

**Curriculum Materials for *Next Generation Science Standards*:
What the Science Education Research Community Can Do**

**Jo Ellen Roseman, American Association for the Advancement of Science
David Fortus, Weizmann Institute of Science, Israel
Joseph Krajcik, Michigan State University
Brian J. Reiser (discussant), Northwestern University**

**Symposium Paper
Presented at the
2015 NARST Annual International Conference
Chicago, IL
April 11 – 14, 2015**

ABSTRACT

Realizing the vision of *Next Generation Science Standards* (NGSS) (NGSS Lead States, 2013) requires curriculum materials that truly integrate disciplinary core ideas, science and engineering practices, and crosscutting concepts to support three-dimensional learning, in which students use practices to develop and use the science ideas to make sense of phenomena and design solutions to problems. Given the many challenges of developing such materials, it will be years before high-quality materials exist that can help teachers make the NGSS vision a reality in their classrooms. In the meantime, what can the science education research community do to help educators understand what it means for curriculum materials to align to NGSS and respond to its call for three-dimensional learning and teaching. In this paper three curriculum development groups report on preliminary findings from two independent analyses of their materials using selected criteria for alignment to NGSS as articulated in the Educators Evaluating the Quality of Instructional Products (EQuIP) Rubric (Achieve, 2014). Each case study (a) presents evidence to justify claims of the material's alignment to NGSS, (b) describes weaknesses in the material identified in the analyses, and (c) considers how the findings could inform revisions to the material. The paper concludes with some lessons learned from using the EQuIP Rubric so far and suggestions for improving the rubric's usability and value to the science education research community.

INTRODUCTION

The Challenge of NGSS for Curriculum Design

The most significant aspect of the reform recommendations laid out in the *Next Generation Science Standards* (NGSS) (NGSS Lead States, 2013) is the required integration of all three dimensions of *A Framework for K-12 Science Education* (National Research Council [NRC], 2012)—disciplinary core ideas, science practices, and crosscutting concepts—in a set of performance expectations (Osborne, 2014; Reiser, 2013). Although the NGSS performance expectations identify specific combinations of core ideas, practices, and crosscutting concepts to be assessed, NGSS makes clear that these combinations are not intended to constrain curriculum or instruction:

Pairing practices with DCIs is necessary to define a discrete set of blended standards, but should not be viewed as the only combinations that appear in instructional materials. In fact, quality instructional materials and instruction must allow students to learn and apply the science practices, separately and in combination, in multiple disciplinary contexts. (p. xviii)

The *Framework* states that the practices are to be used “iteratively and in combination” to make sense of phenomena (pp. 49-53), even though most performance expectations couple a single practice with a single disciplinary core idea. This leaves decisions to curriculum materials developers about which core ideas, practices, and crosscutting concepts to integrate to prepare students to meet the performance expectations. In making such decisions, materials developers need to ensure that their materials are coherent and provide adequate support for student learning (e.g., Roseman, Stern, & Koppal, 2010; Kesidou & Roseman, 2002; Stern & Roseman, 2004) and include assessments to monitor student progress to inform decisions about instruction and materials revision (Stern & Ahlgren, 2002).

NGSS also challenges developers to present ideas coherently throughout the curriculum; that is, ideas must build upon each other within and across lessons and units. Coherence requires that materials motivate students to engage in the learning activities that are provided and take account of essential prerequisite ideas, students’ misconceptions, and where students are in their own sense making (Roseman, Linn, & Koppal, 2008). Considering where students are in the own sensemaking requires more than making sure students have developed prerequisite ideas on which more complex ideas can be built. NGSS targets three-dimensional learning, in which the practices develop and use science ideas to make sense of phenomena or solve problems. This requires that students have a sensemaking or explanatory question or an engineering challenge in mind as they engage in practices, rather than simply “performing” a practice as if it were a rote skill (Reiser, 2013).

As a starting point for thinking about coherence, both the *Framework* and NGSS provide learning progressions that describe the disciplinary core ideas that occur at each grade band. In addition, the *Atlas of Science Literacy* (American Association for the Advancement of Science [AAAS], 2001; 2007) maps the development of nearly 100 “big ideas” in science, mathematics, and technology from kindergarten through high school and summarizes the available research on students’ conceptual difficulties for each topic. While the NGSS learning progressions and *Atlas* maps can be useful tools, for example to determine which parts of disciplinary core ideas are built in each grade band, curriculum developers in creating individual units or courses will need to refine their content storylines, select phenomena-based experiences and activities for students, and provide the instructional scaffolding that are necessary for ensuring coherence in their materials.

Alignment with the NGSS requires that curriculum materials do much more than simply “cover” a set of specified ideas and skills. Some developers and publishers are attempting to modify their materials while others are already making claims of alignment. To date, however, there has been little guidance available for understanding what it means to align to NGSS or to support students in achieving the NGSS performance expectations. The EQuIP Rubric (Achieve, 2014) has the potential to fill that gap by giving the science education research community a new tool for designing and evaluating materials for their fit to NGSS.

The EQuIP Rubric

The [EQuIP Rubric](#) identifies a set of criteria that specify the characteristics of materials that are well aligned to NGSS and support achievement of NGSS goals through high-quality instruction and assessment. The rubric has three categories of criteria that can be used to examine (1) the overall alignment of a material to the NGSS core ideas, practices, and crosscutting concepts; (2) the quality of the instructional support provided in a material, and (3) the extent to which the material provides support for monitoring students’ progress.

Criteria used from the first category of the rubric focus not only on whether a material includes disciplinary core ideas, practices, and crosscutting concepts but also on whether the three dimensions *work together* in the material to help students make sense of phenomena or to design solutions for problems. This category also includes criteria for judging whether the lessons unfold coherently over time, in which “each lesson links to previous lessons and provides a need to engage in the current lesson.” For materials that are still in development, applying these criteria at an early stage in the process can help ensure a strong alignment to NGSS. For existing materials, judging whether they meet the criteria in this category is an essential first step. If lessons and units do not contribute to students’ three-dimensional learning (or cannot be revised to do so), there is no need to proceed with an analysis of an existing material. Moreover, the three-dimensional learning needs to be in the service of helping students make sense of phenomena or design solutions. Criteria from the second category focus on the instructional supports provided in a material. These include providing students with a purpose, such as explaining multiple phenomena; identifying and building on students’ prior knowledge; and providing opportunities for students to explain their ideas and respond to feedback. Criteria from the third category focus on the supports provided in a material for monitoring students’ progress, including pre-instruction assessment and formative, summative, and self-assessment measures that monitor students’ three-dimensional learning. It should be noted that the EQuIP Rubric’s criteria have not yet been fully clarified or calibrated to indicate the level at which materials do or do not meet each individual criterion. According to Achieve, the goal is to further develop the rubric to describe these levels and to provide examples from materials to illustrate each (2014).

About the Case Studies

In this paper, which is based on a symposium presented at the NARST 2015 Annual Conference, principal investigators from three experienced curriculum research and development teams present preliminary findings from case studies of analyses of their own materials using criteria for alignment and coherence from the first category of the EQuIP Rubric. These case studies focus on different materials that are at different stages in the development process. Case Study 1 examines a published material that is currently being used in the classroom. Case Study 2 looks at a material that is being revised after three rounds of classroom testing. Case Study 3 focuses on a recently funded material that is still in its early development phase. These case studies are among the first formal applications of the EQuIP Rubric to science curriculum materials and are not yet complete. Nevertheless, these

early findings from the case studies should provide important insights into the utility and value of the new rubric as well as information on the alignment of the three materials to NGSS.

Each case study presents evidence to justify claims of alignment to NGSS as specified by the EQuIP Rubric criteria and describes how the analysis findings could inform the design of or revisions to the case study material. The paper concludes with some lessons learned from using the EQuIP Rubric so far and suggestions for further clarifying or enhancing the rubric to better meet the needs of researchers and curriculum developers as well as district curriculum specialists and classroom teachers.

For each case study, the developer of the material and another principal investigator from the symposium panel conducted independent analyses of the material. Results from the two analyses were reconciled and those reconciled results are reported in this paper. Prior to the analyses, the symposium panelists interpreted and clarified the meaning of each EQuIP criterion used in the case studies and agreed on what would and would not count as evidence.

THREE CURRICULUM CASE STUDIES

CASE STUDY 1 - *Investigating & Questioning our World Through Science & Technology (IQWST): A Published Multi-Year Curriculum Material*

The focus of this case study is a comprehensive three-year middle school science curriculum that targets core ideas in physics, chemistry, life science, and earth science; science practices such as modeling and explanation; and crosscutting concepts such as energy, systems, and the particle nature of matter. The *Investigating & Questioning our World through Science & Technology (IQWST)* curriculum was developed prior to the release of the NGSS (Krajcik, Reiser, Sutherland, & Fortus, 2013).

About the IQWST Curriculum

The IQWST curriculum is driven by performance expectations and provides multiple types of instructional supports and numerous assessments, at different levels of resolution, throughout and at the end of each unit. Table 1 shows the sequence of the units in the IQWST curriculum.

Table 1. IQWST Scope and Sequence for the three-year middle school curriculum

| | | | | |
|-----------------------|--|--|--|--|
| 6 th grade | Physical Science: Light Waves, their Role in Sight, and their Interaction with Matter | Chemistry: Particle Nature Of Matter, Phase Changes | Life Science: Organism and Ecosystems | Earth science: Water and Rock Cycles |
| 7 th grade | Chemistry: Chemical Reactions, Conservation of Matter | Physical science: Transformation and Conservation of Energy | Earth science: Atmospheric Processes In Weather and Climate | Life Science: Body Systems and Cellular Processes |
| 8 th grade | Earth Science: Geologic Processes, Plate Tectonics | Life science: Heredity and Natural Selection | Physical science: Force and Motion | Chemistry: Chemical Reactions in Living Things |

Inter-unit coherence in the IQWST curriculum. The IQWST curriculum was explicitly designed to address two types of coherence. First, each unit is internally coherent by being organized around a storyline in which students develop the science ideas to make sense of phenomena and/or to solve problems (Edelson, 2001; Krajcik, McNeill, & Reiser, 2008). Second, the units are designed to build

and extend science ideas and practices across units. In this way, units build on one another and students build clear connections across ideas and units. Scientific practices were interwoven throughout the entire curriculum. Not all practices receive identical emphasis in different units. The integration of each practice in a given unit builds off the experience students have gained in engaging in this practice in earlier units. Thus, the performance that can be expected of students at the end of the three-year sequence is much better than could have been obtained had each practice been learned in a collection of independent units.

Inter-unit coherence should be especially beneficial for cross-cutting concepts, such as energy, which by definition require instruction that extends across disciplines. Since all new knowledge is constructed on the foundations provided by prior knowledge, this curriculum is expected to allow for ideas from different units to build off one another, supporting students in constructing an integrated understanding of cross-cutting key ideas in ways not possible with a non-coherent curriculum composed of independent, stand-alone units. Thus, the knowledge of the crosscutting concept constructed by students in an early unit is expected to positively predict the learning related to this concept in later units (Fortus & Krajcik, 2012).

Energy is a critical concept across all science disciplines and as such serves as both a disciplinary core idea in multiple disciplines and a crosscutting concept (NGSS Lead States, 2013; NRC, 2012). It is essential for explaining a wide range of phenomena, solving problems that occur in everyday life, and learning other science ideas. For these reasons, energy plays a central role in the IQWST curriculum and is interwoven throughout the units at each grade level. The concept of energy is first introduced implicitly in the very first unit in the sequence, the Light Unit. Students learn two ideas that are relevant in later units when discussing energy: (a) light, when absorbed by an object or substance, can make things happen (e.g., such as making the substance warmer), and (b) the total amount of light reaching an object is equal to the sum of the amounts of light reflected, transmitted, and absorbed by the object. The first idea is a precursor to the notions of energy transfer and transformation – energy can be transferred to an object by radiation, and this energy can be transformed into other types, such as thermal energy. The second idea is a precursor to the notion of energy conservation – the total amount of energy entering a system (the object) must equal the amount of energy remaining in the system (the amount of light energy absorbed) and the amount of energy leaving the system (the amount of light energy being transmitted and reflected). Note, however, that although foundational concepts are taught in the unit, the term *energy* is not used at this point in the curriculum sequence.

Later units in the IQWST curriculum build off these ideas and the experiences students have when learning about them: the 6th grade life science unit on organisms and ecosystems, the 7th grade physics unit on energy, the 7th grade life science unit on cells and body systems, the 7th grade earth science unit on climate and weather, the 8th grade chemistry unit on photosynthesis and respiration, and the 8th grade physics unit on forces and motion. Figure 1 shows the results of an analysis of the learning outcomes for these units (Fortus, Sutherland et al., 2015). The energy-related learning in the Light Unit (P6) was positively related to the learning of energy in the later units, with this relation being mediated by the learning constructed in the Energy Unit (P7).

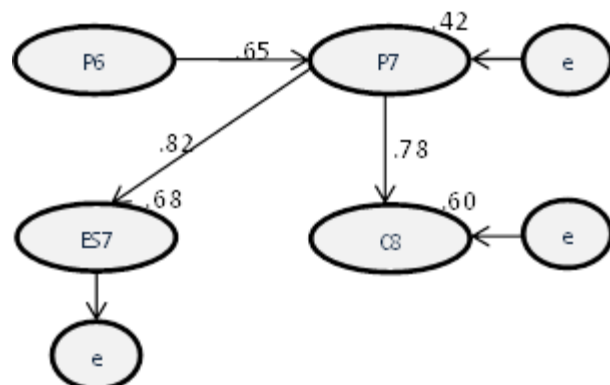


Figure 1. Learning Outcomes Across IQWST Units

The post-test results on the energy-related items in the Light Unit (P6) predicted 42% of the variance in the post-test results on the Energy Unit (P7). Similarly the post-test results on the Energy Unit (P7) predicted 68% and 60% of the variance on the energy-related items in the post-tests for the Weather and Climate Unit (ES7) and the Photosynthesis and Respiration Unit (C8), respectively. These are very high results, indicating a strong contribution of the inter-unit coherence on energy to student learning.

EQuIP Analysis of IQWST Light Unit: Reconciled Results

For inter-unit coherence to be attainable, each unit in the curriculum must also be intra-unit coherent. To evaluate the extent to which the IQWST Light Unit is coherent, the lead developer of the unit and another member of the symposium panel conducted independent analyses of a lesson from the Light Unit (P6) using criteria from the EQuIP rubric.

Figure 2 illustrates the structure of the Light Unit. The analysis centered on Lesson 6, which deals with the reflection and scattering of light, but also looked at how the lesson related to the lessons surrounding it. Lesson 6 is a step in the unit toward addressing NGSS Performance Expectation **MS-PS4-2: Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials**. The lesson incorporates four NGSS science practices: Practice 2: Developing and Using Models – Develop and/or use a model to predict and/or describe phenomena; Practice 3: Planning and Carrying out Investigations – Conduct an investigation to produce data to serve as the basis for evidence that meet the goals of the investigation; Practice 4: Analyzing and Interpreting Data – Analyze data to provide evidence for phenomena; and Practice 6: Constructing Explanations – Apply scientific ideas, principles, and evidence to construct, revise, and use an explanation for real-world phenomena, examples, or events. As shown in Table 2, a first step in the analysis was to identify all the phenomena used in the lesson together with the science practices that are brought to bear when studying these phenomena.

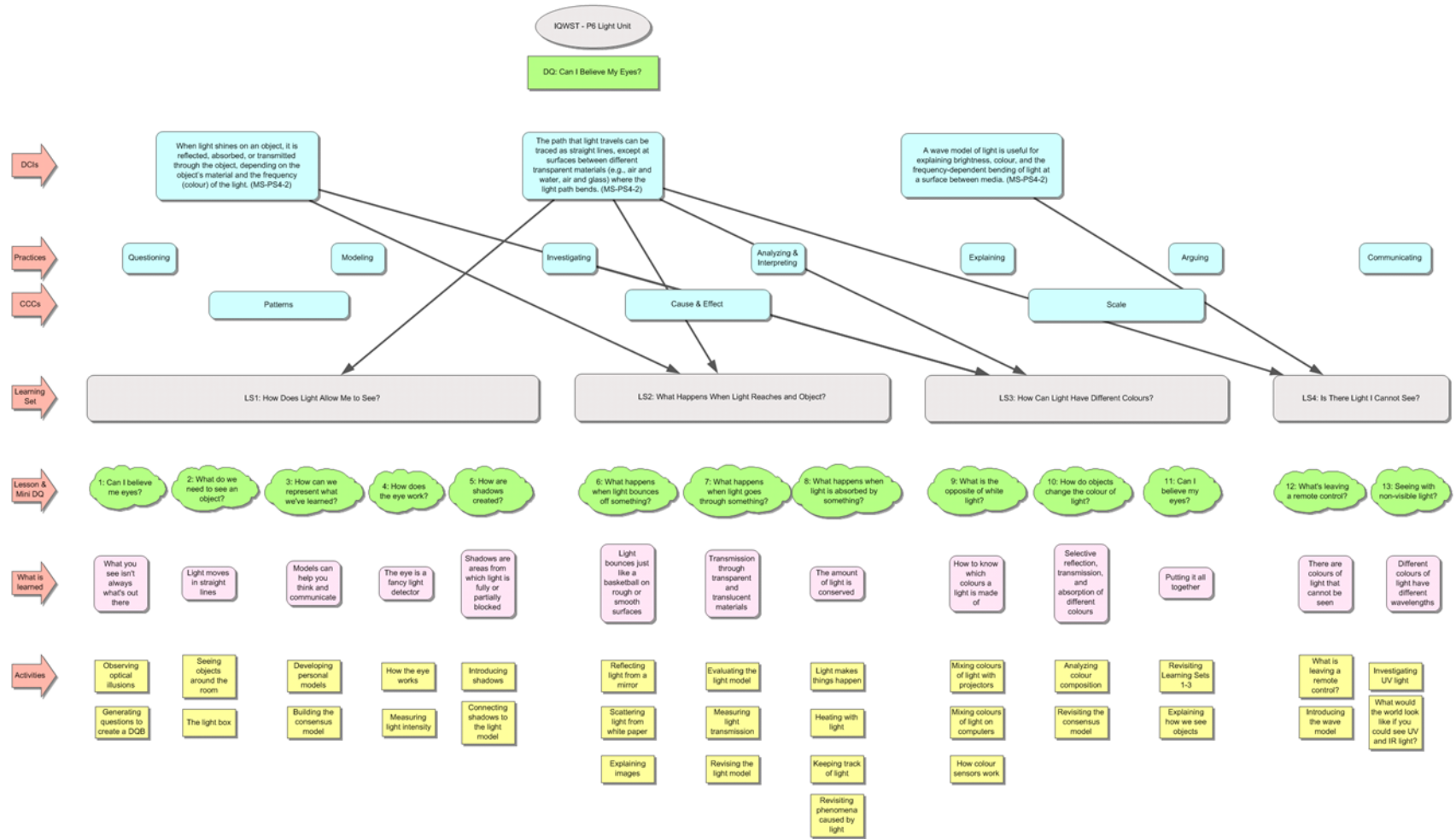


Figure 2. Structure of the IQWST Light Unit

Table 2. Key Phenomena in Lesson 6 of IQWST Light Unit

| Activity, page numbers | Phenomena | Data Analysis | Modeling |
|---|---|--|--|
| Activity 6.1, pp. 51-54 in student material, pp. 93-96 in Teacher guide | When light is shined on a mirror, it is reflected along the lines of a symmetrical V pattern | Analyze data to provide evidence that light rays reflected from a mirror create a symmetrical V pattern. | Construct a model of what happens to light rays when they reach a mirror. |
| Activity 6.2, pp. 55-58 in student material, pp. 97-98 in Teacher guide | Scattering light from a white sheet of paper | Analyze data to identify that light rays are scattered in all direction from a white sheet of paper. | Construct a model of what happens to light rays when they reach a rough object. |
| Homework 6.2, pp. 59-60 in student material, pp. 98-99 in Teacher guide | Where does one need to stand to see light from a flashlight being reflected by a mirror or being scattered by a sheet of paper. | Analyze the paths of lights rays reaching a mirror and a sheet of paper, to determine how they will be reflected or scattered. | Use a model of light reflecting from a mirror and knowledge of the conditions for sight (from Lessons 2-5) to conclude where observers can be located. |
| Activity 6.3, pp. 61-61 in student material, pp. 99-102 in Teacher guide | Seeing reflected images in shiny objects but not in rough ones. | Analyze the paths of light rays to determine whether they appear to be coming from a single light source. | Construct a model of light reflecting from a mirror to determine whether the rays could have come from a single light source. |
| Homework 6.3, p. 63 in student material, p. 102 in Teacher guide | Seeing a car's reflection in a wet road but not in a dry one. | Analyze 2 photos of a car on a road to reach conclusions about the surface of the road. | ----- |
| Reading 6.3, pp. 64-66 in student material, p. 103 & p. 102 in chapter 7 of Teacher guide | Making objects reflective by polishing them | Analyze a microscopic image of wood to determine why light scatters from its surface rather than being reflected. | Use a model of light reflecting from a mirror to determine why it looks as if the light comes from behind the mirror. |

Consistent with the methods described earlier in this paper, the lead developer on the IQWST team and a symposium panelist carried out independent analyses of Lesson 6 in the IQWST unit using EQuIP criteria. Results from the two analyses were reconciled, and those reconciled results are reported below. EQuIP criterion 1.A was applied to the lesson to judge alignment to the three dimensions of NGSS, and EQuIP criterion I.B was applied to a sequence of three IQWST lessons to judge coherence across a set of lessons.

Analysis Findings for EQuIP Criterion I.A: Grade-appropriate elements of the science and engineering practice(s), disciplinary core idea(s), and crosscutting concept(s) work together to support students in three-dimensional learning to make sense of phenomena and/or to design solutions to problems.

The two analysts gathered evidence from Lesson 6 of IQWST to determine the extent to which the lesson supported students in constructing three-dimensional learning about the phenomena listed in Table 2 and in achieving the relevant NGSS performance expectation. The two analysts compared their findings and resolved any differences; their findings are presented in Tables 3a through 3d.

Table 3a. Evidence for EQulP Criterion 1.A in IQWST Lesson 6. The column on the left of each table lists the indicators of meeting EQulP Criterion 1.A and highlights the indicator for which evidence is provided in the column on the right.

| EQulP Criterion 1.A | Specific evidence from materials and reviewers' reasoning |
|--|--|
| <p>A. Grade-appropriate elements of the science and engineering practice(s), disciplinary core idea(s), and crosscutting concept(s), work together to support students in three-dimensional learning to make sense of phenomena and/or to design solutions to problems.</p> <p>i. Provides opportunities to develop and use specific elements of the practice(s) to make sense of phenomena and/or to design solutions to problems.</p> <p>ii. Provides opportunities to develop and use specific elements of the disciplinary core idea(s) to make sense of phenomena and/or to design solutions to problems.</p> <p>iii. Provides opportunities to develop and use specific elements of the crosscutting concept(s) to make sense of phenomena and/or to design solutions to problems.</p> <p>iv. The three dimensions work together to support students to make sense of phenomena and/or to design solutions to problems.</p> | <p>The following practices are addressed in the lesson:</p> <p>a. Developing and using models:</p> <ul style="list-style-type: none"> ▪ Constructing a model of the manner in which light rays are reflected from a mirror, pp. 54 & 59 in Student guide ▪ Constructing a model of the manner in which light is scattered by a rough surface, p. 60 in Student guide ▪ Using a model to explain why we can see an image of ourselves in a mirror but not in a sheet of paper, p. 61 in Student Guide ▪ Using a model to explain why polishing a surface enhances its specular reflection while diminishes its diffuse reflection (scattering), p. 65 in Student guide <p>b. Planning and carrying out investigations:</p> <ul style="list-style-type: none"> ▪ Investigating what happens when light strikes a mirror and bounces off of it, pp. 51-53 in Student guide ▪ Investigating what happens to light is scattered from a white sheet of paper, pp. 55-56, & 58 in Student guide <p>c. Analyzing and interpreting data:</p> <ul style="list-style-type: none"> ▪ Analyzing data of light reflected from a mirror, pp. 53-54 in Student guide ▪ Analyzing data of light being scattered from a white sheet of paper, pp. 56-58 in Student guide <p>d. Constructing explanations:</p> <ul style="list-style-type: none"> ▪ Constructing an explanation why light from a flashlight reflected by a mirror can be seen in certain locations but not in others, p. 59 in Student guide ▪ Constructing an explanation why light from a flashlight scattered by a wall can be seen in any location, p. 60 in Student guide ▪ Constructing an explanation why we can see an image of ourselves in a mirror but not in a sheet of paper, pp. 62 & 64 in Student guide ▪ Constructing an explanation why it is possible to see an image of the car on a wet road but not on a dry road, p. 63 in Student guide ▪ Constructing an explanation why even smooth objects still scatter a bit of light, p. 67 in Student guide |

Table 3b.

| EQuIP Criterion 1.A | Specific evidence from materials and reviewers' reasoning |
|---|---|
| <p>A. Grade-appropriate elements of the science and engineering practice(s), disciplinary core idea(s), and crosscutting concept(s), work together to support students in three-dimensional learning to make sense of phenomena and/or to design solutions to problems.</p> <ul style="list-style-type: none"> i. Provides opportunities to develop and use specific elements of the practice(s) to make sense of phenomena and/or to design solutions to problems. ii. Provides opportunities to develop and use specific elements of the disciplinary core idea(s) to make sense of phenomena and/or to design solutions to problems. iii. Provides opportunities to develop and use specific elements of the crosscutting concept(s) to make sense of phenomena and/or to design solutions to problems. iv. The three dimensions work together to support students to make sense of phenomena and/or to design solutions to problems. | <p>The following disciplinary core ideas are addressed in Lesson 6 or earlier lessons:</p> <ul style="list-style-type: none"> a. When light shines on an object, it is reflected, absorbed, or transmitted through the object, depending on the object's material and the frequency (color) of the light. <ul style="list-style-type: none"> ▪ The phenomenon of light reflection is addressed in every page of this lesson, pp. 51-67 in the Student guide. b. The path that light travels can be traced as straight lines, except at surfaces between different transparent materials (e.g., air and water, air and glass) where the light path bends. <ul style="list-style-type: none"> ▪ The idea that light can be traced as straight lines is dealt with in Lesson 2-5 of this unit. Lesson 6 makes use of this idea and builds upon it, assuming the students already understand it. ▪ The idea that light travels in straight lines is used when constructing and using models on pp. 54-55, 59-61, & 65 of the Student guide. c. An object can be seen when light reflected from its surface enters the eyes. <ul style="list-style-type: none"> ▪ The idea that light needs to enter the viewer's eyes in order for the object to be seen is the focus of Lessons 2-4 in this unit. Lesson 6 makes use of this idea and builds upon it, assuming the students already understand it. ▪ The idea that for an object to be seen, light reflected from it has to enter the eyes is implicit throughout the chapter, but is addressed explicitly in the models on pp. 59-60 of the Student guide. |

Table 3c.

| EQulP Criterion 1.A | Specific evidence from materials and reviewers' reasoning |
|--|--|
| <p>A. Grade-appropriate elements of the science and engineering practice(s), disciplinary core idea(s), and crosscutting concept(s), work together to support students in three-dimensional learning to make sense of phenomena and/or to design solutions to problems.</p> <p>i. Provides opportunities to develop and use specific elements of the practice(s) to make sense of phenomena and/or to design solutions to problems.</p> <p>ii. Provides opportunities to develop and use specific elements of the disciplinary core idea(s) to make sense of phenomena and/or to design solutions to problems.</p> <p>iii. Provides opportunities to develop and use specific elements of the crosscutting concept(s) to make sense of phenomena and/or to design solutions to problems.</p> <p>iv. The three dimensions work together to support students to make sense of phenomena and/or to design solutions to problems.</p> | <p>The following crosscutting concepts are addressed in the lesson:</p> <p>a. <i>Patterns</i>: Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them.</p> <ul style="list-style-type: none"> ▪ A pattern is identified in data collected in an investigation of light reflection by a mirror – the incident ray and its reflection always create a symmetrical V shape. See pp. 53-54 in the Student guide ▪ A pattern is identified in data collected in an investigation of light scattering by a white sheet of paper – regardless of the direction of an incident ray, the reflected rays go in all directions with an intensity that is much lower than the intensity of the incident ray. See pp. 56-58 in the Student guide ▪ One can often use the direction from which light rays come to infer the location of the light source – see pp. 61 & 65 in the Student guide <p>b. <i>Cause and effect: Mechanism and explanation</i>. Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.</p> <ul style="list-style-type: none"> ▪ Recurring throughout the unit and in Lesson 6 is the notion that for something to be seen, light reflected by the object has to enter a viewer's eyes. The cause here is light with certain characteristics due to its interaction with an object entering a viewer's eyes. The effect is the conscious perception of seeing an object or seeing light. This connection is explicit in the discussion of two models of reflected light on pp. 59-60 of the Student guide <p>c. <i>Structure and function</i>. The way in which an object or living thing is shaped and its substructure determine many of its properties and functions.</p> <ul style="list-style-type: none"> ▪ The smoothness of an object determines the degree to which reflection from the object will be specular or diffuse – see pp. 57, 63-67 in the Student guide |

Table 3d.

| EQulP Criterion 1.A | Specific evidence from materials and reviewers' reasoning |
|---|--|
| <p>A. Grade-appropriate elements of the science and engineering practice(s), disciplinary core idea(s), and crosscutting concept(s), work together to support students in three-dimensional learning to make sense of phenomena and/or to design solutions to problems.</p> <ul style="list-style-type: none"> i. Provides opportunities to develop and use specific elements of the practice(s) to make sense of phenomena and/or to design solutions to problems. ii. Provides opportunities to develop and use specific elements of the disciplinary core idea(s) to make sense of phenomena and/or to design solutions to problems. iii. Provides opportunities to develop and use specific elements of the crosscutting concept(s) to make sense of phenomena and/or to design solutions to problems. iv. The three dimensions work together to support students to make sense of phenomena and/or to design solutions to problems. | <p>The three dimensions work together in the following phenomena:</p> <ul style="list-style-type: none"> a. Activity 6.1, reflecting light from a mirror, addresses DCI PS4-2 while engaging students in four practices – modeling, carrying out investigations, analyzing data and constructing explanations – and incorporates the crosscutting concept of identifying patterns in data. b. Activity 6.2, scattering light from a white sheet of paper, addresses DCI PS4-2 while engaging students in four practices – modeling, carrying out investigations, analyzing data and constructing explanations – and incorporates the crosscutting concept of identifying patterns in data. c. Homework 6.2, where does one need to be positioned to see reflected or scattered light, addresses DCI PS4-2 while engaging students in two practices – modeling and constructing explanations – and incorporates the crosscutting concept of cause and effect. d. Activity 6.3, determining where the light appears to be coming from, addresses DCI PS4-2 while engaging students in two practices – modeling and constructing explanations – and incorporates the crosscutting concept of structure and function. e. Homework 6.3, seeing a car's reflection in a wet road but not in a dry one, addresses DCI PS4-2 while engaging students in the practice of constructing explanations and incorporates the crosscutting concept of structure and function. f. Reading 6.3, making objects reflective by polishing them, addresses DCI PS4-2 while engaging students in two practices – modeling and constructing explanations – and incorporates the crosscutting concept of structure and function. |

Analysis Findings for EQuIP Criterion 1.B: Lessons fit together coherently targeting a set of performance expectations.

The analysts applied EQuIP criterion I.B to a sequence of IQWST lessons (Lessons 6 through 8) to see whether they fit together coherently and whether they also targeted Performance Expectation **MS-PS4-2: *Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.*** Evidence to support their claim of coherence is shown in Table 4.

Table 4. Evidence for EQuIP Criterion I.B in IQWST Lessons 6 through 8

| EQuIP Criterion 1.B | Specific evidence from materials and reviewers' reasoning |
|--|--|
| <p>B. Lessons fit together coherently targeting a set of performance expectations.</p> <ul style="list-style-type: none"> i. Each lesson links to previous lessons and provides a need to engage in the current lesson. ii. The lessons help students develop proficiency on a targeted set of performance expectations. | <p>Each lesson in the unit begins and ends with an explicit link to the previous and following lesson. Lessons 6-8 target the same performance expectation: MS-PS4-2: Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials. Lesson 5 ends with the sentence "What does the model currently explain about how light interacts with transparent materials? Explain that this is an important phenomenon that the model does not yet explain. In the next set of investigations, students will collect data on how light interacts with different kinds of materials, including transparent materials" (p. 83 in T guide). This question raised the need to consider the characteristics of the materials with which light interacts, which is the focus of the following 3 lessons.</p> |

Summary of Findings and Implications for Using EQuIP

The EQuIP analysis indicated that in Lesson 6 of the IQWST Light Unit, grade-appropriate elements of the scientific practices, disciplinary core ideas, and crosscutting concepts work together to support students in three-dimensional learning to make sense of phenomena and/or to design solutions to problems. It also indicated that the lesson fit together with other lessons to coherently target a performance expectation. Assuming that Lesson 6 is representative of all the lessons in the Light Unit, we would expect the unit to be highly supportive of students learning toward the targeted performance expectations. Indeed, as indicated in Figure 3, a study using data gathered during national field tests identified large learning gains, with an effect size of 2.5.

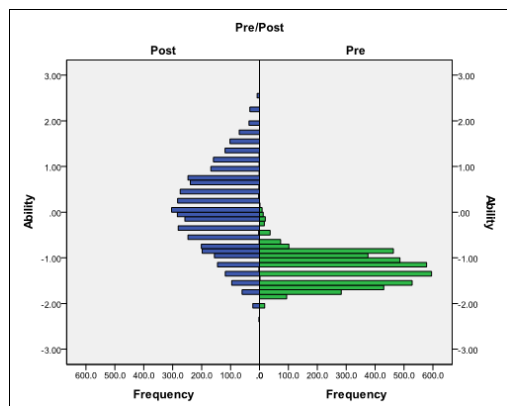


Figure 3. IQWST Learning Gains Pre- and Post-Test

CASE STUDY 2: *Toward High School Biology: A Curriculum Material Undergoing Final Revision*¹

The focus of this case study is an eight-week middle school unit developed by a team of researchers and curriculum developers at Project 2061 of the American Association for the Advancement of Science (AAAS) and BSCS that targets core ideas about chemical reactions in non-living and living systems, the crosscutting concept of matter conservation across physical and life science, and the science practices of data analysis, modeling, explanation, and communication. The unit has undergone several rounds of pilot testing and shown promise in improving students' understanding of and ability to apply concepts to explain novel phenomena in non-living and living systems compared with control classrooms using district curriculum materials covering the same concepts (Herrmann Abell, Flanagan, & Roseman, 2014).

Although the design of the *Toward High School Biology* (THSB) unit began prior to the release of the NRC *Framework*, NGSS, and the EQuIP Rubric, more recent iterations of the unit have been guided by the new standards and by the criteria in the rubric. How these and other resources contributed to the development of the unit is described below, followed by the results of the EQuIP analysis of a single lesson from the THSB unit.

About the THSB Unit

The development approach for the THSB unit is grounded in the coherence of the science ideas students are expected to learn and how those ideas unfold over time. During the initial phase of development, disciplinary core ideas and crosscutting concepts about atom rearrangement and conservation in non-living and living systems were unpacked and elaborated as **Science Ideas #1-17** shown in Figure 4. Each box on the map contains the text of a specific science idea: science ideas in white boxes develop the core idea that new substances form during chemical reactions because atoms of reactant molecules rearrange to form product molecules; science ideas in grey boxes develop the core idea that mass is conserved in chemical reactions because atoms are conserved; science ideas in blue boxes develop the element of the core idea that animals build body structures for growth (and repair) through chemical reactions, during which atoms rearrange and are conserved; and science ideas in green boxes develop the element of the core idea that plants build body structures for growth (and repair) during chemical reactions in which atoms rearrange and are conserved. Each box references the disciplinary core idea from which it is derived and, where appropriate, the crosscutting concept it manifests.

The science ideas on the map are written so as to make explicit connections across physical and life science (i.e., explicitly stating in **Science Ideas #12** and **#15** that atoms are rearranged and conserved when characterizing animal and plant growth, describing in **Science Idea #6** a special case of atom rearrangement and conservation—namely the formation of a polymer plus water molecules from monomers—as a bridge between chemical reactions involving small molecules and the complex polymers living things need to produce to build their body structures). The science ideas also explicitly address student misconceptions (i.e., explaining in **Science Ideas #10, #13, & #17** why changes in measured mass in chemical reactions including those involved in biological growth don't violate conservation). Thus, the language used in the science ideas provides a first step

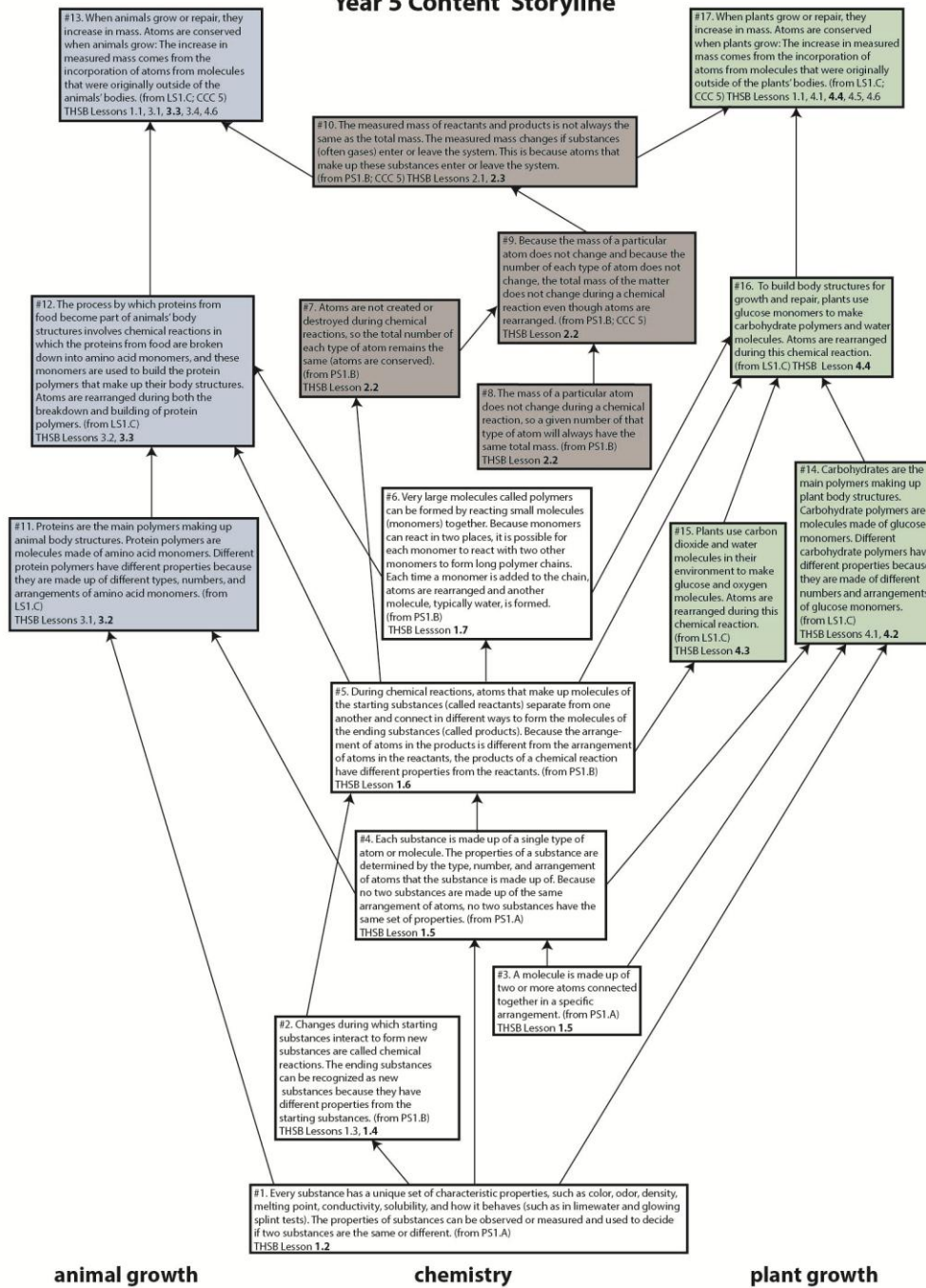
¹ The research reported on in Case Study 2 was supported by the Institute of Education Sciences, U.S. Department of Education, through Grant R305A100714 to the American Association for the Advancement of Science. The opinions expressed are those of the authors and do not represent views of the Institute or the U.S. Department of Education.

in establishing matter conservation as a concept that cuts across the physical and life sciences content in the unit.

Similarly, THSB developers unpacked the science practices to be targeted, using *Science for All Americans* (AAAS, 1989) to clarify expectations for high school graduates, maps in *Atlas of Science Literacy* (AAAS 2001, 2007) to clarify boundaries for middle school students, and summaries of learning research accompanying the maps to highlight misconceptions and learning difficulties the curriculum would need to address. Particularly helpful were *Atlas* maps and accompanying research for the topics of Scientific Inquiry (vol. 1, pp. 16-21), Detecting Flaws in Arguments (vol. 2, pp. 112-113), Models (vol. 2, pp. 92-93), and Reasoning (vol. 2, pp. 68-69).

Role of phenomena in the development of THSB. The next step in unit development consisted of identifying a range of phenomena that students could make sense of using the science ideas, crosscutting concepts, and appropriate science practices. Several considerations guided the selection of phenomena. In addition to the obvious ones of alignment to both physical and life science core ideas, comprehensibility, and potential for engaging a wide range of students, the developers sought to include (1) phenomena where the production of substances with different properties could be directly observed or at least required minimal inferences from data and (2) phenomena where more sophisticated inferences from data could be supported with modeling activities. For the latter, the developers took advantage of the rich scientific literature using radioactively-labeled atoms to determine the products of a chemical reaction and/or to monitor the effects of various factors on the amount of products produced. All phenomena were initially tested with students for engagement and comprehensibility and then to see if students could use the practices for making sense of them. The set of phenomena to be used to develop the core ideas and crosscutting concepts was finalized after Year 3 in the development process and is shown in Table 5.

Toward High School Biology (THSB) Year 5 Content Storyline



Copyright 2015 American Association for the Advancement of Science

04/07/2015

Figure 4. "Unpacked" Science Ideas in *Toward High School Biology* unit

Table 5. Key phenomena for each THSB chapter. Each phenomenon listed in the right-hand column is observed, modeled, and explained using the core ideas and crosscutting concepts in the column on the left. The unit includes additional phenomena that students are asked to make sense of as they use disciplinary core ideas, crosscutting concepts, and practices.

| Chapter #, Disciplinary Core Ideas, & Crosscutting Concepts | Students Observe, Model, & Explain These Phenomena: |
|---|--|
| 1. New substances form during chemical reactions because atoms rearrange to form new molecules. | Why substances with different properties form when: <ul style="list-style-type: none"> • Vinegar is mixed with baking soda • Iron is exposed to air • Hexamethylenediamine is mixed with adipic acid |
| 2. Mass is conserved in chemical reactions because atoms are conserved. | Why the measured mass of a system can change even though atoms aren't created or destroyed when: <ul style="list-style-type: none"> • Vinegar is mixed with baking soda • Iron is exposed to air • Hexamethylenediamine is mixed with adipic acid |
| 3. Animals build body structures for growth through chemical reactions, during which atoms rearrange and are conserved. | How animals produce proteins for growth of their body structures that are different from what they eat when: <ul style="list-style-type: none"> • Egg-eating snake eats only eggs but can replace its shed skin • Humans eat muscles but can also make tendons • Herring fish eat ¹⁴C-labeled brine shrimp and make ¹⁴C-labeled body structures (mostly muscle) |
| 4. Plants build body structures for growth through chemical reactions, during which atoms rearrange and are conserved. | How plants produce carbohydrates for growth of their body structures that are different from substances they take in from their environment when: <ul style="list-style-type: none"> • Algae produce ¹⁴C-glucose from ¹⁴C-carbon dioxide and they produce ¹⁸O-oxygen (not ¹⁸O-glucose) from ¹⁸O-water • Mouse-ear cress plants make more ¹⁴C-cellulose from ¹⁴C-glucose when grown without herbicide than with it |

Students are introduced to each science idea only after they have observed and tried to make sense of the phenomena. For example, ideas about atom rearrangement explaining the production of new substances and atom conservation explaining mass conservation are introduced only after students have observed and modeled three chemical reactions: one in which a gas is produced (baking soda + vinegar), a second in which a gas is consumed (iron rusting), and a third in which a solid polymer is produced at the interface of two liquids (nylon formation). Students use LEGO® bricks and ball-and-stick models to model atom rearrangement and conservation in closed and open systems, enabling explanations for why new substances with different properties form during chemical reactions (but not necessarily other changes) and why measured mass can change in open systems without violating conservation principles. For animal and plant growth, where chemical reactions occur in complex mixtures, students examine data from radioactive-labeling experiments and model atom rearrangement and conservation that leads to the production of biomaterials for growth. (A yellow dot on a carbon atom of a reactant molecule allows students to track what molecule it ends up in after the reaction has occurred.)

Role of the EQUiP Rubric in the development of THSB. The EQUiP Rubric (both the first draft released by Achieve in March 2014 and the current draft released in September 2014) provided criteria for analyzing the unit's alignment and coherence, instructional support, and support for monitoring students' progress as formative feedback to the development process. The THSB development team used the EQUiP criteria to analyze the unit, clarifying the criteria whenever necessary using AAAS Project 2061's content coherence and instructional support criteria

(Roseman, Stern, & Koppal, 2010; Kesidou & Roseman, 2002; Stern & Roseman, 2004). Findings from the EQuIP analysis were used by the team to inform revisions to the unit during its fourth year of development. Revisions to the Student Edition of THSB were relatively minor, consisting mainly of making the crosscutting concept of matter conservation more explicit and adding additional scaffolding for the science practice of explanation. For the Teacher Edition, the developers added rubrics for scoring embedded assessments and tables that presented evidence from the Student Edition showing that the THSB unit was aligned to NGSS, coherent, and provided appropriate supports for instruction and assessment. The reconciled analysis described below will inform further revisions in the final year of development.

EQuIP Analysis of THSB: Reconciled Results

Consistent with the methods described earlier in this paper, the developer and a symposium panelist carried out independent analyses of the THSB unit using EQuIP criteria. Results from the two analyses were reconciled, and those reconciled results are reported below. EQuIP criterion 1.A was applied to a single lesson from the THSB unit to judge alignment to the three dimensions of NGSS by both coders, and EQuIP criterion I.B.i was applied to Chapter 1 of the unit to judge coherence across a set of lessons.

Analysis Findings for EQuIP Criterion I.A: Grade-appropriate elements of the science and engineering practice(s), disciplinary core idea(s), and crosscutting concept(s) work together to support students in three-dimensional learning to make sense of phenomena and/or to design solutions to problems.

Both the NRC *Framework* and NGSS emphasize the three-dimensional nature of meaningful science learning and call for all three dimensions to be integrated into curriculum, instruction, and assessment. EQuIP criterion I.A asks for an evidence-based judgment about whether or not curriculum materials integrate the three dimensions to help students make sense of phenomena. The two coders were largely in agreement, with a few discrepancies where one coder questioned whether a task in which students were expected to use models in their written explanations of phenomena sufficiently reflected the meaning of “use a model” as described in NGSS, volume 2, p. 53 and whether using the terms monomer/polymer to characterize reactants and products of protein digestion and protein synthesis went beyond NGSS expectations for middle school students. As noted in Table 5b, the Teacher Edition justifies the inclusion of these terms in the curriculum (though not in the assessment), stating that they are needed to help students communicate about the essential aspects of nylon formation, synthesis of proteins for building animal body structures, and synthesis of complex carbohydrates for building plant body structures, specifically that chemical reactions are involved even if only a few atoms rearrange. However, differences in interpreting “use a model” were not resolved.

Table 6a through Table 6d provide evidence of alignment to NGSS identified in a single THSB lesson in Chapter 3 and in earlier lessons that address prerequisites. In the few cases where there were discrepancies between the coders’ analyses, the evidence is provided for others to judge.

Table 6a – Table 6d. Evidence for EQUiP Criterion 1.A in THSB Lesson 3.3 and Prerequisite Lessons. The column on the left of each table lists the indicators of meeting EQUiP Criterion 1.A and highlights the indicator for which evidence is provided in the column on the right.

Table 6a.

| EQUiP Criterion 1.A | Specific evidence from materials and reviewers' reasoning |
|--|--|
| <p>A. Grade-appropriate elements of the science and engineering practice(s), disciplinary core idea(s), and crosscutting concept(s), work together to support students in three-dimensional learning to make sense of phenomena and/or to design solutions to problems.</p> <p>i. Provides opportunities to develop and use specific elements of the practice(s) to make sense of phenomena and/or to design solutions to problems.</p> <p>ii. Provides opportunities to develop and use specific elements of the disciplinary core idea(s) to make sense of phenomena and/or to design solutions to problems.</p> <p>iii. Provides opportunities to develop and use specific elements of the crosscutting concept(s) to make sense of phenomena and/or to design solutions to problems.</p> <p>iv. The three dimensions work together to support students to make sense of phenomena and/or to design solutions to problems.</p> | <p>The following practices are addressed in Lesson 3.3:</p> <p>a. Obtaining, evaluating, and communicating information:</p> <ul style="list-style-type: none"> ▪ Students critically read a scientific text adapted for classroom use to determine the central idea: herring fish incorporate radioactively-labeled proteins from herring fish (food) into their body structures (<i>Activity 1</i>, pp. 108-112) <p>b. Analyzing and interpreting data:</p> <ul style="list-style-type: none"> ▪ Students analyze and interpret data about the amount of labeled carbon atoms found in three locations 24 hours after feeding the fish with food containing labeled carbon atoms (<i>Activity 1</i>, p. 112) as evidence that fish incorporate 20% of the protein into their body structures ▪ Students had already learned in Lesson 3.1 from analyzing and interpreting data about the relative mass of protein, fat, and carbohydrate molecules in some animal bodies (<i>Activity 1</i>, p. 93) and data on the average weight of human body parts (<i>Activity 1</i>, p. 94) that most of the mass of fish body structures is due to muscle protein <p>c. Developing and using models:</p> <ul style="list-style-type: none"> ▪ Students model the process by which brine shrimp (food) protein becomes part of a herring fish's body structures: using ball-and-stick models of a piece of protein, students react it with water molecules to "digest" it amino acid monomers and then synthesize a new protein plus water molecules from the amino acids (<i>Activity 2</i>, pp. 113-116) ▪ Students use model-based reasoning and science ideas about atom rearrangement and conservation during animal growth (<i>Science Ideas</i>, #12 and #13) to explain how your body builds scar tissue to seal up a cut (<i>Pulling It Together</i> Question 2, p. 118) and what would happen to the total number of LEGO bricks representing a consumed turkey sandwich immediately after eating the sandwich and after a few hours (<i>Pulling It Together</i> Question 3, p. 119) <p>d. Constructing explanations:</p> <ul style="list-style-type: none"> ▪ Construct an explanation for how animals use proteins from food to build their body structures (<i>Pulling It Together</i> Question 1, p. 118) ▪ Construct an explanation for how your body builds scar tissue to seal up a cut (<i>Pulling It Together</i> Question 2, p. 118) ▪ Construct an explanation for what would happen to the total number of LEGO bricks representing a consumed turkey sandwich immediately after eating the sandwich and after a few hours (<i>Pulling It Together</i> Question 3, p. 119) ▪ Construct an explanation for how the addition of new protein molecules contributes to the growth of animal's body structures and body (<i>Pulling It Together</i> Question 4, p. 119) |

Table 6b.

| EQuIP Criterion 1.A | Specific evidence from materials and reviewers' reasoning |
|--|--|
| <p>A. Grade-appropriate elements of the science and engineering practice(s), disciplinary core idea(s), and crosscutting concept(s), work together to support students in three-dimensional learning to make sense of phenomena and/or to design solutions to problems.</p> <p>i. Provides opportunities to develop and use specific elements of the practice(s) to make sense of phenomena and/or to design solutions to problems.</p> <p>ii. Provides opportunities to develop and use specific elements of the disciplinary core idea(s) to make sense of phenomena and/or to design solutions to problems.</p> <p>iii. Provides opportunities to develop and use specific elements of the crosscutting concept(s) to make sense of phenomena and/or to design solutions to problems.</p> <p>iv. The three dimensions work together to support students to make sense of phenomena and/or to design solutions to problems.</p> | <p>The following science ideas are addressed in Lesson 3.3 (or earlier lessons):</p> <p>The process by which proteins from food become part of animals' body structures involves chemical reactions in which the proteins from food are broken down into amino acid monomers, and these monomers are used to build the protein polymers that make up their body structures. Atoms are rearranged during both the breakdown and building of protein polymers. (Science Idea #12)</p> <ul style="list-style-type: none"> ▪ Students use the idea that <u>atoms rearrange to form new molecules</u> to make sense of the production of new substances during chemical reactions in non-living systems in earlier lessons: the production of carbon dioxide when baking soda reacts with vinegar and the production of rust when iron reacts with oxygen in the air (Lesson 1.6, pp. 39-50), why the formation of bubbles when hydrogen peroxide is put on a wound involves a chemical reaction but the formation of bubbles when water is heated on a stove does not (Lesson 1.6, pp. 47-49) ▪ Students use the idea that <u>polymers can be built from monomers</u> to make sense of the production of nylon thread when two clear colorless liquids—hexamethylenediamine and adipic acid—react (Lesson 1.7, pp. 51-58), which they will then apply to the production of protein polymers for building animal body structures (see rationale for using terms monomer and polymer in Teacher Edition, p. xi) ▪ Students use the idea that <u>animal growth requires building new body structures</u> to make sense of their observations in an earlier lesson that body structures increase in size when a German shepherd puppy, human baby girl, and lobster grow and when a lizard regrows its lost tail (Lesson 3.1, p. 91) ▪ Students use the idea that animals <u>need to make different proteins</u> from proteins they eat in an earlier lesson when they compare proteins an animal eats (e.g., egg-eating snake must make keratin to replace its shed skin, humans must make collagen for tendons) are different from proteins in its food (e.g., egg white is mostly ovalbumin, humans typically eat actin and myosin in muscle, not collagen in tendons) (Lesson 3.2, p. 103) ▪ Students use the idea that <u>proteins from food are broken down to amino acid monomers that are used to build new body proteins</u> to explain how herring fish incorporate radioactive carbon atoms from brine shrimp into their body structures (L 3.3, pp. 108-112), how animals use proteins from food to build their body structures (L 3.3, Question 1, p. 118), and how your body builds scar tissue to seal up a cut (Lesson 3.3, Question 2, p. 118) <p>When animals grow or repair, they increase in mass. Atoms are conserved when animals grow: The increase in measured mass comes from the incorporation of atoms from molecules that were originally outside of the animals bodies. (Science Idea #13)</p> <ul style="list-style-type: none"> ▪ Students use the idea that <u>measured mass can change</u> during a chemical reaction if atoms can enter or leave the system to explain why the measured mass decreases when baking soda reacts with vinegar and why the measured mass increases when iron reacts with oxygen in open containers (Lesson 2.3, pp. 76-89), whether the human body is like an open or a closed system, and why the mass of the Statue of Liberty increases in mass over time (p. 88) ▪ Students use the idea that the <u>increase in an animal's mass during growth results from the incorporation of atoms that were originally outside the animal</u> to predict what would happen to the mass of the fish 24 hours after feeding and after many days of feeding (p. 112) and to explain what would happen to the total number of LEGO bricks representing a turkey sandwich immediately after the sandwich was eaten and after a few hours (p. 119, Question 3) and how the addition of new protein molecules contributes to the growth of animal's body structures and body (p. 119, Question 4) |

Table 6c.

| EQulP Criterion I.A | Specific evidence from materials and reviewers' reasoning |
|--|--|
| <p>A. Grade-appropriate elements of the science and engineering practice(s), disciplinary core idea(s), and crosscutting concept(s), work together to support students in three-dimensional learning to make sense of phenomena and/or to design solutions to problems.</p> <p>i. Provides opportunities to develop and use specific elements of the practice(s) to make sense of phenomena and/or to design solutions to problems.</p> <p>ii. Provides opportunities to develop and use specific elements of the disciplinary core idea(s) to make sense of phenomena and/or to design solutions to problems.</p> <p>iii. Provides opportunities to develop and use specific elements of the crosscutting concept(s) to make sense of phenomena and/or to design solutions to problems.</p> <p>iv. The three dimensions work together to support students to make sense of phenomena and/or to design solutions to problems.</p> | <p>The following Crosscutting Concept is addressed in Lesson 3.3 (or earlier lessons):</p> <p>Energy and Matter: Matter is conserved because atoms are conserved in physical and chemical processes.</p> <ul style="list-style-type: none"> ▪ Students use the crosscutting concept in an earlier lesson to explain why (a) the total mass of LEGO bricks used to make models of molecules of baking soda and vinegar is the same as the total mass of LEGO bricks used to make models of molecules of carbon dioxide, sodium acetate, and water and (b) the total mass of LEGO bricks used to make models of iron and oxygen is the same as the total mass of LEGO bricks used to make molecules of rust (iron oxide) (Lesson 2.2, <i>Activity 2</i>, pp. 70-72) ▪ Students use the crosscutting concept in an earlier lesson to explain how rearranging atoms keeps the total mass constant during chemical reactions (Lesson 2.2, Question 1, p. 73) and to figure out what models would leave and how the mass of the models remaining on the balance would change when the container of the baking soda and vinegar reaction is opened (Lesson 2.2, Question 2, pp. 73-75). ▪ Students use the crosscutting concept in an earlier lesson to make sense of the observation (from a simulation) that when 10 H₂ are mixed with 10 O₂, only 10 H₂O form even though there are 5 O₂ left and how the total number of atoms and total mass of the atoms after the reaction is the same as before (Lesson 2.3, <i>Activity 1</i>, pp. 77-79) ▪ Students use the crosscutting concept in an earlier lesson to make sense of (a) why the measured mass decreased after the sealed bag with the baking soda and vinegar reaction was opened and (b) why the measured mass increased after the flask with iron and air was opened (Lesson 2.3, <i>Activity 2</i>, pp. 80-83) ▪ Students use the crosscutting concept in an earlier lesson to construct and critique an explanation for why (a) total mass was conserved even though measured mass increased when iron reacted with oxygen in an open container and (b) total mass was conserved even though measured mass decreased when baking soda and vinegar reacted in an open container (Lesson 2.3, <i>Activity 3</i>, p. 85-86). ▪ Students use the crosscutting concept in an earlier lesson to (a) explain why measured mass sometimes increases and why it sometimes decreases when a container is opened, (b) explain why the mass decreases when nylon thread is removed from the beaker, (c) compare the rusting reaction to a young child eating food, and (d) predict and explain what happens to the measured mass of the Statue of Liberty (Lesson 2.3, Questions 1-4, pp. 87-88). ▪ Students use crosscutting concept to predict what would happen to the mass of the fish 24 hours after feeding and after many days of feeding (Lesson 3.3, p. 112), to explain what would happen to the total number of LEGO® bricks representing a consumed turkey sandwich immediately after eating the sandwich and after a few hours (Lesson 3.3, p. 119, Q3) and how the addition of new protein molecules contributes to the growth of animal's body structures and body (Lesson 3.3, p. 119, Q4) |

Table 6d.

| EQulP Criterion I.A | Specific evidence from materials and reviewers' reasoning |
|--|---|
| <p>A. Grade-appropriate elements of the science and engineering practice(s), disciplinary core idea(s), and crosscutting concept(s), work together to support students in three-dimensional learning to make sense of phenomena and/or to design solutions to problems.</p> <p>i. Provides opportunities to develop and use specific elements of the practice(s) to make sense of phenomena and/or to design solutions to problems.</p> <p>ii. Provides opportunities to develop and use specific elements of the disciplinary core idea(s) to make sense of phenomena and/or to design solutions to problems.</p> <p>iii. Provides opportunities to develop and use specific elements of the crosscutting concept(s) to make sense of phenomena and/or to design solutions to problems.</p> <p>iv. The three dimensions work together to support students to make sense of phenomena and/or to design solutions to problems.</p> | <p>The three dimensions work together in the following phenomena in Lesson 3.3:</p> <ul style="list-style-type: none"> ▪ Lesson 3.3, <i>Activity 1</i>, Following “labeled “ protein when one animal eats another animal, addresses DCI LS1.C, the crosscutting concept of matter conservation, and the science practices of obtaining, evaluating, and communicating information and analyzing and interpreting data ▪ Lesson 3.3, <i>Activity 2</i>, Modeling the breakdown and building of proteins in herring fish, addresses DCI LS1.C, the crosscutting concept of matter conservation, and the science practices of modeling and explanation ▪ Lesson 3.3, <i>Pulling It Together</i> Question 1, explain how animals use proteins from food to build their body structures, addresses DCI LS1.C, the crosscutting concept of matter conservation, and the science practice of constructing explanations. ▪ Lesson 3.3, <i>Pulling It Together</i> Question 2, explain how your body builds scar tissue to seal up a cut, addresses DCI LS1.C, the crosscutting concept of matter conservation, and the science practice of constructing explanations. ▪ Lesson 3.3, <i>Pulling It Together</i> Question 3, explain what would happen to the total number of LEGO® bricks representing a consumed turkey sandwich immediately after eating the sandwich and after a few hours, addresses DCI LS1.C, the crosscutting concept of matter conservation, and the science practice of constructing explanations. ▪ Lesson 3.3, <i>Pulling It Together</i> Question 4, explain how the addition of new protein molecules contributes to the growth of an animal’s body structures and body, addresses DCI LS1.C, the crosscutting concept of matter conservation, and the science practice of constructing explanations. |

In summary, the two coders agreed that the evidence shows that in THSB Lesson 3.3, the set of science practices work with the disciplinary core ideas and crosscutting concepts in ways that are consistent with EQuIP criterion 1.A: published scientific research studies that are adapted for classroom use serve as sources of data; students analyze and interpret data to provide evidence for phenomena that illustrate the science ideas, students use modeling to make abstract phenomena visible and help explain them; students explain familiar and novel phenomena and in so doing showcase the explanatory power of the science ideas; and students support explanations of phenomena by logical reasoning from evidence, science ideas, and models.

Analysis Findings for EQuIP Criterion I.B.i: Each lesson links to previous lessons and provides a need to engage in the current lesson.

Although a coherent *content* storyline is necessary, it is not sufficient to ensure that a material achieves coherence from a *student perspective* as NGSS intends. A content storyline such as the one shown for THSB in Figure 4 is a useful tool to help developers maintain a coherent narrative throughout the development process. This storyline is also included in the THSB Teacher Edition to help teachers understand what the unit, chapters, and lessons are trying to accomplish in terms of the NGSS disciplinary core ideas and crosscutting concepts. But students must understand what they are doing and why and see the activities as helping them achieve the established purpose of the unit, lessons, and activities (Reiser, 2013). EQuIP criterion I.B.i asks for an evidence-based judgment about whether or not a material supports students in understanding what they are doing and why. Findings for Criterion I.B.i for Case Study 2 are based on an analysis of THSB Lesson 3.3 and of THSB Chapter 1.

The lesson structure for THSB is designed to provide students with the rationale for what they are doing in each lesson and how it relates to earlier and later lessons. Each lesson begins with a section *What do we know and what are we trying to find out?* This framing section revisits what students did in the previous lesson and introduces the *Key Question* students will explore in the current lesson. Students write and discuss their initial ideas about the *Key Question* at the beginning of the lesson (e.g., Lesson 3.3, p. 107), engage in Activities that help them answer the *Key Question*, and revisit it as one of the *Pulling It Together* questions at the end of the lesson (e.g., Lesson 3.3, p. 118-119). The Teacher Edition provides text for teachers to use in closing each lesson and linking it to the next. For example, Lesson 3.3 begins:

What do we know and what are we trying to find out?

In the last lesson, we saw that the proteins an animal eats are rarely exactly the same proteins it needs to build its body structures. So what happens to food when an animal eats? In this lesson, you will have the chance to use experimental data and models to find out what happens to the proteins in food once an animal has eaten them, and how they help an animal to grow and repair its body structures.

Answer the Key Question to the best of your knowledge. Be prepared to share your ideas with the class.

Key Question: How do animals use proteins from food to repair and build their body structures? (p. 107)

Teacher notes instruct teachers to lead a whole class discussion whose “purpose is primarily eliciting and probing student ideas” but to “challenge any ideas that are inconsistent with learning from previous lessons” (Teacher Edition, p. 107a).

Students engage in the following activities:

Activity 1: Following “Labeled” Protein When One Animal Eats another Animal (pp. 108-112)

Activity 2: Modeling the Breakdown and Building of Proteins in Herring Fish (pp. 113-116)

Then they read the section that introduces **Science Ideas #12** and **#13**:

Science Ideas

Lesson 3.3 was intended to help you understand some important ideas about how food relates to growth in animals. Read the idea below. Notice that Science Ideas #12 and #13 explain observations about animal growth in terms of atoms. We can observe what happens when animals grow, but we can't see atoms rearranging or entering or leaving the system. However, because Science Ideas #12 and #13 state general principles that are consistent with a wide range of observations and data, we can use them to reason about the growth of all animals. You will be expected to use ideas about atoms to explain phenomena involving animal growth.

Look back through Lesson 3.3. Describe at least one example from your work so that that illustrates each of the science ideas listed below.

Science Idea #12: The process by which proteins from food become part of animals' body structures involves chemical reactions in which the proteins from food are broken down to amino acid monomers, and these monomers are used to build different protein polymers that make up body structures. Atoms are rearranged during both the breakdown and the building of protein polymers.

Science Idea #13: When animals grow or repair, they increase in mass. Atoms are conserved when animals grow: The increase in measured mass comes from the incorporation of atoms from molecules that were originally outside of the animals' bodies. (p. 117)

Students then revisit the *Key Question* and explain other phenomena using what they have learned in the lesson.

In the Teacher Edition, teachers are instructed to lead a discussion to close the lesson and link it to the next lesson drawing on the suggested text:

We've learned that when animals eat, some of the atoms from proteins in food become part of the animal's body. We used models to visualize how this happens—inside animal bodies, protein polymers react with H₂O molecules and are broken down into amino acids. This happens in the digestive system.

The amino acids enter the blood stream where they are carried throughout the body. These amino acids react to form different proteins and H₂O molecules. This happens wherever the body needs new proteins for growth or repair of body structures.

In the next lesson, you will examine how scientists explain their conclusions about muscle growth and repair. (Teacher Edition, p. 119a)

Table 7 presents additional evidence from THSB Chapter 3 to support a claim that lessons in the chapter fit together coherently as required in EQUiP criterion 1.B.i. For another approach to representing the coherence in storylines, one that makes explicit how the flow of questions--from the students' perspective--motivates students' engagement with phenomena to build and use pieces of science ideas incrementally over time, see Reiser (2013; 2014).

Table 7. Evidence for EQUiP Criterion 1.B.i in THSB Chapter 3.

| Lesson #: Title | Links to Previous Lesson | Provides Need to Engage in Current Lesson | What Students Do to Satisfy the Need |
|---|---|---|--|
| Lesson 3.1: The "Stuff" That Makes Up Animals | <i>What do we know and what are we trying to find out?</i> (see text) | <i>Key Question:</i> What are animals made up of? | <i>Activity 1:</i> Observe what structures get bigger when a puppy, human girl, lobster grows and lizard regrows its tail; analyze and interpret data on animal growth as evidence for mass increase <i>Activity 2:</i> Analyze data to determine that animals are mostly |

| | | | |
|---|--|---|---|
| | in Student Edition p. 90) | | protein and that most human body mass is muscle <i>Pulling It Together:</i> Revisit <i>Key Question</i> and consider what happens to the number of atoms making up animal bodies as they grow |
| Lesson 3.2: Proteins in Animal Bodies and Food | <i>What do we know and what are we trying to find out?</i> (see text in Student Edition, p. 96) | <i>Key Question:</i> Are the proteins that animals eat exactly the same as the proteins that make up their bodies? | <i>Activity 1:</i> Examine ball-and-stick model of protein to consider its composition and how it might form from amino acids <i>Activity 2:</i> Examine data on properties of various proteins to decide whether they are the same or different and why; examine two amino acid sequences to determine if they are the same or different and consider how this might relate to properties <i>Activity 3:</i> Comparing proteins in animal’s food to proteins making up its body <i>Science Ideas:</i> Read and give an example of Science Idea #11 (see Figure 1) <i>Pulling It Together:</i> Revisit <i>Key Question</i> , explain why people can make new fingernails without eating keratin, and compare proteins to nylon |
| Lesson 3.3: Explaining Animal Growth with Atoms and Molecules | <i>What do we know and what are we trying to find out?</i> (see text in Student Edition, p. 107) | <i>Key Question:</i> How do animals use proteins from food to repair and build their body structures? | <i>Activity 1:</i> Analyze and interpret data to provide evidence that herring incorporate brine shrimp protein into their body structures <i>Activity 2:</i> Model the digestion and synthesis reactions of the incorporation process <i>Science Ideas:</i> Read and give an example of Science Ideas #12 & #13 (see Figure 1) <i>Pulling It Together:</i> Revisit <i>Key Question</i> , explain how cut heals, what happens to a turkey sandwich, and how addition of new proteins contributes to animal growth |
| Lesson 3.4: Examining Explanations of Animal Growth and Repair | <i>What do we know and what are we trying to find out?</i> (see text in Student Edition, p. 51) | <i>Key Question:</i> How are the explanations we have been writing similar to the explanations that scientists write when they publish their work? | <i>Activity 1:</i> Analyze and interpret a scientist’s data, methods, and conclusions about the effect of taking an amino acid supplement on protein production in elderly men <i>Pulling It Together:</i> Revisit <i>Key Question</i> and explain why a friend who thinks chemical reactions only happen in labs is incorrect |

Coherence from the student’s perspective. The symposium panelist for Case Study 2 conducted an independent analysis of THSB Chapter 1, which raised concerns that while activities in the chapter are logically sequenced, a coherent story doesn’t necessarily unfold at each step for students. For example, while it was clear to the teacher how a particular activity would address the *Key Question*, the panelist identified places where this would be apparent to the student only after the activity was completed.

The developer of THSB then used this feedback from the panelist’s analysis of Chapter 1 to further clarify EQuIP Criterion I.B.i and apply it to Lesson 3.3. In doing so, the developer identified several places where coherence from the student’s perspective could be improved.

Sequencing of tasks within activities: Activity 1 asks students to “read about the radioactive labeling method and then work with your group to respond to the following questions:

1. Think back to Chapter 1 when we reacted baking soda with vinegar and observed carbon dioxide gas. How did we know that the carbon dioxide was produced in the chemical reaction? (*Students should know that since they started with only 2 substances that disappeared when the carbon dioxide was formed, they had evidence that the carbon dioxide came from the reaction between the two substances.*)
2. What if our reactants had been mixtures of many substances, and we poured the mixtures together? How would we know which substances reacted to produce the carbon dioxide? (*Students should realize that they wouldn't know.*)

The activity would be more coherent if students responded to the questions *before* reading about the radioactive labeling method. By reversing the order, the radioactive labeling method would provide a solution to the problem of how to tell whether or not a new substance was the product of a particular chemical reaction.

Linking to earlier activities: Students may not know why they are modeling protein digestion and protein synthesis in Activity 2, when the experimental data in Activity 1 shows only that 20% of the radioactive carbon atoms from brine shrimp end up in the fish body. Why are students modeling protein synthesis? Some students may recall that data in an earlier lesson showed that herring fish bodies are 72.7 % protein, 8.5% fat, and 0.8% carbohydrate, so herring would be making mostly protein molecules to build body structures. However, students are not asked to consider this question.

Putting the pieces together: At the end of Activity 2, students are not asked to reflect on what their modeling of protein digestion helped them figure out. While individual questions during the modeling activity ask students to think about what they are doing (e.g., where is the labeled carbon atom in the products, where in the fish's body would those molecules be found, what would happen to the measured mass of the fish, pp. 115-116), they aren't asked to put all the pieces of the story together to explain how the amino acids that are produced when one protein is digested can be used to synthesize a different protein. Instead, students are asked only to use what they have just done to describe an example of **Science Idea #12** and **#13**.

Clearly, a deeper understanding of the meaning of coherence from the student perspective showed that more work needs to be done to fully meet this criterion. However, it should be noted that these insights were the result of this particular panelist's unique knowledge and experience; there is nothing articulated in the EQUIP criterion that would enable others to draw these same conclusions.

Analysis Findings for EQUIP I.B.ii: The lessons help students develop proficiency on a targeted set of performance expectations.

As noted earlier, the NRC *Framework* expects students to use multiple practices with core ideas to make sense of phenomena. The NGSS performance expectations specify combinations of a single practice, disciplinary core idea, and crosscutting concept to be assessed. EQUIP criterion I.B.ii asks for an evidence-based judgment about whether or not students are likely to make progress towards the specified performances.

Table 8 presents evidence that THSB Chapter 3 helps students make progress on four out of the five performance expectations targeted in the unit. The fifth performance expectation—construct a scientific explanation for the role of photosynthesis in the cycling of matter and flow of energy into and out of organisms (MS-LS1-6)—is the focus of THSB Chapter 4. Elements of the performance expectations in gray text are not targeted in the unit.

Each row in Table 8 references the activities in THSB Lessons 3.1 through 3.4 that contribute to a performance expectation. Checking the evidence requires examining the reference and determining

whether it provides evidence for the claim. For example, in Lesson 3.2, Activities 2 & 3, pp. 100-103, students analyze and interpret data on the properties of proteins as evidence that the proteins an animal eats are often different from the proteins it needs to make to build or repair its body structures.

Activities listed in contribute to the performance expectation by engaging students with a precursor to the performance expectation. For example in Lesson 3.1, Activity 1 engages students in (a) observing time-lapse photos of animal growth and repair and considering what new body structures they must make and (b) analyzing and interpreting data showing that animals increase in mass as they grow. Activity 2 engages students in analyzing interpreting data showing that proteins make up the majority of the mass of the bodies of a wide variety of animals, which provides the rationale for focusing on protein molecules to explain growth.

Table 8. Evidence for EQUiP Criterion I.B.ii in THSB Chapter 3.

| Lesson | PERFORMANCE EXPECTATIONS | | | |
|--------|--|---|--|---|
| | Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred. (MS-PS1-2) | Develop and use a model to describe how the total number of atoms does not change in a chemical reaction and thus mass is conserved. (MS-PS1-5) | Develop a model to describe how food is rearranged through chemical reactions forming new molecules that support growth and/or release energy as this matter moves through an organism. (MS-LS1-7) | Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large carbon-based molecules. (HS-LS1-6) |
| 3.1 | | | <i>Activity 1:</i> students observe time-lapse photos of animal growth and repair and analyze data on mass changes accompanying animal growth, pp. 91-92 <i>Activity 2:</i> students analyze data on the body composition of a variety animals to find out what molecules and body structures animals must make as they grow, pp. 93-94 | |
| 3.2 | <i>Activity 2:</i> students analyze data about the properties of proteins making up animal body structures as evidence that different proteins have different properties and therefore are different substances pp. 100-102, | | | |

| | | | | |
|-----|--|---|---|--|
| | <p><i>Activity 3:</i> students (a) observe an egg-eating snake (whose diet is mostly ovalbumin) and a photo of a snake shedding its skin (mostly keratin) and (b) consider that humans eat mostly muscle protein but make tendons (mostly collagen) as evidence that these animals make proteins that are different from proteins they eat, p. 103</p> <p>In <i>Science Ideas</i>, students read and give an example of Science Idea #11 that states the general principle across all animals, p. 104</p> | | | |
| 3.3 | | <p><i>Activity 1:</i> students analyze data from radioactive labeling experiments that provide evidence that young herring fish incorporate proteins from their food into their body structures, pp. 108-112</p> <p><i>Activity 2:</i> students model protein digestion (in the fish gut) and protein synthesis (in fish body structures) to make sense of the data, pp. 113-115</p> <p><i>Science Ideas:</i> students give an example of</p> | <p><i>Activity 1:</i> students analyze data from radioactive labeling experiments that provide evidence that young herring fish incorporate proteins from their food into their body structures, pp. 108-112</p> <p><i>Activity 2:</i> students model protein digestion (in the fish gut) and protein synthesis (in fish body structures) to make sense of the data, pp. 113-115</p> <p><i>Science Ideas:</i> students give an example of Science Ideas #12 and #13 that states the general principle about food molecules being rearranged through chemical reactions to support growth of all organisms, p. 117</p> | <p><i>Activity 2:</i> students model how carbon, hydrogen, oxygen, and nitrogen atoms of amino acid monomers rearrange to form protein polymers and water molecules, pp. 113-115</p> <p><i>Pulling It Together:</i> students construct a valid explanation for how your body builds scar tissue to repair a cut, using Explanation Quality Criteria that include citing relevant evidence and reasoning with models and science ideas, p. 119</p> <p>Note: In later activities, students (a) engage in similar data analysis and modeling activities and explanation tasks in Lesson 4.4: Making Carbohydrate Polymers in Plants, pp. 150-155, (b) construct a better explanation than Van Helmont’s for where most of the mass of a dry willow tree comes from in Lesson 4.5, Activity 1, pp. 158-160, and (c) construct an</p> |

| | | | | |
|-----|--|--|--|---|
| | | Science Ideas #12 and #13 that states the general principle about the role of atom rearrangement and conservation in animal growth, p. 117 | | explanation for why the growth of a mushroom on a dead tree does not violate conservation principles, pp. 165-167 |
| 3.4 | | | | <i>Pulling It Together:</i> Students cite evidence, science ideas, and /or models to explain why a friend’s statement that “chemical reactions only hap[pen in labs, not in people or animals” is incorrect, p. 125 |

Analysis Findings for EQuIP Criterion I.C: Where appropriate, disciplinary core ideas from different disciplines are used together to explain phenomena.

The THSB unit uses several strategies to make the connections between ideas in life and physical science explicit to students:

- In both physical and life science contexts students use the same set of practices to help them make sense of phenomena involving the production of new substances, e.g., observing first that substances with different properties are produced, modeling atom rearrangement to account for the production of substances with different properties, constructing evidence-based explanations.
- Students use the same ball-and-stick models to represent monomers/polymers and to model polymer formation in physical and life science examples. In all of these cases, every atom is represented so that students can keep track of which atoms form new connections during the reaction and account for all the atoms of reactants and products. Biology textbooks and the internet use shorthand conventions for large molecules that are accepted by scientists but are incomprehensible to students just learning about atom rearrangement and conservation.
- The science ideas students use to explain phenomena in both physical and life science use similar language, and students are asked to identify the similarities when life science ideas are introduced.
- Students are asked to compare related phenomena across physical and life science, e.g., how is animal growth and plant growth like nylon formation (the Teacher Edition states that all involve chemical reactions that produce polymers and water molecules), how are changes in measured mass accompanying plant growth like iron rusting (the Teacher Edition states that both involve increases in measured mass as molecules of gas from outside the system react to form new molecules, thereby “trapping” the atoms inside the system).

Analysis Findings for EQuIP Criterion 1.D: Where appropriate, crosscutting concepts are used in the explanation of phenomena from a variety of disciplines.

The THSB unit engages students in using the crosscutting concept of matter conservation in the explanation of physical and life science phenomena. Students use the concept of matter conservation to explain why the measured mass stays the same when baking soda + vinegar and iron + oxygen react in closed systems and why conservation isn’t violated even though the measured

mass changes when the reactions occur in open systems. Students are also asked to use the concept of matter conservation to explain where the atoms come from that contribute to the growth of herring fish and the increase in mass of growing plants, to explain why plants grown in CO₂-enriched air grow bigger than plants grown in normal air, and to predict what will happen to the mass of a fallen tree as mushrooms grow on it and to explain why the phenomenon doesn't violate conservation principles.

For the sake of coherence, developers chose not call to attention to experiences students have with the crosscutting concept of systems and system models. Nonetheless, students' experiences could be brought into the foreground and built on in subsequent units. For example, students have numerous experiences with different models of systems where they examine inputs and outputs of matter. Students also observe a variety of different models of the same molecule and note what they have in common and how they differ.

Summary of Findings and Implications for Using EQuIP

The results presented in the discussion and tables above have been agreed upon by the developer and the panelist who carried out independent analyses of the THSB lesson. Based on their reconciled analyses of alignment of THSB Lesson 3.3 and coherence of THSB Chapter 3, the analysts concur that there is strong evidence to show that the THSB unit aligns with the conceptual shifts in NGSS as articulated in the EQuIP rubric. That is, the unit:

- Engages students in using science practices of communication, data analysis and interpretation, modeling, and explanation; core ideas about atom rearrangement and conservation from physical and life science; and the crosscutting concept of matter conservation to make sense of a range of phenomena in non-living and living systems (EQuIP I.A),
- Sequences lessons into a coherent content storyline that makes sense from both the teacher and student perspectives (though some lessons could be better motivated for students) and contributes to five performance expectations (EQuIP I.B),
- Incorporates core ideas about chemical reactions in life and physical science to help students explain phenomena ranging from iron rusting to nylon formation to the growth of living things (EQuIP I.C), and
- Helps students see the explanatory power of conservation principles in both non-living and living systems (EQuIP I.D).

Analysis of the THSB unit using the EQuIP rubric encouraged THSB developers to take a more rigorous look at the extent to which the unit integrated science content with science practices. As a result, the developers made some aspects of the alignment to science practices more explicit, e.g., referring to information about properties of substances as data and making the role of models and the use of science ideas in reasoning an explicit part of scaffolding explanations. Likewise, the process of examining and reconciling evidence for the EQuIP criterion for coherence highlighted a few lessons where the *Key Question* might not have been adequately motivated from the student perspective. This will be addressed in the final round of revisions.

The developers of THSB found the task of using the EQuIP criteria to analyze the student and teacher materials during the development process to be straightforward, albeit time consuming. It is important to acknowledge, however, that their experience may not be typical. First, the THSB developers were already steeped in and had contributed to the development of standards documents that preceded NGSS (e.g., *Benchmarks for Science Literacy*, *Atlas of Science Literacy*, and *National Science*

Education Standards (NRC, 1996) and to the development of both the NRC *Framework* and NGSS itself. The THSB developers also had a deep understanding of the ideas about chemical reactions and conservation that were ultimately included as NGSS disciplinary core ideas and the crosscutting concept of matter conservation, had prior experience analyzing and supporting science practices, and had developed and applied an earlier and widely cited set of research-based criteria for evaluating the content coherence (including alignment) and the quality of instructional support (including assessment) of curriculum materials (Roseman, Kesidou, & Stern, 1997; Kesidou & Roseman, 2002; Stern & Roseman, 2004; Roseman, Stern, & Koppal, 2010). The developers had also provided expert feedback to other curriculum development efforts, including the development of the IQWST unit on light that is the focus of Case Study 1. All of this knowledge and experience was brought to the development of the THSB unit and to the interpretation and application of the EQuIP criteria, including what counts as evidence of the three dimensions “working together to make sense of phenomena.” Other users of the EQuIP Rubric with different levels of knowledge and experience are likely to need more explicit guidance, including examples and counter examples to clarify the criteria, before they are able to apply the rubric effectively. Without such guidance, the EQuIP rubric may not be as widely used as intended.

CASE STUDY 3 - *Using Submicroscopic Interactions to Explain Macroscopic Phenomena: A Curriculum Material Early in the Development Process*

The focus of this case study is a recently funded project to design a curriculum material to help students understand forces at the molecular level. The full case study will be available at a later date; the following is a brief introduction to the case study material.

Understanding electrical forces and interactions is important for explaining and predicting diverse phenomena. These ideas form components of disciplinary core ideas and are included in several of the NGSS high school performance expectations. The abstract nature of these scientific ideas, however, makes them difficult for students to use in explaining macroscopic phenomena (Levy-Nahum, Mamlok-Naaman, Hofstein, & Krajcik, 2006), and students struggle to coordinate their understanding of various phenomena, the underlying scientific ideas that help explain the phenomena, and representations of those phenomena (Stieff, 2011). Most high school materials do not support students in developing these ideas. Moreover, there are few examples of materials that engage learners in the three-dimensional learning called for in NGSS and none that engage students in building understanding of electrical interactions by building models and constructing scientific explanations, two key scientific practices.

The materials were purposefully designed to engage students in the practices of science blended with core ideas and crosscutting concepts, with the goal of developing an understanding of the electrical forces and energy involved in interactions at the microscopic level. To ensure alignment with NGSS, the curriculum design process began by identifying the performance expectations that students should meet, unpacking those ideas, and then creating a coherent storyline to show how those ideas would be developed throughout the unit. Other key design features included: (1) specifying learning goals as lesson-level learning performances that build towards students understanding of the selected NGSS performance expectations, (2) using driving questions to engage learners and help build coherence, (3) providing students with opportunities to experience and explain multiple phenomena, (4) scaffolding students in the construction of models and scientific explanations, (5) supporting students and teachers in making sense of the data and experiences, and (6) using multiple interactive computer-based representations and simulations.

DISCUSSION

One question that arises with a new tool like the EQuIP Rubric, which has ambitious goals for evaluating substantive dimensions of curriculum materials, is whether the tool can be used reliably. The criteria in a tool used for making such judgments could be described generally enough, or imprecisely enough, so that two coders would come to different decisions. The set of case studies presented here provides a rather generous context for exploring the reliability of the rubric – the coders included the developers of the materials who know them well, along with other researchers who are collaborators of the developers, and thus have similar perspectives on science practices, phenomena, the nature of disciplinary core ideas, and other relevant aspects of NGSS and of curriculum materials in general. Thus it may come as no surprise that our judgments were largely similar, and we do not assert that these test cases alone would be sufficient to evaluate the reliability of the EQuIP Rubric.

More important for the present set of case studies, perhaps, are questions about validity and utility. Did performing the EQuIP analysis uncover useful information about the curriculum materials and their alignment with NGSS? Did the analysis prompt useful debate in comparing judgments about a lesson? We argue that the EQuIP judgments are useful both in guiding the development of curriculum materials and in evaluating their strengths and weaknesses. There are three areas in which we highlight how use of the EQuIP Rubric can productively focus attention on ways that materials can better support learning aligned with NGSS: (a) the role of phenomena, (b) the three dimensions working together, and (c) coherence from both disciplinary and student perspectives.

The Role of Phenomena

One key idea we have stressed in the case studies is the critical role of identifying phenomena in each task students engage in. We suggest that the EQuIP Rubric is a useful tool for focusing designers' and teachers' attention on the role of phenomena as part of engaging in three-dimensional learning. As people read about or work with the EQuIP Rubric, there are often questions about why phenomena are included. If phenomena are so important, why were they not made one of the dimensions of the NRC *Framework*, like practices, disciplinary core ideas, and crosscutting concepts? Carrying out an EQuIP analysis forces designers or coders to consider not only the ideas (both disciplinary core ideas and crosscutting concepts) that are targeted in a material and the relevant practices, but also how students are going to build and use those ideas by engaging with particular phenomena to make sense of them or to solve a problem. This is not an additional dimension or criterion. What makes an idea an explanatory disciplinary core idea, and what makes doing science work a practice rather than a rote skill, is that the ideas are built from and applied to real world events to explain those events or to achieve a design goal. Rather than separately ticking off pieces of a disciplinary core idea or indicators of a practice, the EQuIP Rubric requires one to analyze the interaction of the idea and practice with the phenomenon. We suggest this is a key benefit of such an analysis, whether it is done in the context of designing new materials, selecting potential materials for use, or preparing to teach with particular materials.

Phenomena are important precisely for the same reasons that make this type of curriculum analysis challenging. First, describing the phenomena needs to occur in terms of what students will *notice* and *reason about* rather than what they will *do*. The phenomenon is not mixing baking soda and vinegar—that's the activity. The phenomenon students may notice and question is that when mixing baking soda and vinegar, bubbles appear in the liquid. Or they notice that a plastic bag expands. Or they notice that the bag expands, but the mass stays the same. These are all different aspects of the phenomenon, and it is critical to identify exactly which of the aspects of the phenomenon that

students could potentially observe are important and appropriate for them to explain. Second, the phenomenon is not the science idea. The phenomenon is not chemical reactions or open versus closed systems. In many cases, materials may push students to “explain an idea” such as “what is photosynthesis” versus explaining a phenomenon, such as where the additional mass comes from when a small seed grows into a tall tree. Too often students emerge from instruction being able to “explain” photosynthesis, that is, they can say what photosynthesis is and maybe even provide the equation, but they cannot explain the things in the world that the idea is actually relevant for explaining. So, for example, they cannot explain that all the mass in the tree had to come from somewhere, and it came from the carbon and oxygen in the carbon dioxide in the air, which the tree extracted and trapped in glucose in, yes, a chemical reaction called photosynthesis.

Doing the EQuIP analysis can uncover places in a material where a phenomenon is not present or cannot be explained with age-appropriate science ideas. In doing an EQuIP analysis we have to convince ourselves that students have the ammunition they need to make the inferences required, in terms of evidence about the phenomenon and prior ideas that can be essential steps in an argument. It is not unusual to analyze existing curriculum materials and find that, indeed, we do not give students the ammunition. The teacher knows why the phenomenon occurred, but the students only know because the teacher explained the idea before engaging with the phenomenon. But the students wouldn’t be able to explain the phenomena using the science ideas. If the goal in NGSS is to help students argue from evidence to build an understanding of the disciplinary core ideas, we need to be very careful that the phenomenon actually can provide the needed evidence to support the argument. Whether materials actually achieve this goal is revealed when applying the EQuIP I.A criterion (e.g., by judging whether a core idea is built and used by students through practices or is simply provided to the students by the teacher). It also is revealed in judgments using the I.B criterion, which deals with how the pieces of disciplinary core ideas are supposed to fit together across lessons.

Three Dimensions “Working Together” to Explain Phenomena or Solve Problems

A key goal of the EQuIP Rubric is to identify whether the three dimensions of NGSS are working together. In our experience, this is a major challenge for teachers new to EQuIP. Yet it is also a critical factor that can distinguish materials that are truly aligned to NGSS from ones that do not fully reflect three-dimensional learning. While this issue did not arise in the present analyses, in our experience it is not an infrequent failing in many currently available materials. Consider a lesson frequently done in classrooms in which students read about or are told about the theory of natural selection. They then are told to engage in a simulation in which they act as predators, and attempt to collect different colored discs (representing prey), which are randomly spread across colored backgrounds. Students are told to observe how colors that match the background were harder to pick out and survive more attempts at predation. Perhaps they simulate reproduction by increasing numbers of survivors with same-colored progeny. Students then use the idea of natural selection to explain the change in proportions of each color disc in the population over time.

Such a lesson certainly has some benefits, and it does provide the opportunity for students to experience an idea such as natural selection in a lesson. But does it reflect the three dimensions working together to explain phenomena? One could argue that students were engaged in the practice of “developing and using models” connected with the disciplinary core idea of natural selection and perhaps the crosscutting concept of stability and change. However, consider the degree to which these dimensions are really working together in the lesson. The EQuIP Rubric and NGSS expect students to be engaged in the practices to build and use the science ideas. Using ideas means explaining or solving problems with them. But what was there to explain in this example

lesson? The students were already given the idea that is in the disciplinary core idea, i.e., how natural selection occurs. Therefore, the result of their experiment was already known before it was conducted. The modeling lacked any clear explanatory question. The lesson definitely involved working with a simulation to mirror events in real phenomena, but there was no real goal of figuring out how and why the phenomenon occurs. There was no clear explanatory question that working through the model helped answer. Instead, it was just a chance for students to show what they had already learned. While still technically “using” the practice, this lesson does not use the practice to serve knowledge building, that is, by having students engage in a practice in which evidence from phenomena is used to develop, test, or refine core ideas.

The Student Perspective Versus the Disciplinary Perspective

Perhaps the most subtle nuance that emerged in attempting to use the EQuIP Rubric to analyze these case study materials concerned judgments about coherence. In our experience, traditional laboratory exercises or kit-based materials often fall short in meeting the criterion for coherence. While there may be a clear logic from the developer’s perspective as to how lessons fit together, it is often the case that the logic is not apparent to students. They are doing the activities in the lesson because they are simply following the instructions rather than seeing how the activities address a question or problem that has been identified. This approach is in tension with the meaning of science practices in NGSS and what distinguishes them from merely procedural skills. Truly engaging in three-dimensional learning means students are engaging in the practices to figure out something or solve a problem, and not simply because they were told to explain the patterns in a dataset or to model a process they are shown. Cultivating a question from the students’ perspective, even in materials where the logic is clear to teachers, emerged as an area for improvement in the analyses performed for this paper.

Summary

These three case studies have revealed both the promise and challenge of the EQuIP Rubric. It can be time-consuming to engage in these analyses, particularly if one’s goal is documenting all of the evidence in a curriculum material that does or does not support a particular criterion. However, we suggest that these criteria focus on useful and subtle aspects of curriculum materials and can help identify instances when materials are engaging learners in activities that are merely procedural rather than in actual science and engineering practices that are the means through which students develop and use the science ideas.

References

- Achieve, Inc. (2014). *Educators evaluating the quality of instructional products [EQuIP] rubric for lessons and units: Science*. [Version 2, Sept. 2014]. Retrieved from <http://www.nextgenscience.org/resources>
- American Association for the Advancement of Science. (1989). *Science for all Americans*. New York: Oxford University Press.
- American Association for the Advancement of Science. (1993). *Benchmarks for science literacy*. New York: Oxford University Press.
- American Association for the Advancement of Science. (2001, 2007). *Atlas of science literacy* (Vols. 1 & 2). Washington, DC: Author.
- American Association for the Advancement of Science (AAAS)/BSCS. (2015). *Toward high school biology*. Manuscript in preparation.
- Edelson, D. C. (2001). Learning-for-use: A framework for integrating content and process learning in the design of inquiry activities. *Journal of Research in Science Teaching*, 38(3), 355-385.
- Fortus, D., Sutherland, L. M., Reiser, B. J., & Krajcik, J. S. (in press). Assessing the role of curriculum coherence in student learning about energy. *Journal of Research in Science Teaching*.
- Fortus, D., & Krajcik, J. (2012). Curriculum coherence and learning progressions. In B. J. Fraser, C. McRobbie, & K. G. Tobin (Eds.), *International handbook of science education* (2nd ed., pp. 783-798). Dordrecht, The Netherlands: Springer Verlag.
- Herrmann-Abell, C.F., Flanagan, J.C., & Roseman, J.E. (2014, March/April). *Evaluating the promise of an intervention that helps students understand chemical reactions in living systems*. Paper presented at the National Association for Research in Science Teaching Annual International Conference, Pittsburgh, PA.
- Kesidou, S., & Roseman, J. E. (2002). How well do middle school science programs measure up? Findings from Project 2061's curriculum review study. *Journal of Research in Science Teaching*, 39(6), 522-549.
- Krajcik, J., McNeill, K. L., & Reiser, B. J. (2008). Learning-goals-driven design model: Developing curriculum materials that align with national standards and incorporate project-based pedagogy. *Science Education*, 92(1), 1-32.
- Krajcik, J., Reiser, B. J., Sutherland, L. M., & Fortus, D. (2013). *Investigating and questioning our world through science and technology* (IQWST) (2nd ed.). Greenwich, CT: Activate Learning.
- Levy-Nahum, T., Mamlok-Naaman, R., Hofstein A., & Krajcik, J. S. (2006). Developing a new teaching approach for the chemical bonding concept aligned with current scientific and pedagogical knowledge. *Science Education*, 90(4), 579-604.
- National Research Council. (1996). *National science education standards*. Washington, DC: National Academy Press.
- National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: National Academies Press.

- NGSS Lead States. (2013). *Next generation science standards: For states, by states*. Washington, DC: The National Academies Press.
- Osborne, J. F. (2014). Teaching scientific practices: Meeting the challenge of change. *Journal of Science Teacher Education*. doi: 10.1007/s10972-014-9384-1.
- Reiser, B. J. (2013). *What professional development strategies are needed for successful implementation of the Next Generation Science Standards?* Paper presented at the Invitational Research Symposium on Science Assessment, Washington, DC. Retrieved from <http://www.k12center.org/rsc/pdf/reiser.pdf>
- Reiser, B. J. (2014). *Designing coherent storylines aligned with NGSS for the K-12 classroom*. Paper presented at the Professional Development Institute of the National Science Education Leadership Association, Boston, MA. Retrieved from https://www.academia.edu/6884962/Designing_Coherent_Storylines_Aligned_with_NGSS_for_the_K-12_Classroom
- Roseman, J. E., Kesidou, S., & Stern, L. (1997). *Identifying curriculum materials for science literacy: A Project 2061 evaluation tool*. Paper presented at the National Research Council Colloquium "Using the *National Science Education Standards* to Guide the Evaluation, Selection, and Adaptation of Instructional Materials," Washington DC. Retrieved from <http://www.project2061.org/publications/articles/roseman/roseman2.htm>
- Roseman, J. E., Linn, M. C., & Koppal, M. (2008). Characterizing curriculum coherence. In Y. Kali, M. C. Linn, & J. E. Roseman, (Eds.), *Designing coherent science education*. New York: Teachers College Press.
- Roseman, J. E., Stern, L., & Koppal, M. (2010). A method for analyzing the coherence of biology textbooks: A study of its application to the topic of matter and energy transformations in four textbooks. *Journal of Research in Science Teaching*, 47(1), 47-70.
- Stern, L., & Ahlgren, A. (2002). Analysis of students' assessments in middle school curriculum materials: Aiming precisely at benchmarks and standards. *Journal of Research in Science Teaching*, 39(9), 889-910.
- Stern, L., & Roseman, J. E. (2004). Can middle school science textbooks help students learn important ideas? Findings from Project 2061's curriculum evaluation study: Life science. *Journal of Research in Science Teaching*, 41, 538-568.