-29). Note that students discuss that they can get patterns from evidence, but the idea of needing evidence to get patterns is not discussed. In addition, although students are asked to identify patterns in reactivity and connect to placement in the periodic table, it is unclear if students were just following teacher directions and repeating what they were told about the patterns or if they used the lens of patterns to come to their own understanding.

    - Performance Task: "Make and defend a claim based on patterns in evidence as to which of these three metals would make the best cathode for a primary lithium metal battery." "Have students work individually on the Investigation 3 Performance Task. They will connect the patterns of empirical evidence they discovered in the investigation with their ideas about the lithium battery phenomenon and their understanding of how the properties of elements can be used to describe and predict chemical reactions. Students will make a claim about which of the three metal options would make the best cathode and construct an argument to support the claim" (Teacher Edition, page 119).
  - Investigation 3:
    - During a class discussion the teacher is prompted to ask, "now that you have empirical evidence, discuss with your group how you will decide which battery is the 'best' and rank the four batteries from 'best' to 'worst.' Be sure to state your criteria (Teacher Edition, page 109). The provided sample response indicates that students should explain that they see a pattern in the strength of the motor vibration based on the voltage, although the use of the CCC element is not explicit as the requirement for evidence is not discussed.
    - While completing S-43, students are asked, "scientists use empirical evidence to identify patterns in chemical properties. What patterns did you identify in the empirical evidence you gathered?" The following question is: "How could you use the metal activity series model to predict which metals would make the best battery electrode components, based on the patterns you identified

    from your empirical evidence?" (Teacher Edition, page 116). Note that the requirement for empirical evidence is not discussed here.

    - During the Investigation 3 Performance Task students are instructed to, "make and defend a claim based on patterns in evidence as to which of those three metals would make the best cathode for a primary lithium metal battery." One of the prompts provided to support students in making their claim is to "support your claim with at least two empirical evidence patterns and related scientific knowledge" (Teacher Edition, page 118). Note that the requirement for empirical evidence is not discussed here.
    - Remediation Guidance for Evaluation Question 5: "Finally, ask students about the significance of the patterns. How are the patterns useful in predicting what electrode pairs would make the best battery? How did identifying patterns in empirical evidence make this discovery possible?" (Teacher Edition, page 21). In this last question, the claimed CCC element might be elicited, although the provided scoring guidance does not ensure that teachers will be looking for and supporting this particular high school-level element.

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.*
    - Investigation 1, Part A: Students design a battery, they are directed to draw a plan that will serve as a model of "how you will build a battery to power the electric mower" and are reminded to "be sure to show how the individual components work together to complete a working battery–motor system" (Teacher Edition, page 49).
    - Investigation 1, How Does a Battery Work?: "In this investigation, you will develop and build an aluminum–air battery to explore how the components and chemicals in a battery work together to transport energy to power electrical devices" (Teacher Edition, page 40 / Student Edition, page S-6).
    - Investigation 1: "What observable evidence do you have that changes in matter and energy occurred in the battery? Consider the observations you made in this investigation and the chemical equations for the aluminum-air battery" (Teacher Edition, page 62 / Student Edition, page S-16).
    - Investigation 3: "Lead a class discussion to help students make sense of the energy and matter flows in the battery system with two separated half-cells" (Teacher Edition, page 109).
    - Investigation 3: "Now that each group has built a battery with two separated half-cells, consider presenting a model of the battery–load system that shows the flow of matter and energy. Project it so all the groups can study it. Post these guiding questions for the groups to consider: • How does the model show the flow of energy into, out of, and within the system? • How does the model show the flow of matter into, out of, and within the system?" (Teacher Edition, page 111).

  - Final Performance Task: Students “develop a model of how a secondary lithium-ion battery uses changes in the flow of matter and energy from chemical reactions to supply energy to a device” (Teacher Edition, page 125).
  - Final Performance: The student task for the final performance is “on your own, use data from investigations and information obtained from readings and class discussions as evidence to develop a model of how a secondary lithium-ion battery uses changes in the flow of matter and energy from chemical reactions to supply energy to a device.” Students are directed to, “use arrows and notations to show the flow of matter and energy” (Teacher Edition, page 124).

Suggestions for Improvement

Science and Engineering Practices

- The materials identify student engagement in the SEP of **Engaging in Argument from Evidence.** However, it would be helpful to clarify the difference between **Engaging in Argument from Evidence** and **Constructing Explanations**. STEM Teaching Tool #1 highlights this importance and might be a helpful resource, STEM Teaching Tool 1- Argumentation-Explanation - https://stemteachingtools.org/brief/1. Another resource that would be helpful is *A Framework for K–12 Science Education*, pages 67–74. Below are quotes from the Framework that may be helpful to teachers as they distinguish the SEP **Constructing Explanations** and **Engaging in Argument from Evidence**.
  - **Engaging in Argument from Evidence**: “Becoming a critical consumer of science is fostered by opportunities to use critique and evaluation to judge the merits of any scientifically based argument.” “Students should argue for the explanations they construct, defend their interpretations of the associated data, and advocate for the designs they propose. Meanwhile, they should learn how to evaluate critically the scientific arguments of others and present counterarguments.”
  - **Constructing Explanations and Designing Solutions**: “Scientific explanations are accounts that link scientific theory with specific observations or phenomena—for example, they explain observed relationships between variables and describe the mechanisms that support cause and effect inferences about them.” “Asking students to demonstrate their own understanding of the implications of a scientific idea by developing their own explanations of phenomena, whether based on observations they have made or models they have developed, engages them in an essential part of the process by which conceptual change can occur.” Students “should be encouraged to develop explanations of what they observe when conducting their own investigations and to evaluate their own and others’ explanations for consistency with the evidence.”

Disciplinary Core Ideas

- Consider supporting student learning of additional DCI elements during the lesson to ensure that students have enough time and support to reach proficiency on all DCIs in the standards by the end of grade 12.

Crosscutting Concepts

- Consider clarifying claims of students' CCC use or supporting students to use high school-level CCC elements more often in the lesson.

I.C. INTEGRATING THE THREE DIMENSIONS

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

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

The reviewers found extensive evidence that student performances integrate elements of the three dimensions in service of figuring out phenomena or designing solutions to problems because there are numerous tasks in which students are expected to develop their understanding of the phenomenon in a grade-appropriate way by integrating at least part of a grade level SEP, CCC, and DCI element. Each investigation involves multiple dimensions.

Related evidence includes:

- Investigation 1: Students "make and defend a claim based on evidence you gathered in this investigation and your understanding of matter and energy flow in a battery-load system as to what the chemical makeup of the anode and the cathode is for this lithium metal battery" (Teacher Edition, pages 65–67).
  - 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 equations.*
  - SEP: **Engaging in Argument from Evidence**: *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.*
  - 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.*
- Investigation 2: Students "use patterns in evidence you gathered from experiments, the video, the periodic table, your metal activity series model, and class discussions, along with scientific knowledge and scientific reasoning to construct an argument in support of a claim as to why lithium makes a great candidate for supplying energy" (Teacher Edition, page 94).
  - 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 equations.*

  - SEP: **Engaging in Argument from Evidence**: *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.*
  - CCC: **Patterns**: *Empirical evidence is needed to identify patterns.* Note that it is not clear that students use this element in this particular performance, although students build toward this element in the investigation.
- Investigation 3: "Now that each group has built a battery with two separated half-cells, consider presenting a model of the battery-load system that shows the flow of matter and energy. Project it so all the groups can study it. Post these guiding questions for the groups to consider: • How does the model show the flow of energy into, out of, and within the system? • How does the model show the flow of matter into, out of, and within the system?" (Teacher Edition, page 111).
  - 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 equations.*
  - SEP: **Developing and Using Models**: *Develop, revise, and/or use a model based on evidence to illustrate the relationships between components of a system.*
  - 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.*
- Investigation 3: Students "make and defend a claim based on patterns in evidence as to which of these three metals would make the best cathode for a primary lithium metal battery" (Teacher Edition, page 118).
  - 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 equations.*
  - SEP: **Engaging in Argument from Evidence**: *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.*
  - CCC: **Patterns**: *Empirical evidence is needed to identify patterns.* Note that it is not clear that students use this particular element in this performance.

Suggestions for Improvement

N/A

OVERALL CATEGORY I SCORE: 1 (0, 1, 2, 3)	
Lesson Scoring Guide – Category I	
Criteria A-C	
3	Extensive evidence to meet at least two criteria and at least adequate evidence for the third.
2	Adequate evidence to meet all three criteria in the category.
1	Adequate evidence to meet at least one criterion in the category but insufficient evidence for at least one other criterion.
0	Inadequate (or no) evidence to meet any criteria in the category.

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.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 questions from their own experience.

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

The reviewers found adequate evidence that the materials engage students in authentic and meaningful scenarios that reflect the real world. Students experience the phenomenon as directly as possible, and the claimed phenomenon is somewhat engaging to students. However, it is not motivating enough to ensure that the learning is largely student driven. In addition, the connections between student experiences and the phenomenon are somewhat weak.

Related evidence includes:

- Teacher's Edition materials provide opportunities for students to experience the phenomenon as directly as possible. For example:
  - Launching the Phenomenon: "Students watch a video featuring a 1972 Datsun car that accelerates from 0–60 mph in 1.8 seconds and races a quarter mile in just over 10 seconds, powered by a lithium battery. Students are asked to think about and list the many different devices they know about that use lithium batteries for power. Next, they generate a list of things they know about batteries and things they wonder about" (Teacher Edition, page 17).
  - Instructional Support: The material states that "everyone is familiar with the AA and AAA batteries used in toys, remote controls, and wireless computer keyboards and mice," (Teacher Edition, page 26). However, this guidance appears to only be for additional background knowledge for teachers and it is unclear if it is intended to be shared with students.
  - Investigation 1: Students build an aluminum-air battery using common materials they are likely familiar with: aluminum foil, salt water, charcoal, paper towel, and a mini motor. "Work with your group to develop a model that shows the relationship between components and chemical reactions of the aluminum-air battery system. "Students will build an aluminum-air battery from simple materials and use it to power a small electric

motor. They examine the half-reactions of the electrochemical cell and use that information to trace the flow of charge through the system. They will use the evidence they gathered to create a model that illustrates the relationship between components of the battery system, including the flow of matter and energy due to chemical reactions and the flow of energy into and out of the battery's external circuits. Students will apply what they have learned about batteries, in general, to develop, draw, and label a model of a lithium metal battery that illustrates the relationship between battery components and the flow of matter and energy through the battery" (Teacher Edition, page 41).

  - Investigation 2: Students observe the reactivity of metals directly. Students are directed to, "Place the solid metal into the solution in test tube 1." Record "observations of the chemical reaction in the "Observation" column of Data Table 2.2" and are reminded to, "Pay close attention to any signs that a chemical reaction is happening" and "describe any evidence you observed for a reaction" (Teacher Edition, page 74 / Student Edition, page S-21).
  - Investigation 3, students build batteries to collect evidence on the best metals to use as anodes and cathode pairs. "Students build a simple battery, using one of the four pairs of metal electrodes, and use the battery to power the mini motor." They directly "collect data on motor vibration observations and voltage readings from all four of the different battery combinations" and then "They use the evidence they collect to identify patterns in metal reactivity and make a claim for the pair of metal electrodes that makes the best and the worst battery" (Teacher Edition, page 99).

- Teacher's Edition materials provide guidance for connecting the instruction to the student's home. For example:
  - Launching the Phenomenon: "Lead a discussion on batteries to build interest and assess prior knowledge. Use the discussion prompts below to discover what students already know about batteries." Sample discussion prompt: "Have you ever built a battery, such as a lemon battery or potato battery?" This is the first question teachers ask, prior to watching the lithium-powered race car video. Although this prompt allows the teacher to find out who has experience building a battery, it could potentially and immediately disengage those who did not.
  - Instructional Support: The materials explain that "students are asked to think about and list the many different devices they know about that use lithium batteries for power. Next, they generate a list of things they know about batteries, and things they wonder about" (Teacher Edition, page 17).
  - Launching the Phenomenon: Students generate a list of devices they think use lithium batteries. An included Teaching Tip suggests that "in addition to the class list of devices that use lithium batteries, you might want to encourage students to create a jamboard or other digital file with images of devices that use a lithium battery" (Teacher Edition, page 32).
  - Investigation 1: The student activity includes a short passage which states "Many small devices are powered by alkaline batteries. You would recognize them as being called AAA, AA, or perhaps C or D. You have probably replaced an old alkaline battery with a

new one in a remote-control device, a flashlight, a wireless computer mouse, or a video game controller" (Teacher Edition, page 40).

Suggestions for Improvement

- When launching the phenomenon, consider ways for the teacher to access students' prior knowledge and funds of knowledge for all students (not just those who have built batteries). The following resource might be helpful — STEM Teaching Tool #53 "How to avoid known pitfalls associated with culturally responsive instruction."
- Consider additional ways to help students connect what they are learning to their home and community. Students are shown a video of a racecar powered by a battery and asked to think about other things from their daily life that require the use of batteries. Further opportunities to build on examples of related phenomenon might help students connect what they are learning beyond the walls of the classroom.
- Consider finding additional ways for students to relate to the phenomenon through problem-solving an issue closely related to their own experiences.

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. The materials provide support to teachers for eliciting student ideas, although student artifacts don't necessarily elicit evidence of how students' reflective thinking has changed over time. The materials provide opportunities for students to discuss each other's ideas, but little support is provided for students to receive constructive feedback from peers.

Related evidence includes:

- The teacher has enough support to act as an expert facilitator to draw out student ideas. The DQB is introduced as a way to draw out student ideas. "While the DQB can be revisited informally at any point during the lesson, it should be explicitly revisited after each investigation in the lesson sequence so that unanswered or new questions can serve as the transition into the next investigation. A structure for this process is provided in the Lesson Guidance section of this Teacher's Manual and in the Introduction and Reflect portions of the Student Guide" (Teacher Edition, page 18). Note that this statement is not customized to the lesson materials so it might not be as impactful as it could be.

- Student ideas are clarified, justified, and built upon. Some examples include:
    - Teacher's Edition materials provide specific clusters of discussion questions, often with specific follow-up questions throughout the lesson. Examples of discussion prompts paired with additional questions to draw out additional student understanding are found in the Teacher Edition, pages 35, 46, 50, 56, 102, 106, and 111.
    - Launching the Phenomenon: After the launch of the phenomenon, the teacher is instructed to, "ask students to respond to question 4 individually, where they make a claim about why lithium makes a good battery. Then, have students share their response with a partner" (Teacher Edition, page 33). Note that directing students to share responses with a partner without more explicit guidance may not result in discourse that includes students expressing, clarifying, or justifying their reasoning.
    - Launching the Phenomenon: The student page tells students "with a partner, share and discuss your understandings about batteries and what you wonder about them. Work together to develop two questions to help you investigate batteries and how they use chemical reactions to power devices" (Teacher Edition, page 37).
    - Investigation 1: The teacher is instructed to, "ask students to answer the Stop-and-Think questions individually, and then have volunteers share their models" (Teacher Edition, page 43).
    - Investigation 3: While students are brainstorming questions the teacher is instructed to, "allow students to share ideas, and let them know they have the opportunity to investigate their predictions" (Teacher Edition, page 103).
- Students have multiple, structured opportunities to receive, respond to, and reflect on peer feedback. Students have some opportunities to receive teacher feedback. Examples include:
    - Investigation 1: After groups of students develop an initial model of an aluminum-air battery system, the teacher is instructed to, "assign each group one or two models that they did not develop. Ask them to write questions, suggestions for possible changes, or affirmations of content and clarity, and post those notes on the model where needed. Give groups time to read the sticky-note feedback on the model they developed and to make any changes they with on the basis of the feedback." Later, the teacher is instructed to, "give students time to revise their models as necessary to accommodate what they have learned from the class consensus model discussion" (Teacher Edition, page 58).
    - Investigation 1: During investigation 1 the teacher is instructed to, "encourage students to discuss their answers with their group, seeking feedback and gathering additional evidence. Encourage them to revise their answers based on peer feedback" (Teacher Edition, page 63).
    - Investigation 2: Students use a carousel session to develop a class consensus model. "Each lab group will prepare a display to share the chemical reactions they have conducted, their group activity series model, and their evidence and reasoning. Allow time in class to prepare their displays. Provide them with markers and chart paper or poster boards. An Activity Series Display Template is provided in your digital resources if you wish to use it with your students. Assign each group a location in the classroom for

    their display. Distribute sticky notes for groups to write down questions or comments they have about other models. For the carousel session, have lab groups work together to examine the metals in each reactivity model, compare other models with their own, take notes, and then rotate as a group" (Teacher Edition, page 81).
    - Investigation 2: After groups have developed their consensus models the teacher is instructed to, "organize a group sharing session so that each group can share their model with at least two other groups." Groups are then advised to revise their consensus models (Teacher Edition, page 82).
    - Investigation 2: During the performance task an optional opportunity for peer feedback is provided. "If you choose to have students defend their claim, give each student time to share an argument with at least two other students" (Teacher Edition, page 94).
    - Investigation 3: During the Investigation 2: Performance task an optional opportunity for peer feedback is provided. "If you choose to have students defend their claim, give each student time to share an argument with at least two other students" (Teacher Edition, page 119).
- Student artifacts show how students' reflective thinking changed over time. For example:
    - Investigation 1, 2, and 3, Reflection: "Complete the following table to track your progress on questions" (Teacher Edition, pages 68, 96, and 122). At the end of each investigation, students are asked to write questions they have, what they figured out, and new questions that they have. Note that students are rarely asked to include reasoning and reflections (using writing, oral, pictorial, kinesthetic, or models) that clearly show how reasoning and thinking changed over the length of lesson.
    - Investigation 3: In the Final Reflection, students are asked, "How has your thinking about models changed over the course of this lesson?"

Suggestions for Improvement

- Consider providing additional opportunities for students and teachers to provide constructive feedback that will push student thinking.
- Consider additional opportunities and teacher support requiring students to justify their thinking. This could include shifting optional opportunities to recommended opportunities.
- Consider providing additional and explicit opportunities for students to clearly show how their thinking has changed over time.
- Consider opportunities and explicit guidance to help teachers provide feedback followed by opportunities for students to reflect on and refine thinking based on the feedback.

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 materials include progressions from related elements from the 6–8 grade level as well as earlier lessons in high school chemistry. There is also support for the teacher to clarify misconceptions, and the lessons clearly build on learning from previous lessons. However, the focus is primarily on having students build on elements of the DCIs, and the suggestions provided to address alternate conceptions students have do not leverage or value variation in life experiences.

Related evidence includes:

- Lesson Materials include a "Prior Learning: Progression from Middle School" Chart. This chart includes the 6–8-level elements for the three dimensions and a description of "How This Lesson Builds on the Element." For example:
    - "DCI MS PS1.B: Chemical Reactions. 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."
        - How This Lesson Builds on the Element: "When atoms interact and create new substances in chemical reactions, atoms are not created or destroyed; the atoms that are present in the reactants are also present in the products. Elements have unique chemical properties, such as the number of valence electrons, whether metallic or nonmetallic, and degree of chemical reactivity. These properties can be used to describe and predict chemical reactions, in addition to recognizing them" (Teacher Edition, page 16). Note that this section does not describe students' learning experiences, but only what they are meant to build on.
    - "CCC Patterns: Patterns can be used to identify cause-and-effect relationships."
        - How This Lesson Builds on the Element: "Students examine the evidence gathered from observing chemical reactions in order to identify patterns, then use those patterns to develop a metal activity series model. They reflect on how

identifying patterns in empirical evidence helped them create their model. They use observations of how strongly a motor runs and voltage measurements from batteries made with different pairs of electrodes to identify patterns of performance. They then use these patterns of performance and their metal activity series model to develop a method to predict which pairs of metals would make the best battery electrodes. They also support their claim of which metal would make the best cathode for a lithium battery based on patterns of evidence" (Teacher Edition, page 16).

  - "SEP Developing and Using Models: Develop and/or use a model to predict and/or describe phenomena."
    - How This Lesson Builds on the Element: Students use a model of a voltaic cell to describe the flow of energy and matter through the cell, illustrating the relationships between components and processes of the system. As they progress through the lesson, they develop an initial metal activity series model, based on empirical evidence, and revise it based on class pooling of data. They use the model to describe and predict which combination of electrodes would make the best battery" (Teacher Edition, page 16).
- Learning Summary Charts are included for Investigation 1, Investigation 2, and Investigation 3. Learning Summary Charts include the lesson question, what students will do, and what students will figure out, and what's next. For example:
  - Question: "How does a battery work?"
  - What Students Will Do: "Students will build an aluminum-air battery from simple materials and use it to power a small electric motor. They examine the half-reactions of the electrochemical cell and use that information to trace the flow of charge through the system."
  - What Students Will Figure Out: "A battery cell is made up of two electrodes, an electrolyte, and an external circuit for electrons to flow." Note that these sections do not describe new learning related to SEPs or CCCs. For example, for the CCC **Patterns**, it is not yet clear how the sequence of the lesson helps students build capacity with the element *Empirical evidence is needed to identify patterns*.
  - What's Next: "Students explore chemical reactions to develop a metal activity series model. After predicting where lithium would fit in their model, students update the claim they made at the beginning of the lesson about why lithium is such a great candidate for supplying energy in a battery" (Teacher Edition, page 41).
- Launching the Phenomenon: When launching the phenomenon, the teacher is instructed to, "lead a discussion on batteries to build interested and assess prior knowledge," (Teacher Edition, page 32). However, the target element or dimension of the prior knowledge is unclear.
- Launching the Phenomenon: Students are instructed to, "gather information about the element lithium using the periodic table and your prior knowledge of the physical and chemical properties of elements" (Teacher Edition, page 39). However, the target element or dimension of the prior knowledge is unclear.

- Prior to starting Investigation 1, Part B: Investigate the Chemical Reactions and Revise the Battery teachers are advised that "Part B of the Investigation assumes that students already know how to represent chemical reactions with balanced chemical equations. Before having students begin Part B of the investigation, use the following discussion prompts to help students connect prior learning of chemical reactions to the concept of half-reactions in electrochemistry applications. For students who have prior experience with oxidation–reduction (redox reaction pairs), consider having them use that terminology when describing the half-reactions" (Teacher Edition, page 50).
- Prior to starting Investigation 2, Launching the Investigation: Teachers are provided with a "note" on previous learning. "Note that previous lessons will have focused on the DCIs regarding atomic substructure and how the periodic table shows repeating patterns of similar chemical properties and outer electron states" (Teacher Edition, page 73).
- Investigation 2: Students are instructed to, "explain your reasons for the predicted products. Use your prior knowledge of elements and the periodic table to help you develop your explanations" (Teacher Edition, page 77). However, the target element or dimension of the prior knowledge is unclear.
- Prompts are provided to help teachers assess students' prior understanding in relation to DCIs. For example:
    - Launching the Phenomenon: "Use the prompts below to assess students' understanding about metals, nonmetals, group characteristics, and valence electrons. By listening to students' explanations, you will be able to gauge student understanding from previous chemistry lessons so they may be successful in seeing periodic patterns and applying the DCI for this lesson" (Teacher Edition, page 33). Discussion prompts include: "What happens to matter during a chemical reaction?", "What is the role of energy in a chemical reaction such as photosynthesis? Cellular respiration?", and "What do you know about lithium's chemical properties?" (Teacher Edition, page 35).
    - Investigation 1, How Does a Battery Work: "Use the following discussion prompts to leverage students' prior learning from middle school on the relationship between chemical reactions and energy" (Teacher Edition, page 41).
    - Investigation 2, Launching Investigation 2: "Guiding Questions: What did you learn from the previous investigation about which parts of a battery contribute to the chemical reactions? • What kinds of 'rules' are you familiar with that might help you predict if a chemical reaction occurs? • What patterns of the periodic table might be helpful for predicting chemical reactions?" (Teacher Edition, page 73).
    - Investigation 2, Guiding Questions: Prior to predicting reactivity of metals in aqueous metallic salt solutions "What periodic trends do you think could help you figure out whether a reaction will occur?" "Does the number of valence electrons in a metal tell you anything about its reactivity?" "What happens to a metal atom when it loses an electron?" "What happens to a metal cation when it gains an electron?"
        - Investigation 3, Guiding Questions: Prior to starting the investigation, students are asked, "What do you know about the materials that make up a battery's electrodes? What evidence could you look for when investigating electrodes to

support your ideas?" Teachers are provided with the following Guiding Questions: Does it make sense for both electrodes to be made of the same metal?", "What happens at the electrodes?", and "What did you learn about reactive metals in the previous investigation?" (Teacher Edition, page 101).

- Charts are provided to guide three separate discussions: Discussion 1.1 Properties of Materials, Discussion 1.2 Electrochemistry, Discussion 1.3 Identifying relationships between components of the aluminum-air battery system. Each discussion table includes a set of teacher questions, sample student responses, and extending the discussion suggestions. For example:
    - Discussion 1.3: Identifying relationships between components of the aluminum-air battery system.
        - Discussion Prompt: "What property of matter allows battery systems to convert chemical energy to electrical energy?"
        - Sample Student Response: "That atoms and molecules can form positively or negatively charged ions when they interact and that opposite charges attract."
        - Extending the Discussion: "How is charge separation important to a battery system?" Sample response: "If you have a positive area separated from a negative area, and then you connect those areas so the electrons can move from one side to the other, you have a flow of charge, or electricity that can do work such as run a motor, a fan, or other electric device" (Teacher Edition, page 56).
    - Discussion 3.1: Structure and Materials of Batteries
        - Discussion Prompt: "Think of the variety of different types of batteries with which you are familiar. What are some possible reasons why there are different types of battery designs?"
        - Sample Student Response: "Batteries are different sizes, depending on the device they are powering. Also, some batteries need to provide more energy than others. An electric vehicle battery needs to be designed to provide a lot more energy than a battery used in a flashlight. Some batteries can be recharged, and other batteries can be used only once."
        - Extending the Discussion: "Alkaline batteries that are referred to as AA and AAA use the same chemical reactions and they both produce about 1.5 volts of electricity. Why do you think we need both types of batteries?" Sample Response: "Perhaps the AAA batteries are necessary because they fit into smaller devices than AA batteries can. Perhaps AA batteries last longer because they are larger" (Teacher Edition, page 102).
- Support is provided to teachers to clarify potential alternate conceptions that they or their students might have. For example:

- Investigation 2, Addressing Misconceptions: “Students may have the misconception that if any two chemicals are mixed, a chemical reaction will take place. You might want to take the opportunity to emphasize that without adding energy, chemical reactions take place only when the reaction results in products that are more stable than the reactants, with the product having stronger bonds. In the case of the reaction between a solid metal and an aqueous metallic solution, a single-replacement reaction might occur. The spontaneous chemical reaction will occur only if the stand-alone metal on the reactant side is more reactive than the aqueous metal ion, forming a more stable solid metal and ionic compound on the product side” (Teacher Edition, page 79).

Suggestions for Improvement
Consider clarifying the learning progressions of the SEPs and CCCs.

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

The reviewers found adequate evidence that the materials use scientifically accurate and grade-appropriate scientific information. Only minor issues were found with the science ideas as they relate to the SEPs and student facing material.

Related evidence includes:

- The Teacher Manual includes a “Science Background” section that highlights what could be teacher misconceptions and misunderstandings. For example:
  - “At first glance, the phenomenon of a battery-load system lends itself best to questions primarily answered by physics and related topics in electricity and electrical engineering. However, when you begin asking some basic questions (How do batteries work? How do batteries generate an electric current? Why can some batteries be recharged, and others not be? Why do some lithium-ion batteries explode or catch fire?), you begin to realize that a basic understanding of chemistry is critical to understanding the relationships between components of a battery-load system. The most basic chemical

property of elements, their tendency to gain, lose, or share electrons with other elements, is the foundational scientific principle behind how batteries work. An understanding that ions and electrons move around when elements participate in chemical reactions can lead to an understanding that harnessing the electrons and giving them a path to follow is a way to create an electric current that can power devices" (Teacher Edition, page 24).

  - Cell vs Battery: "The term 'battery' is often used for devices that are not, technically speaking, batteries. A cell is a single unit that converts chemical energy to electrical energy, whereas a battery is a device made up of more than one cell. Common alkaline batteries, referred to by sizes such as AAA, AA, C, or D, are cells, not batteries. The voltage is usually a good indicator of whether a battery is a true battery or just a single cell. The spontaneous oxidation-reduction reactions of a single electrochemical cell are typically able to produce up to as much as 3 volts. Most common alkaline cells used in flashlights, remote controls, and wireless keyboards give about 1.5 volts each. True batteries, on the other hand, are made up of more than one cell, so their voltages are higher, such as in the case of a typical 9-volt smoke alarm battery or a 12-volt vehicle battery. It is widely accepted to define a battery as having 'one or more' electrochemical cells, even though the strict definition is that a battery consists of more than one cell. To simplify, you can refer to all the devices that convert chemical energy to electrical energy as batteries" (Teacher Edition, page 24).
  - The lesson-level phenomenon is identified as "Every day, we use devices that use different sizes of lithium batteries—sometimes many devices in a single day! How do batteries use chemical reactions to change and move matter and energy so that all of these different devices receive power?" (Teacher Edition, page 32). Note that including the lesson question and reflection related to the phenomenon of lithium batteries being used to power devices under the label of "Phenomenon" could be misleading and lead to confusion about the nature of a phenomenon (observable event that occurs in the universe that we can use our science knowledge to explain or predict).

- Investigation 1: Students develop a model of an aluminum-air battery system. In the Addressing Misconceptions section, it is suggested "you might want to give students the following analogy to help them understand this part of how a battery–device system works. The external circuit, when designed and built correctly, forms a closed loop between the anode of the battery, the electrical device that needs energy, the cathode of the battery, the electrolyte, and back to the anode. You can ask students to use a finger to trace the pathway on the model. The battery acts as a 'charge pump' that drives electrons through the system. Consider how a waterfall feature in a homemade backyard pond works. Water flows down the waterfall and into a pool because of the natural pull of gravity, somewhat like the way electrons move from a negative area to a positive area in a closed circuit because of the pull of charge attraction. A water pump pushes the water in the pool back up to a high energy state at the top of the waterfall, and a battery uses chemical reactions to push electrons back up to a higher energy state. The cycle then repeats" (Teacher Edition, page 59). The purpose of this analogy is to help students understand the concept of a closed loop, although this purpose is not quite clear and might be misinterpreted as it is within the "Misconceptions" section.

- Investigation 1, Addressing Misconceptions: "The aluminum-air battery system model does a good job of illustrating relationships between components of the system. However, like all models, there are limitations to what the model can explain. One limitation of the model is that it might make students question why the motor does not 'use up the electrons' supplied by the battery. The model shows electrons leaving the anode, entering the motor, and then exiting the motor to return to the cathode. The model does not really explain how this is possible, so you might want to give students the following analogy to help them understand this part of how a battery–device system works" (Teacher Edition, page 59). Note that a student misconception is not explicitly named, so teacher use of this model limitation might be different than intended.

Suggestions for Improvement

- When identifying the phenomenon, such as on page 32 of the Teacher Edition, consider ensuring that it is a phenomenon.
- Consider re-framing the electrical circuit-water fall pump analogy in a way that explicitly states the reason for the analogy is to help students understand the concept of a closed loop accompanied by information for the teachers as to the fundamental differences between the two.
- Consider changing the title of the section "Addressing Misconceptions" on page 59 of the Teacher Manual to align with the purpose of helping teachers understand the limitation of the model. Alternately, consider adding wording to describe the misconception that students might have if they misinterpret the model.

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

The reviewers found adequate evidence that the materials provide guidance for teachers to support differentiated instruction. Differentiated instructional strategies are provided for a wide variety of different student groups. However, the support designed for learners with disabilities, multilingual learners, and students who read well below grade level is not specific to the activities, learning goals, or needs of individual students.

Related evidence includes:

- The materials provide generalized guidance for supporting reading, writing, listening, and speaking alternatives. For example:
    - Launching the Phenomenon: Students watch a video to motivate learning in the lesson (Teacher Edition, page 17). However, it is unclear if the PBS: Powering Torque in the Trunk video is available in languages other than English and/or if closed captioning is enabled.
    - The “Writing Support” Section includes information on writing scaffolds, sustained silent writing, and multiple modalities.
        - “Scaffolds: Constructing scientific evidence and arguing from evidence are aided in this lesson by writing scaffolds that are included in the Student Edition. These include the C–E–R framework (Claim, Evidence, and Reasoning) and scaffolds for constructing explanations and presenting arguments for how the evidence supports or refutes an explanation.”
        - “Sustained Silent Writing: This strategy involves providing students with a prompt and dedicating part of the class time for students to silently write their response. Sustained silent writing helps students develop their “writing muscle,” including writing skills and stamina. It is also a means of making student thinking

    visible while paving the way for new ideas and learning. Using the strategy regularly offers a safe time and place for students to practice writing. For constructing explanations, this process helps students reason out how the evidence supports their explanations."
    - Multiple Modalities: "To address the needs of all learners, students are encouraged to make their thinking visible in multiple ways. For example, during classroom discussions that activate prior knowledge, build concepts, and elicit ideas, students are given ample space and appropriate prompts in the Student Guide to record ideas and important points through their choice of words, graphic organizers, diagrams, and illustrations. Students are then encouraged to share and compare their notes with others to find commonalities and record additional information they might have missed but want to remember. Throughout the lesson, students interact with physical components, tables, firsthand observations, videos, and annotated background research articles to help them gather a variety of evidence to support arguments and explanations" (Teacher Edition, page 23).
  - Opportunities to use multiple ways to make thinking visible include:
    - Investigation 1: "How do matter and energy flow in, out, and through a battery–device system? You may want to use words, sketches, a flowchart, a diagram, or a combination to communicate your ideas" (Teacher Edition, page 42 / Student Edition, page S-7).
    - Investigation 1, Differentiated Instruction: "Throughout the lesson, as you conduct class discussions such as Discussion 1.1: Properties of Materials, students are prompted to record their ideas, evidence, and things they want to remember in the space provided in the Student Guide. Support diverse learners by reminding students that there are a variety of ways to record notes during class discussions: words, images, drawings, flowcharts, diagrams, and use of color and highlights are just a few of the ways to record ideas and things to remember from a discussion" (Teacher Edition, page 47).
  - The "Speaking and Listening Skills" Section includes a reminder that "as students participate in small- and large-group discussions, they connect new ideas to prior knowledge and personal experience, clarify their understanding, work collaboratively, and engage in productive discourse, with the goal of deeper understanding." This statement is followed by two strategies: patterns in evidence helped them develop a model for star classification. This strategy requires students to 1) think individually about an answer to a question, and 2) share their ideas with a partner and discuss them. This simple strategy enhances students' oral communication skills as it helps them engage collaboratively in reflecting on an important crosscutting concept."
- Guidance is provided for multilingual learners and learners who read well below grade level:
  - Reading support for multilingual learners is provided on page 22 of the Teacher's Edition through two specific strategies. First, annotating text "supports student sense-making while reading complex text such as the readings provided in this lesson." Second, a word

    wall “helps students build science language.” One additional suggestion is to, “use a tool such as Google Docs online word-processing application to serve as the wall. Encourage students to include pictures of physical examples of each word where appropriate.”
    - Instructional Support: The material states that “to support the needs of multilingual learners, students who struggle with reading, and students who read below grade level, use the following strategy for each reading: 1) Have students identify the questions about the phenomenon that they are trying to answer from the reading. 2) Have students read through once to see what it is about, then read a second time to annotate the text and highlight important ideas. 3) Ask students to summarize the key ideas in the reading in their own words. Also encourage them to use diagrams, flowcharts, and other graphic organizers in addition to words” (Teacher Edition, page 22).
- Guidance for students who are struggling to demonstrate mastery of the target dimensions is provided in the scoring rubrics for each performance task. For example:
    - Investigation 2: A remediation strategy suggested is, “for students who partially meet or are approaching this target, have them complete the interactive lesson ‘The Reactivity Series,’ available in your Digital Resources. Have them identify empirical evidence patterns in the lesson materials. Let students know that this is an additional source of reliable evidence they can cite in support of their argument” (Teacher Edition, page 95).
    - Investigation 2: A remediation strategy suggested is, “for students who partially meet or are approaching this target, have them review the class consensus model for the aluminum-air battery system. It may be helpful for students to use one color to highlight the aspects of the model that show how matter flows, and another color to highlight the aspects of the model that show how electrons flow. Then, ask students to compare the highlighted portions of the class consensus model with their claim and balanced reaction” (Teacher Edition, page 67).
- Additional guidance for struggling students includes:
    - Investigation 1: Differentiated Instruction: “If any groups struggle to figure out how all the components could work together in a system, have them watch the brief video Five-Cent Battery available in your digital resources. Then ask students to compare how that battery works with how they might be able to get their aluminum-air battery to work. The idea of layering components, such as placing the saltwater-soaked paper towel between the aluminum foil and charcoal layers, might be more evident after seeing how the five cent battery is constructed. If further remediation is necessary, consider conducting a whole-class discussion of several different student models. Point out how each model conveys the way in which components work together to make a battery–motor system. Then ask groups to add to or revise their initial model before using it to build a battery” (Teacher Edition, page 47).
    - Investigation 2: When recording observations about reactions in a data table: “For some students, it might be helpful to provide or display the table as they examine the reactants on their list, predict possible products, and write and balance chemical equations” (Teacher Edition, page 78).

  - Investigation 2: When developing a metal activity series model: "It may be helpful for students to write the name of each of the four metals they are testing on an index card or sticky note. They can use the cards to sequence the metals into order based on their observations and results. This allows students to shift around the components of their model as they explore ideas as they reason through the concepts" (Teacher Edition, page 81).
  - Investigation 2: When preparing to display chemical reactions for the class: "An Activity Series Display Template is provided in your digital resources if you wish to use it with your students" (Teacher Edition, page 81).
  - Scoring Guide for Investigation 2 Performance Task: "For students who understand lithium's properties but cannot connect that to why it makes a good battery component, ask students to go back to the battery–load system diagram in Investigation 1. Have them trace the flow of energy through that system and ask them to summarize how electrons are important to that system. Have them identify the metal that donated electrons in the aluminum-air battery. Ask them to compare aluminum's place in the metal activity series model with lithium's. Then ask them to revise their claim, using this newly understood evidence and reasoning." "For students who partially meet or are approaching this target, have them work with a partner and review their answers to the multipart Explain question 5, where students consider how the metal activity series model is important to battery design. Ask students to annotate their answers to identify scientific knowledge and reasoning that can be used to connect their evidence to their claim" (Teacher Edition, pages 94–95).
  - Scoring Guide for Investigation 3 Performance Task: "For students who partially meet or are approaching this target, ask them to work with a partner to explain why the pair of elements in a cathode–anode combination is more important than the individual elements. Then have them consider which of the three elements would pair best with lithium" (Teacher Edition, page 120).
- Guidance is provided for students who have already met or exceeded the targeted dimensions is provided in the scoring rubrics for each performance task. However, these supports do not extend targeted CCCs. For example:
  - Investigation 1: In the scoring rubric for Investigation 1 Performance Task, a differentiation strategy suggested is that "for students who meet or exceed this target, have them write the complete, balanced, net ionic equation for the lithium-manganese dioxide battery" (Teacher Edition, page 66).
  - Investigation 1: In the scoring rubric for investigation 1 Performance Task, a differentiation strategy suggested is, "for students who meet or exceed this target, ask them to identify and label the presence of oxidation and reduction reactions on the class consensus model of the aluminum-air battery. For students who need a refresher on oxidation and reduction reactions, remind them of the 'OIL RIG' mnemonic (oxidation is losing electron; reduction is gaining electrons" (Teacher Edition, page 67).
  - Investigation 2: In the scoring rubric for Investigation 2 Performance Task, a differentiation strategy suggested is, "for students who meet or exceed the target, ask

    them to imagine what it would be like to repeat the aluminum-air battery activity in Investigation 1, using lithium instead of aluminum. Have them create a cartoon storyboard or a diagram, or have them write a paragraph to describe how handling lithium would be so much more difficult and too dangerous for them to use for this classroom activity" (Teacher Edition, page 94).
    - Investigation 3, Scoring Guide for Investigation 3 Performance Task: "For students who meet or exceed the target, have them do some research on the performance and uses for lithium–iron disulfide batteries, commonly used in low-drain devices such as remote controls and smoke detectors. They have a longer shelf life than alkaline batteries typically have." "For students who meet or exceed the target, have them research the most common elements that are used as cathodes in lithium-based batteries, select one, and summarize the benefits and drawbacks of using that element in lithium battery design." "For students who meet or exceed the target, consider having them complete the advanced interactive digital lesson 'Electrochemical Series of Metals,' which compares the reducing abilities of metals and considers the importance of standard reduction potential values" (Teacher Edition, pages 120–121).

Suggestions for Improvement

- Consider providing more explicit and activity-specific support within the materials for multilingual learners, learners with special needs, and learners who read well below grade level throughout the lesson material.
- The "Writing Supports" and "Speaking and Listening Skills" sections in the Teacher Manual highlight specific strategies. Consider also highlighting or linking to these strategies within the lesson material when they are used such that a teacher would know to consider their use, similarly to the way "silent writing" was called out on step 30 of Investigation 1. "Use sustained silent writing to have individual students complete the Explain questions in the Student Guide" (Teacher Edition, page 63) and on step 34 of Investigation 2: "Use sustained silent writing to have individual students complete the Explain questions in the Student Guide" (Teacher Edition, page 89).
- Investigation 1: On Discussion 1.3, Extending the Discussion Column the teachers are provided with the question, "Did it matter which motor clip was connected to the anode and which was connected to the cathode?" and the sample answer, "No, if we switched them, the motor still ran." This is followed with the guidance, "Although these motors will run in either direction, other load devices, such as LEDs or light bulbs or buzzers, work only when connected in one direction" (Teacher Edition, page 57). Rather than just suggesting the teachers provide this information to the students, researching this could be highlighted as an opportunity for students who have already met performance expectations (PEs).

OVERALL CATEGORY II SCORE:

3

(0, 1, 2, 3)

Lesson Scoring Guide – Category II	
Criteria A-E	
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 four criteria, including A
1	Adequate evidence for at least two criteria in the category
0	Adequate evidence for no more than one criterion 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.A. MONITORING 3D STUDENT PERFORMANCES

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

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

The reviewers found extensive evidence that the materials elicit direct, observable evidence of students using practices with DCIs and CCCs to make sense of phenomena or design solutions. Each of the investigations and the final performance task elicits direct, observable evidence of integration of the target elements across the three dimensions, and many of these are used at the high school level. The lesson provides teachers with the opportunity to assess students' understanding of the claimed elements at the high school level multiple times. However, in several assessments there is a mismatch between the CCC claimed and what students are required to use.

Related evidence includes:

- Investigation 1: The explanation for the performance task claims that students "will connect evidence they have gathered about battery systems with their ideas about the lithium battery phenomenon and their understanding of the flow of matter and energy through a lithium metal battery. Students will make a claim about which of the components of the half-reactions represent the anode and which represents the cathode and construct an argument to support the claim" (Teacher Edition, page 65).
    - DCI: **PS1.B: Chemical Reactions**: Teacher's Edition, page 6, claims that after collecting information about batteries "they explain what the complete balanced chemical equation reveals about how the aluminum-air battery system works."
    - SEP: **Engaging in Argument from Evidence**: *Make and defend a claim based on evidence about the natural word or the effectiveness of a design solution that reflects scientific knowledge, and student generated evidence*: Teacher's Edition, page 5, claims that students "use evidence they gather and the patterns they observe to develop and revise a metal activity series model. By the end of the investigation, students make a claim as to where lithium belongs in the metal activity series, as well as a final claim as to why lithium makes a great candidate for supplying energy in a battery."
    - 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*: Teacher's Edition, page 7, claims that "after building and aluminum-air battery, students develop a model to show, among other things, the flow of energy into and out of the external circuit, and the movement of matter (ions) through the system, including the role of the dissolved sodium chloride. At the end of the investigation, students reflect on how their model of

the aluminum-air battery system helps them understand the flows of energy and matter into, out of, and within the system."

- Investigation 2: The materials explain that "students will complete a performance task to demonstrate their progress on constructing an argument, identifying patterns of evidence, and applying the scientific principle they discovered from the investigation, building on the initial claim they made in the Introduction of the lesson. Have students work on their own to make a claim about why lithium makes a good battery material and construct an argument to support the claim" (Teacher Edition, page 94).
    - DCI: **PS1.B Chemical Reactions**. Teacher's Edition, page 6, claims that students will "reflect on how the scientific principle of atom conservation, together with knowledge of the chemical properties of elements, allows one to predict whether a single-replacement reaction will take place, and if so, what the reaction products will be."
    - SEP: **Developing and Using Models**: *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*. Teacher's Edition, page 5, claims that students "use the evidence they gather and the patterns they observe to develop and revise a metal activity series model. By the end of the investigation, students make a claim as to where lithium belongs in the metal activity series, as well as a final claim as to why lithium makes a great candidate for supplying energy in a battery."
    - CCC: **Patterns**: *Empirical evidence is needed to identify patterns*. Teacher's Edition, page 7, claims that "students are asked to identify patterns in the empirical evidence they collect by performing four different single-replacement reactions. Then, after compiling class-wide results of many different reactions, students identify patterns to support the development of a metal activity series model." However, in this performance, students are only required to use the related K–2-level CCC element: *Patterns in the natural and human designed world can be observed, used to describe phenomena, and used as evidence.*
- Investigation 3: The materials claim that students "will connect the patterns of empirical evidence they have discovered in the investigation with their ideas about the lithium battery phenomenon and their understanding of how the properties of elements can be used to describe and predict chemical reactions. Students will make a claim about which of the three metal options would make the best cathode and construct an argument to support the claim" (Teacher Edition, page 119).
    - DCI: **PS1.B Chemical Reactions**: Teacher's Edition, page 6, claims that "students explore the chemical relationship between a battery's anode and cathode by building and observe batteries with different combinations of metal electrodes."
    - SEP: **Engaging in Argument from Evidence**: *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.* Teacher's Edition, page 5, claims that following observations of batteries with a variety of electrode combinations, students "share evidence among groups, determine what makes the 'best' battery, and make a

claim as to which of the three elements (iron, potassium, or magnesium) would make the best cathode to use with lithium in a lithium metal battery."

  - CCC: **Patterns**: *Empirical evidence is needed to identify patterns.* Teacher's Edition, page 7, claims that "students are asked to identify a pattern in the evidence that can serve as criteria for determining which battery is the 'best.' At the end of the investigation, students make a claim as to which of three metals would make the best cathode in a primary lithium metal battery and use at least two empirical evidence patterns to support the claim." In this performance, students are asked, "How did identifying patterns in empirical evidence make this discovery possible?" However, the teacher is not supported to look for evidence in student performance other than that for the related K–2-level CCC element: *Patterns in the natural and human designed world can be observed, used to describe phenomena, and used as evidence.*

- Final Performance: The material claims that "after constructing this final model, students use the model to explain what happens to allow the lithium-ion battery to be recharged. Finally, students reflect on what they have learned through the modeling process, and how their understanding of the role of chemical reactions in batteries has changed as a result of the lesson" (Teacher Edition, page 125).
  - DCI*:* **PS1.B Chemical Reactions**: The Teacher's Edition, page 6, claims that "students develop a model that relates how chemical reactions are responsible for allowing a lithium-ion battery to power a device and to be recharged."
  - SEP*:* **Developing and Using Models**: *Develop, revise, and/or use a model based on evidence to illustrate the relationships between components of a system.* The Teacher's Edition, page 4, claims that "students use the evidence they have gathered to develop a model of how a secondary lithium-ion battery uses changes in the flow of matter and energy from chemical reactions to supply energy to a device. Then they use the model to explain how it is possible to recharge the secondary battery."
  - 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.* The Teacher's Edition, page 7, claims that "students develop a model to show how the movement of energy and matter allows a secondary lithium-ion battery to power a device and then be recharged."

Suggestions for Improvement

Consider ensuring that student assessment prompts match the assessment targets for all three dimensions at a grade-appropriate level.

III.B. FORMATIVE

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

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

The reviewers found adequate evidence that the materials embed formative assessment processes throughout that evaluate student learning and inform instruction. Formative assessment opportunities are called out explicitly in each investigation and some support is provided for teachers to modify their instruction based on student responses. Formative assessment supports address all three dimensions at some point during the lesson. However, the called-out formative assessments are each limited to a single dimension when they are addressed. Additionally, most of the provided support is based on the needs of most students rather than on attending to students' individual needs.

Related evidence includes:

- "Ask groups to work together to develop an initial model of the aluminum-air battery system as described in step 9. Consider having students record their models on chart paper to make it easier to conduct a class review/discussion of the models. This modeling activity serves as a formative assessment checkpoint to gauge students' thinking on the relationships between components of the battery and the chemical reactions. The model they develop is important in demonstrating an understanding that the changes in matter from the chemical reactions and the arrangement of components in the battery work together to drive the transformation of chemical energy to electrical energy" (Teacher Edition, page 58).
- Investigation 1: The material states that "the first reflection question serves as a formative assessment checkpoint that gives students an opportunity to consider how their model of the aluminum-air battery system helps them understand the flows of matter and energy in the system and reflect on the evidence that supports their model." Remediation guidance is provided in the Teacher's Edition on page 20, including alternate language to use and suggestions for students with difficulty verbalizing their understanding (Teacher Edition, page 69).
- Investigation 2: The material states that "Question 4 serves as a formative assessment checkpoint for the science and engineering practice of Engaging in Argument from Evidence to see how well students are able to identify valid evidence and use it to construct an argument to support a claim." Remediation guidance is provided in the Teacher's Edition on page 20, including the suggestion that "for students who struggle with identifying supporting evidence that puts lithium at the top of the metal activity series, prompt them to find a pattern between the location of an element on the periodic table and its position on the metal activity series, using the metals they have already investigated (Teacher Edition, page 89).

- Investigation 2: During the reflection for the second investigation, the lesson material states that “the first question serves as a formative assessment checkpoint to measure students’ understanding of how single-replacement reactions can be described and predicted using knowledge of the conservation of atoms and the reactivity of reactant metals.” Remediation guidance is provided in the Teacher’s Edition on page 20, including two prompts for struggling students (Teacher Edition, page 97).
- Investigation 3: “Have students individually fill out the table in step 6. This table will help you gauge how well students understand the connections between reactivity of a metal, the role of the anode and cathode, and how electrons are transferred between the electrodes” (Teacher Edition, page 103).
- Investigation 3: The lesson materials state that “Question 5 serves as a formative assessment checkpoint for the crosscutting concept of Patterns to see how well students are able to identify patterns of electrode pair relative reactivity in the activity series model.” Remediation guidance is provided in the Teacher’s Edition on page 21, including specific support for students struggling with identifying patterns in data (Teacher Edition, page 115). However, this remediation support focuses on the SEP of **Analyzing Data**, and the students are only asked to use a K–2-level CCC element of **Patterns** in this assessment.
- Instructional Support: The lesson material states that “classroom discourse provides an opportunity for informal formative assessment.” The Teacher’s Edition also suggests specific opportunities for discussion (Teacher Edition, page 23). For example:
    - Launching the Phenomenon: The teacher is instructed to, “Lead a discussion on batteries to build interest and assess prior knowledge. Use the discussion prompts below to discover what students already know about batteries” (Teacher Edition, page 32).
    - Launching the Phenomenon: The teacher is instructed to, “have pairs share their claims about lithium and then facilitate a class discussion. This discussion provides the opportunity to review the placement and properties of elements in the periodic table. Use the prompts below to assess students’ understanding about metals, nonmetals, group characteristics, and valence electrons. By listening to students’ explanations, you will be able to gauge student understanding from previous chemistry lessons so they may be successful in seeing periodic patterns and applying the DCI for this lesson” (Teacher Edition, page 33).
    - Launching the Phenomenon: A table of discussion prompts, sample student responses, and guidance for extending the discussion is provided (Teacher Edition, page 35). Additional tables of discussion prompts are included on Teacher Edition pages 46, 50, 56, and 102. However, support for modifying instruction based on varied student responses is not included.

Suggestions for Improvement

- Consider providing support for teachers to address issues of student equity through formative assessments by including culturally- and linguistically-responsive strategies to help elicit,

interpret, and respond to student thinking. For example, consider providing support for teachers to elicit, interpret, and respond to student thinking related to the learning targets.
- Consider ensuring that teachers are supported to monitor students' progress toward all targeted elements of the three dimensions.

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

The reviewers found adequate evidence that the materials include aligned rubrics and scoring guidelines that help the teacher interpret student performance for all three dimensions. Explicit guidance is provided to teachers to interpret student progress, but students have little support to track their own progress. Some possible student responses are included but do not represent a range of student responses. Additionally, scoring guidance is only provided for the Performance Tasks and not the other assessments in the lesson.

Related evidence includes:

- Scoring guidance is included for Investigations 1, 2, and 3 performance tasks. "At the end of each investigation, individual students are asked to complete a performance task to assess current student thinking and understanding of the phenomenon and provide actions for differentiation, including remediation and extensions of learning. These performance tasks serve as artifacts of student progress toward the targeted dimensions. A Scoring and Differentiation Guide for each performance task is provided in this Teacher's Manual. Each guide provides evidence of proficiency, including key targets that should be demonstrated in the task, and actions to take based on the evidence of learning, including remediation actions for partial and limited understanding and extensions of learning for full understanding" (Teacher Edition, page 18). For example:
    - Scoring Guide for Investigation 1 Performance Task: "Make and defend a claim based on evidence you gathered in this investigation and your understanding of matter and energy flow in a battery–load system as to what the chemical makeup of the anode and the cathode is for this lithium metal battery. Use the organizer below to construct your evidence-based argument." This is followed by a rubric that includes the targeted dimensions and partially met, approaching, met, and exceeds description followed by an accurate claim. "Target Dimension: The fact that atoms are conserved, together with

knowledge of the chemical properties of elements involved, are used to describe and predict chemical reactions." "Accurate claim: The anode for this battery is lithium metal, and the cathode in this battery is manganese dioxide. Complete balanced reaction: $Mn^{IV}O_2 + Li \rightarrow LiMn^{III}O_2$" (Teacher Edition, page 65).
  - This same level of guidance is provided for the Investigation 2 Performance Task on pages 94–95, Investigation 3 Performance Task on pages 120–121, and the Final Performance Task on pages 125–127.
- Formative assessment checkpoints and remediation are "Indicated in the Teacher's Manual with a check mark…This checkmark is used at key points in the lesson to help you gauge student understanding and provide remediation as needed." Examples include:
  - Investigation 3: Explain question 5. "Scientists use empirical evidence to identify patterns in chemical properties. What patterns did you identify in the empirical evidence you gathered?" "Focal Dimension: CCC: **Patterns** Students should be able to identify patterns in their data." Note that this scoring guidance does not describe a high school-level CCC performance; instead, it describes an elementary level use of the SEP **Analyzing and Interpreting Data**.
- Students are provided with opportunities to reflect on and track their learning progress after completing each of the three investigations. For example:
  - Investigation 1, Teaching Guide: Students are asked to, "Add arrows, symbols, and/or words to the model to show how energy and matter flow into, out of, and within the battery–load system" (Teacher Edition, page 45). They are then provided with a sample answer and asked, "How does this model of a battery–load system compare with your initial ideas of how energy and matter flow through a battery–load system?" (Teacher Edition, page 45).
  - Students are provided with reflection tables following each investigation. Example: Investigation 1: "Complete the following table to track your progress on questions." The table includes three columns: "Questions I had about how batteries work", "What I figured out about how batteries work", and "New questions I have about batteries" (Teacher Edition, page 68 / Student Edition, page S-18).
  - Sustained silent writing opportunities are used to provide time for students to complete reflection questions provided at the end of each investigation. Example: Investigation 2: "Use sustained silent writing to have individual students complete the Reflection questions in the Student Guide." Reflection questions following Investigation 2 include: "How does the scientific principle of atom conservation, together with knowledge of the chemical properties of elements, allow you to predict whether a single-replacement reaction will take place, and if it will, what the products will be?", and "How did identifying patterns in empirical evidence help you create your metal activity series model?" (Teacher Edition, page 97).
  - Final Lesson Performance: Students "reflect on what they have learned through the modeling process, and how their understanding of the role of chemical reactions in batteries has changed as a result of the lesson." They are asked to reflect on, "How has

your thinking about models changed over the course of this lesson?” (Teacher Edition, pages 125–126 / Student Edition, page S-49).

- Sample answers are provided for student handouts for S-4, S-5, S-7, S-8, S-9, S-10, S-11, S-12, S-13, S-15, S-16, S-18, S-20, S-26, S-27, S-28, S-29, S-30, S-31, S-32, S-34, S-36, S-37, S-38, S-40, S-41, S-42, S-43, S-44, S-46, and S-47. However, only a single level of response is provided for the sample answers.

Suggestions for Improvement

- Consider supplying scoring guidance for additional tasks provided in the Student Edition.
- Consider explicitly connecting the assessments to grade-level elements of the dimensions that they assess.
- Consider providing a range of possible student responses in addition to the provided rubric for the Performance Tasks.

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 presented material is supplied at grade level and is unbiased. There are some opportunities for students to give answers in multiple modalities, although teacher support materials are typically not explicit when student responses may be given in multiple modalities. It is also unclear if all digital resources are available in languages other than English and/or if closed captioning is available.

Related evidence includes:

- Appropriate text and vocabulary are present in the supplied readings for scientific and non-scientific terms. For example:
    - The digital resources included with the materials provide video clips to support the lesson, including videos explaining how to use and read a multimeter, an episode of Crash Course Chemistry, and clips from PBS Learning Media. Supplied clips include grade-appropriate vocabulary.

    - The digital resources include several components labeled as multimedia lessons. The multimedia lessons provide students with interactive modules and short readings with missing text that students must complete. Teacher's Edition, page 33, explains that "Interactive digital lessons are provided for review and can be assigned to individual students for homework, or they can be used in class on a whiteboard." It is unclear if all students will have access or the opportunity to engage with these learning opportunities, and therefore have equal opportunities to excel on the assessments.
    - Launching the Phenomenon: "In addition to a video of a lithium-ion battery-powered race car, an overview of key research and a graph of predicted electric vehicle sales are suggested as 'More Opportunities for Launching Phenomenon.' 'The U.S. Department of Energy's *National Blueprint for Lithium Batteries 2021–2030* gives an overview of the key issues and strategies for accelerating the research and development of lithium-based advanced battery technologies. Consider reviewing this rich resource for discussion ideas when launching the phenomenon. The graph of predicted electric vehicle sales in the millions is particularly interesting'" (Teacher Edition, page 32).
    - Hunting the Elements. This brief video can supplement and extend the class discussion of chemical reactions and the periodic table (Teacher Edition, page 33).
- There are missed opportunities to support teachers in their awareness of the limitations of the scenario for reaching all students. For example:
    - Investigation 1: When developing a consensus model of an aluminum-air battery system: "Once all models have been reviewed, select one model to revise into a class consensus model" (Teacher Edition, page 58). Note that it is possible that selecting a single model and building from it may result in students who did not create the chosen model feeling like they did not meet the expectations and were not part of developing the consensus model, and therefore might disengage from related assessments.
    - Launching the Phenomenon: The teacher is told to, "Lead a discussion about the devices on the class chart and what they might have in common. Work with the class to move the sticky notes around and organize the devices into categories based on how the devices are used. Suggested categories include consumer electronics (laptops, phones, tablets), renewable energy storage (solar and wind power on the grid or homes), transportation (automobiles, bikes, scooters, wheelchairs), and medical devices (implantable ones, thermometers, pumps)" (Teacher Edition, page 32). However, these lists may contain some culturally- or geographically-specific information.
    - Instructional Support: The lesson material states that "students are asked to think about and list the many different devices they know about that use lithium batteries for power" (Teacher Edition, page 17). Students from a variety of backgrounds may have different levels of access to technology that uses lithium batteries, but support is built throughout the lesson such that the assessments should be accessible to all students.
- Multiple modalities in tasks and expected answers are specifically called out in the lesson materials for several lessons. For example:
    - Instructional Support: The lesson materials state that "to address the needs of all learners, students are encouraged to make their thinking visible in multiple ways. For

example, during classroom discussions that activate prior knowledge, build concepts, and elicit ideas, students are given ample space and appropriate prompts in the Student Guide to record ideas and important points through their choice of words, graphic organizers, diagrams, and illustrations. Students are then encouraged to share and compare their notes with others to find commonalities and record additional information they might have missed but want to remember. Throughout the lesson, students interact with physical components, tables, firsthand observations, videos, and annotated background research articles to help them gather a variety of evidence to support arguments and explanations" (Teacher Edition, page 23). However, in student materials, it is not always clear that students have the option to express their knowledge in a wide range of modalities. While it is explicitly called out in several locations, the language used in the directions and sample student replies are almost exclusively in written form.

  - Investigation 1: "How do matter and energy flow in, out, and through a battery–device system? You may want to use words, sketches, a flowchart, a diagram, or a combination to communicate your ideas" (Teacher Edition, page 42 / Student Edition, page S-7).

Suggestions for Improvement

- Consider explicitly linking and providing details as to how to access digital resources such as Crash Course Chemistry in languages other than English and with closed captioning.
- Consider providing clearer opportunities for students to give answers using multiple modalities in addition to the language provided in the Instructional Support pages.
- Consider including at least one significant task that provides students with a choice of responses across multiple modalities.
- Consider providing additional background information or scaffolds in the student materials to support students with content that may be unfamiliar to them.

OVERALL CATEGORY III SCORE: 3 (0, 1, 2, 3)	
Lesson Scoring Guide – Category III	
Criteria A-D	
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 three criteria, including A
1	Adequate evidence for at least two criteria in the category
0	Adequate evidence for no more than one criterion in the category

SCORING GUIDES

SCORING GUIDES FOR EACH CATEGORY

LESSON SCORING GUIDE – CATEGORY I (CRITERIA A–C)

LESSON SCORING GUIDE – CATEGORY II (CRITERIA A–E)

LESSON SCORING GUIDE – CATEGORY III (CRITERIA A–D)

OVERALL SCORING GUIDE

Scoring Guides for Each Category

Lesson Scoring Guide – Category I (Criteria A–C)	
3	Extensive evidence to meet at least two criteria and at least adequate evidence for the third.
2	Adequate evidence to meet all three criteria in the category.
1	Adequate evidence to meet at least one criterion in the category but insufficient evidence for at least one other criterion.
0	Inadequate (or no) evidence to meet any criteria in the category.

Lesson Scoring Guide – Category II (Criteria A–E)	
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 four criteria, including A
1	Adequate evidence for at least two criteria in the category
0	Adequate evidence for no more than one criterion in the category

Lesson Scoring Guide – Category III (Criteria A–D)	
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 three criteria, including A
1	Adequate evidence for at least two criteria in the category
0	Adequate evidence for no more than one criterion in the category

Lithium-Based Batteries

EQuIP RUBRIC FOR SCIENCE EVALUATION

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)