Developing and Evaluating an Eighth Grade Curriculum Unit that Links Foundational Chemistry to Biological Growth:
Designing Professional Development to Support Teaching

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Abstract

AAAS and BSCS are collaborating to develop and study a curriculum unit that supports students' ability to explain a variety of biological processes such as growth in chemical terms. The unit provides conceptual coherence between chemical processes in nonliving and living systems through the core idea of atom rearrangement and conservation during chemical reactions, which is critical for understanding how growth occurs while conserving matter. Abundant evidence in the literature suggests that many middle school teachers lack adequate science preparation, but even teachers with excellent science content knowledge often lack pedagogical skills necessary to effectively use research-based curricular materials. Thus, we consider teacher support materials and professional development (PD) to be a critical component of this intervention. We will describe the design of teacher support materials and professional development to support teachers' implementation of the curriculum through developing their knowledge and skills in the areas of Content Coherence and Pedagogical Support for Student Learning. In the context of face-to-face and online interactions with the curriculum unit, teachers learn about science content, student ideas, and strategies for teaching the content and curriculum effectively. This paper reports on the iterative development of the suite of teacher support materials and PD, highlights of key features, findings of our Year 2 field test, and implications of those findings for future revisions.

Introduction

Student understanding in science. Evidence from large-scale student assessments makes it clear that U.S. students are not well prepared in science. For example, on the NAEP 2011 science assessment, only 32% of eighth grade students scored at or above the proficient level, whereas 35% performed below basic (National Center for Education Statistics, 2012). While these data show improvement from the 2009 science assessment data, there is still a significant number of students entering high school with below basic understanding of science. Furthermore, on the 2009 NAEP science assessment only 21% of 12th grade students reached proficient, and 40% performed below basic (National Center for Education Statistics, 2012), indicating that little more is learned during high school. Today's middle and high school students must be better prepared, whether to succeed in college-level science or just to participate productively in a society becoming increasingly reliant on scientific and technology literacy.

Although U.S. students are not performing well in any of the sciences, we are particularly concerned about students' low achievement on topics that are essential for further study of biology (e.g., Andersson, 1986; Mohan *et al.*, 2009). The National Research Council has called attention to the increased dependency of biology on chemistry, noting that this "trend will continue, as more and more biological phenomena are explained in fundamental chemical terms" (2003, p. 136). Anderson *et al.* (1990) claim that "students' difficulties in understanding biological processes are rooted in misunderstandings about concepts in the physical sciences, such as conservation of matter … and atomic molecular theory, [that] were not addressed in instruction" (p. 775). Similarly, we have found that student misconceptions related to these topics and biological growth are prevalent at the middle and high school levels (AAAS Project 2061, n.d.). Taken together, these findings suggest that there is a need for more-effective curriculum materials that can provide students with a foundation of chemistry knowledge on which to build new biology knowledge.

The teacher-curriculum relationship. Curriculum materials play a defining role in classrooms. Ball and Cohen state: "They are the stuff of lessons and units, of what teachers and students do … they are well positioned to influence teachers' work … they have 'reach' in the system" (1996, p. 6). But curriculum materials are often less influential than anticipated because developers do not consider the role that teachers play in enacting curriculum in the classroom. Teachers play an interpretive role in bringing curricula to life for their students—deciding which parts to select for instruction, or which parts to emphasize or deemphasize given teachers' own understandings and beliefs about what is best for their students. This interpretation may result in enactment of curricula that is very different from the developers' initial intentions (Ball & Cohen, 1996).

Remillard (2005) has described a "teacher-curriculum relationship" as being rooted in context, dependent upon both the teacher and curriculum, and related to other teacher practices. Ball and Cohen (1996) call for developers to acknowledge this relationship between teachers and curricula: "Curriculum materials could contribute to professional practice if they were created with closer attention to the processes of curricular enactment" (p. 7). In other words, curriculum development that attends to the teacher-curriculum relationship may result in curriculum that positively influences teacher practice and serves as a valuable intervention for improving student interest and achievement in science.

The Toward High School Biology Project. The Toward High School Biology Project is a three-year collaboration between AAAS Project 2061 and BSCS focused on the development and study of a middle school curriculum intervention that connects core chemistry and biology ideas in order to help students build a strong conceptual foundation for their study of biology in high school and beyond. The curriculum intervention consists of instructional materials for both students and teachers and a suite of hybrid (face-to-face and online) professional development materials. We have also developed a suite of measures to study student knowledge and skills, teacher knowledge and skills, and feasibility of using the curriculum as intended. The findings of these measures are used to improve the coherence and usability of the curriculum toward helping students to understand and apply chemistry ideas in explaining a range of biological contexts involving growth.

We value the essential role that teachers play in students' learning processes and have designed teacher materials and professional development to support this value. The teacher materials are designed to be highly educative in that they help science teachers develop their pedagogical content knowledge for science ideas and practices while deepening their own subject matter knowledge. The professional development is centered on the effective implementation of the curriculum materials, providing teachers opportunities to develop both knowledge and skills to create better learning opportunities for students using the curriculum.

We are currently in the final year of the project. In the first year, we pilot tested an initial version of the unit with a small number of schools (Herrmann Abell *et al*., 2012). Data from the pilot test was used to revise the unit in preparation for the field test in Year 2. This paper reports on the iterative development of the suite of teacher support materials and PD, focusing on the Year 2 suite, findings, and implications of those findings for future revisions.

This paper reports on the design and development of teacher support materials and professional development. Other papers in this set detail the selection of core ideas and practices (Roseman *et al.*, 2013), the design and development of the curriculum unit (Kruse *et al.*, 2013), measures of students' understanding and field study results (Herrmann Abell *et al.*, 2013), and measures of teachers' knowledge of the content and curriculum and field study results (Flanagan *et al.*, 2013). The Toward High School Biology Project is funded by a U.S. Department of Education IES Goal 2 Development and Innovation grant to develop and study the feasibility and usability of the curriculum and a suite of teacher support materials.

Methodology

Research-based design of teacher support. Our iterative, multifaceted development process carefully integrates design with current research findings, which is an approach that is well aligned with the theory on effective teacher learning.

Guiding the design and development of the teacher support materials is a theory of change positing that teacher support materials that improve (1) teachers' knowledge of the science content in the unit and their knowledge of students' ideas about the content and (2) teachers' knowledge of the unit itself, including its content storyline, its various pedagogical features, and the rationale for the specific phenomena and model-based reasoning activities will promote students' learning from the curriculum. Teachers who understand the underlying content, strategic function, and strategies for revealing and supporting student responses are better equipped to respond to events that occur in the classroom when teaching the curriculum. This view is supported by a growing literature base about educative materials and effective professional development.

In the teacher-curriculum relationship, teachers often play the role of learners. Teachers use their curricula to deepen their own content knowledge, for ideas on presenting information to students, or for assessment of student learning. Curriculum materials that explicitly address the teacher as learner have been described as "educative" (Ball & Cohen, 1996; Davis & Krajcik, 2005). Davis and Krajcik identified nine "heuristics" of educative science materials that articulate how science curricula may support teachers as they implement reform-based curriculum with their students. The heuristics focus on teachers' subject matter knowledge as well as teachers' pedagogical content knowledge, rationale for curricular design decisions, and supports to teachers to adapt the materials to respond to their own instructional contexts, including student learning needs. Most teachers are not familiar with educative curriculum materials and are not experienced at using them in a manner that allows them to take full advantage of these features (Ball & Cohen, 1996).

The effective implementation of curriculum materials is greatly enhanced by professional development. Research suggests that high-quality curriculum coupled with professional development focused on the implementation of the curriculum can have a significant impact on both teaching and learning (Krajcik *et al.*, 1994; Powell & Anderson, 2002; Taylor *et al.*, 2003, 2008). There is a growing consensus (Darling-Hammond, 1997; Cohen & Hill, 2001; Loucks-Horsley *et al.*, 2010; Wei *et al.*, 2009) that effective professional development should emphasis analysis-of-practice formats that

- treat content in teachers' curriculum as central and intertwined with pedagogy;
- enables teachers to see content and teaching issues embedded in real classroom contexts;
- focus on the tasks of teaching, assessment, observation, and reflection on student learning; and
- are guided by an articulated theory of teacher learning

This research underpinning our theory of change influenced the articulation of a set of teacher learning goals. The learning goals for teachers serve as the basis for the design of measures to assess teacher knowledge and practice described elsewhere (Flanagan *et al.*, 2013) and in the clarification of design principles guiding the suite of teacher support materials. Because the student materials are being designed to meet both Content Coherence and Instructional Support criteria from the AAAS Textbook Evaluation Criteria (Roseman *et al.*, 1997; Kesidou & Roseman, 2002; Roseman *et al.*, 2010), we are able to focus our attention on helping teachers to understand and use the materials rather than on helping teachers to compensate for them. Thus, the knowledge and skills fall under two broad categories: Content Coherence and Pedagogical Support for Student Learning. Broadly speaking, the Content Coherence category includes knowledge of the science ideas and practices within the content storyline and the ability to use the models to explain phenomena. The Pedagogical Support category includes knowledge of pedagogical features in the curriculum unit to find out students' ideas (including misconceptions) and ability to productively guide students' thinking and reasoning. Tables 1 and 2 outline the two categories of teacher knowledge and skills.

Table 1. Teacher knowledge and skills framework: Content coherence

Knowledge	Skills
• Knowledge of the **key ideas** about matter that are targeted in the unit (including their boundaries) and why the treatment of energy ideas is not included	• Describe the **content storyline** and the contribution each lesson is intended to make to it
• Knowledge of **commonly held student ideas** and how they might be manifest in student explanations of phenomena	• Describe the **phenomena** used in the unit to illustrate the general principles stated in the substance-level key ideas and explained by the atomic-molecular ideas
• Knowledge of the **phenomena** the unit uses to illustrate the ideas targeted or to illustrate the explanatory power of the ideas and why these particular phenomena were selected	• Use the **representations** employed in the unit (LEGO bricks, ball-and-stick models, structural formulas, molecular formulas) **to explain** the phenomena presented in the unit and other relevant phenomena that might come up in class discussions
• Knowledge of the **representations/models** included in the unit, why they were selected, and how they are expected to support student reasoning about and explanations of phenomena	• Describe incorrect explanations of phenomena that students might provide and the misconceptions these **incorrect explanations** might reflect
• Knowledge of the **science content storyline** for the unit, what each lesson contributes to it, and where students are expected to be after each lesson	

Table 2. Teacher knowledge and skills framework: Pedagogical support for student learning

Knowledge	Skills
• Knowledge of **student misconceptions** documented in the learning research literature and how they may be manifest in student explanations or questions • Knowledge of the features provided by the student and teacher materials to help teachers find out students' ideas and help them move towards a more scientifically correct understanding	• Determine if students are able to make the intended **observations of phenomena** and support claims with evidence • Determine if students are able to **use the representations/models** to reason about and **explain** the phenomena and support claims with evidence • Use class and small-group discussions to guide student reasoning about explanations of phenomena • Summarize **students' ideas** at the end of the lesson, citing responses to *Stop and Think* or *Summarize, Reflect, and Connect* • Determine if students are generalizing the **substance-level science ideas** from their experiences with phenomena and supporting claims with evidence • Determine if students are using the **atomic-molecular science ideas** to explain substance-level phenomena and supporting claims with evidence • Summarize the **progress** a sample of students have made in understanding and applying the science ideas (including misconceptions they still have) and supporting claims with evidence

We translated the Teacher Knowledge and Skills Framework into design principles that became the unifying features of the suite of teacher materials and professional development. These design principles that emerged from our goals on teacher learning include the following:

1. Knowledge of the unit storyline. The suite of teacher support materials helps teachers to see the big picture, the science content storyline of the unit. The science content storyline includes the science content ideas and the activities that are used to support their development.
2. Knowledge of content and practices. The suite of teacher support materials helps to deepen teachers' knowledge of science content and practices related to the unit.

3. Knowledge of pedagogical purposes. The suite of teacher support materials helps teachers to understand the design, intention, structure, and resources of each piece of the curriculum, especially phenomena, data, and models used in the lesson activities.
4. Knowledge of lesson storylines. The suite of teacher support materials helps teachers to understand the science content storyline (both ideas and activities) within each lesson.
5. Knowledge of teaching strategies that support making the storyline visible to students. The suite of teacher support materials helps teachers to develop teaching strategies that will enhance the implementation of the curriculum and the visibility of the science content storyline.
6. Knowledge of teaching strategies that encourage the development of student thinking. The suite of teacher support materials helps teachers learn to elicit, listen to, and respond effectively to student ideas in support of student learning.
7. Analytical stance to teaching. The suite of teacher support materials helps teachers take an analytical stance towards teachers' planning, teaching, use of curriculum materials, and assessment of student learning and learning needs.

Our rationale for design principles that primarily support teachers' knowledge (rather than skills) is that in the limited time we have for teacher PD and through the teacher support materials we can realistically do more to increase teachers' awareness than we can to develop skills. It is through the teaching of the unit and completion of strategic analytical tasks that we anticipate teachers will develop some skills necessary to teach the unit, though we realize that improvement of skills benefits from feedback and is often prompted through self-analysis and reflection.

The Year 2 Suite of Teacher Support Materials

We developed an integrated suite of teacher support materials consisting of

- an educative web-based digital teacher edition (TE),
- face-to-face professional development activities that occur before the teaching of the unit, and
- post-lesson analytical tasks that teachers complete while they are teaching the unit.

Together these materials constituted the coherent professional development program focused on enhancing teachers' abilities to help students construct meaningful understandings of the curriculum's learning goals while developing teachers' analytical stance toward the teaching and learning of science.

First, the educative digital teacher edition was developed using the Curriculum Customization Service (CCS) platform. CCS is a web-based system built using National Science Digital Library's (NSDL's) EduPak tools. CCS is designed to

- promote purposeful planning,
- guide teachers to make conceptually coherent customizations,
- support busy teachers to gradually integrate customizing into their normal planning practices, and
- enable teachers to share their customizations with their professional learning community

Since the Toward High School Biology project is a research and development project that seeks to evaluate the impacts of the curriculum on student learning with high fidelity of implementation, during the field test we did not use the customization features that CCS offers. We leveraged CCS's platform which allows for interactive, just-in-time, and purposeful planning to develop a teacher edition that includes the basic features outlined for the teacher support materials suite.

In an effort to support teachers' knowledge of the unit and lesson storylines, learning goals are the central organizing concept of the CCS-Toward High School Biology interface. Teachers can select a specific lesson-level learning goal and immediately see the curricular components that support the key concept(s) in the tabbed sections of the interface. The lesson-level components of the digital teacher edition are described in Table 3. The components map to the design principles described above.

Table 3. Digital teacher edition components

"Before You Teach" expandable menu
• Graphic organizer to cue teachers to where lesson fits in the chapter content storyline • Background content knowledge for chapter • Common student ideas/misconceptions for chapter • Lesson overview (e.g., key question, learning goal, outcomes and indicators of success, materials/advance prep, lesson outline that links activity synopses with science ideas)
"Instructional Support Materials" expandable menu
• Printable facilitation guides that include o Teacher questions/talk o Anticipated student responses (identifying any common student ideas) o Teacher follow-up questions o Embedded assessments • Copymasters used during the lesson • Video used during the lesson • Slide presentations (two formats—PPT and PDF) used during the lesson
"Embedded Assessments" expandable menu
• Printable "outcomes and indicators of success" charts by main learning goal for use during the lesson to monitor student progress • Printable charts containing features of ideal and problematic responses to the lesson key question and *Summarize, Reflect, and Connect* questions to diagnose student understanding from student discussions during the lesson or from work products following each lesson
"After You Teach" expandable menu
• Professional development tasks: survey link for post-lesson analytical tasks and reflections for the teacher

Second, we created face-to-face PD activities that occur before and during teaching the unit. The face-to-face PD occurred as a three-day orientation for teachers before (2 days) and during (1 day) teaching the unit. Third, the post-lesson analytical tasks and reflections bridge the digital teacher edition with the professional development and teacher assessment of knowledge of the curriculum. The face-to-face PD and lesson analysis tasks are described in more detail below.

While the digital TE and the PD incorporate all of the seven design principles, we prioritized teacher learning goals for the PD based on what teachers could reasonably achieve prior to actually teaching the unit and what was most critical to implementing the unit. The overarching objective was to develop the capacity to teach the unit using the student edition (SE) and digital teacher edition, with two primary goals being as follows:

1. Develop teachers' knowledge of the unit's content storyline and the rationale for focusing on a few key concepts rather than on broad superficial coverage of many (Design Principles 1–4)
2. Develop teachers' understanding of pedagogical strategies that attend to student thinking and learning (Design Principles 5–7)

The following examines how these goals were enacted in the professional development and supported in the teacher edition.

PD Goal 1: Develop teachers' knowledge of the unit's content storyline and the rationale for focusing on a few key concepts rather than on broad superficial coverage of many.

Toward Goal 1, face-to-face PD included opportunities for teachers to experience key activities with phenomena and models as learners and collaboratively analyze the curriculum materials for the visible content storyline. These PD strategies were intended to help teachers identify the science ideas that are developed with each activity, identify places where students may get confused, and help prepare teachers for making on-the-spot decisions about what student ideas to address or set aside in service of establishing the coherent content storyline.

Teachers first experienced the key activities with phenomena and models as learners. Just as their own students would later do, teachers constructed understanding by working collaboratively, engaging in scientific conversation, and learning by doing, reading, thinking, and writing. Teachers identified the science ideas developed in each activity by making their own claims, supported by evidence from the activities, and using logic and science ideas in their reasoning. Toward the end of the PD, teachers had opportunities to compare their understandings with the developers' claims-evidence-reasoning-assessment framework. It's also worthwhile to note that this immersion of teachers in both science and pedagogy of the curriculum has additional benefits in that it serves to 1) develop or refine teachers' own understandings of the science concepts and 2) model relevant, effective teaching strategies, giving them a better sense of what the teacher and student should be doing during the activity.

Teachers developed the visible content storyline for each chapter and for the unit through a process that produces a conceptual flow graphic (CFG) as shown in Figure 1.

Figure 1. Conceptual Flow Graphic for THSB unit

The process of developing a CFG includes the following:

1. Teachers individually read each lesson in a chapter of the student edition as homework before the PD.
2. Teachers individually determine and record (in a complete sentence) the science concept that is/are being developed in each lesson as homework before the PD. They are given time in the PD to refine their statement after experiencing the lessons as learners.
3. The group of teachers shares findings and negotiates to write a single-sentence concept for each lesson on a sticky note.
4. The group of teachers determines the big, overarching concept for the chapter and writes it on a sticky note.
5. Teachers use the lesson concept sticky notes and arrows to display the relationship among and between the concepts for each chapter and show the flow of the science content storyline. (Different arrows represent strong, weak, or no connections.)
6. The process is repeated for each chapter.
7. Arrows are used to display the relationship among and between concepts from chapter to chapter and from chapter to the unit central learning goal.

Toward Goal 1, the TE materials also included a variety of components to support teachers in situating themselves in the content storyline of the unit, chapter, and lesson during planning and teaching of the curriculum.

- At the unit level, the *Unit Overview* describes the overarching learning goal of the unit as it relates to the unit central questions and the core disciplinary ideas (NRC, 2012) developed in each chapter in service of the overarching unit learning goal. The *Unit Organizer* provides a visual that highlights how the unit science content storyline builds conceptually from chapter to chapter.
- At the chapter level, the *Chapter Overview* describes the concepts developed in that chapter and provides a short synopsis of what students will do and think about in each lesson. The *Chapter Organizer* provides a visual that highlights how the chapter science content storyline builds conceptually from lesson to lesson.
- At the lesson level, the *Lesson Overview* provides a two-page overview of the lesson, including an outline that explicitly links a short synopsis of what happens during each phase of a lesson to the ideal thinking that should emerge from that phase.
- *Background Content Knowledge* provides more advanced information on the science content, important observations students should make (and any observations teacher might emphasize/de-emphasize), and rationale for the chemical reaction. Tables 4a and 4b provide an example for the reaction between iron in steel wool and air.

Table 4a. Iron in steel wool and air (background)

Steel Wool (Iron) and Air

Steel wool is made mostly of the element iron (Fe). To prevent the iron from rusting, steel wool is coated with an oil-based coating that is removed with vinegar or heating. The rusting of iron is an electrochemical process that begins with the transfer of electrons from iron to oxygen and involves multiple acid-base and dehydration reactions. The rate of rust formation is affected by the presence of water and accelerated by other electrolytes. The products of rust formation depend on the amount of oxygen and water present (e.g., a greenish-blue FeO may form in oxygen-depleted conditions, an orange-brown Fe_2O_3 in oxygen-rich conditions). Iron metal is relatively unaffected by dry oxygen, but because water is both part of the reactants and the products, the following chemical equation is commonly used to represent the process:

$$\mathbf{4\,Fe\,(s) + 3\,O_2\,(g) \rightarrow 2\,Fe_2O_3\,(s)}$$

Given sufficient time, oxygen, and water, any iron sample will eventually convert completely to rust. The Fe_2O_3 rust product is a delicate and brittle orange-brown solid that breaks apart with the slightest touch. This change in texture often leads to misconceptions that rusting causes a decrease in mass, as opposed to the increase in mass caused by chemically combining iron and oxygen. As this happens, an increase in mass occurs from chemically combining iron and oxygen.

Since oxygen atoms have mass, rusted steel wool weighs more than the original steel wool. If the entire sample of steel wool rusted (which is accomplished more easily by burning steel wool) it would weigh 30% more than its original mass:

4 Fe (s) +	3 O_2 (g) →	2 Fe_2O_3 (s)
4 × 56 amu	3 × 32 amu	2 × 160 amu
224 amu	96 amu	320 amu

(amu stands for atomic mass units)

Table 4b. Iron in steel wool and air (intended observations and rationale)

Chapter 1

Intended observations: Students will observe rust products that form on steel wool. By carrying out the reaction in a flask sealed with a balloon, they will also have evidence that a gas in the flask is involved in the reaction (e.g., the balloon is pushed or inverted into the flask as the air pressure inside the flask decreases). Water plays an important role in this reaction, but is present at the beginning (from vinegar) and at the end (product of dehydration reactions, will condense in the sealed flask). Kids will make note of this, but try to focus students' observations on what happens to the steel wool and the balloon. In some instances, students have observed the greenish-blue FeO rather than the orange-brown Fe_2O_3 when the flask is sealed by the balloon. Upon removing the balloon and exposing the steel wool to more air, the orange-brown Fe_2O_3 appears.

Rationale for this reaction: In chapter 1, rusting provides an example of gaseous reactants yielding solid products. This is analogous to photosynthesis reactions that "fix" carbon dioxide from the air to form glucose for building plant materials.

Chapter 2

Intended observations: Students will observe that when the reaction is carried out in a sealed container, a gas is used (as evidence by the inverted balloon) and a new solid forms, but the measured mass does not change. When the container is opened, the measured mass will increase over time until all of the iron has reacted to form rust.

Rationale for this reaction: Rusting provides an example of gaseous reactants yielding solid products. In this reaction, the increase in measured mass that occurs when the container is opened is due to chemically combining iron and oxygen from the air. This challenges common misconceptions that matter is destroyed during rusting or that mass decreases when steel wool rusts. Thus, rusting may help support students in contemplating photosynthesis reactions that "fix" gaseous carbon dioxide in glucose monomers. Thus, carbon dioxide gas is the primary source of a plant's matter (and hence, mass).

PD Goal 2: Develop teachers' understanding of pedagogical strategies that attend to student thinking and learning.

In face-to-face PD, teachers were introduced to questioning strategies intended to help them reveal, support, and guide students' thinking and reasoning and to prepare them for responding productively to student difficulties and misconceptions. Teachers learned about purpose and key features for the three types of questions used in the SE and TE materials: questions to elicit, probe, and challenge student thinking. Teachers reviewed the SE and TE materials and found clear instances of each type of question and noted where used (phase) in the lesson. Teachers discussed how to elicit and probe student thinking in whole-class format with maximum student engagement. Teachers interviewed each other about content related to the unit in order to practice on-the-spot use of probe and challenge questions. Teachers also practiced crafting their own probe and challenge questions for a preselected sample of student responses from pilot study notebooks.

During face-to-face PD teachers were also introduced to **Lesson Analysis Tasks** and **Embedded Assessment Analysis Chart** tools used to support these tasks. The tasks and charts are intended to help teachers diagnose and reflect upon student learning revealed by a representative sample of student work in terms of indicators of success (e.g., use complete and accurate science ideas in their explanations) and indicators of difficulty (e.g., use common or incomplete ideas in their explanations) at the conclusion of key lessons in the unit. During PD teachers were introduced to the 14 scaffolded tasks. They had opportunities to practice using the tools to diagnose and reflect upon pre-selected student responses from pilot study notebooks and share their findings with the group. Teachers then completed these 14 scaffolded tasks during their implementation of the unit through survey links within the digital teacher edition. These post-lesson analytical tasks and reflections were intended to bridge the digital teacher edition with the professional development, as well as serve as a research measure of teachers' knowledge of the curriculum. Details regarding the lesson analysis tasks are provided in Table 5. Table 5 outlines the purpose of the tasks, preparation, and procedure for completing tasks.

Table 5. Lesson Analysis Tasks

<u>Purpose</u>: To monitor and assess the impact of these lessons on student learning, you will periodically analyze the thinking and learning of a subset of your students using analysis tools provided to you.

<u>Preparation for Lesson Analysis Tasks</u>

- Identify the target students.
  Before beginning your first lesson analysis task, identify 20 students whose work you will analyze across the unit. The selected students might all be from one section, but they should represent the range of students you teach in terms of ability, performance, and effort.
- Assign a number to each target student.
  - Make a list of target students and assign each a number from 1 to 20.
  - Use this list each time you fill out an embedded assessment analysis chart.
- For each lesson analysis task, you will look at how each of your 20 target students responded to one selected question in the curriculum.

<u>Directions for Doing the Lesson Analysis Tasks</u>

Step 1. Gather target student responses to the assigned lesson analysis question.

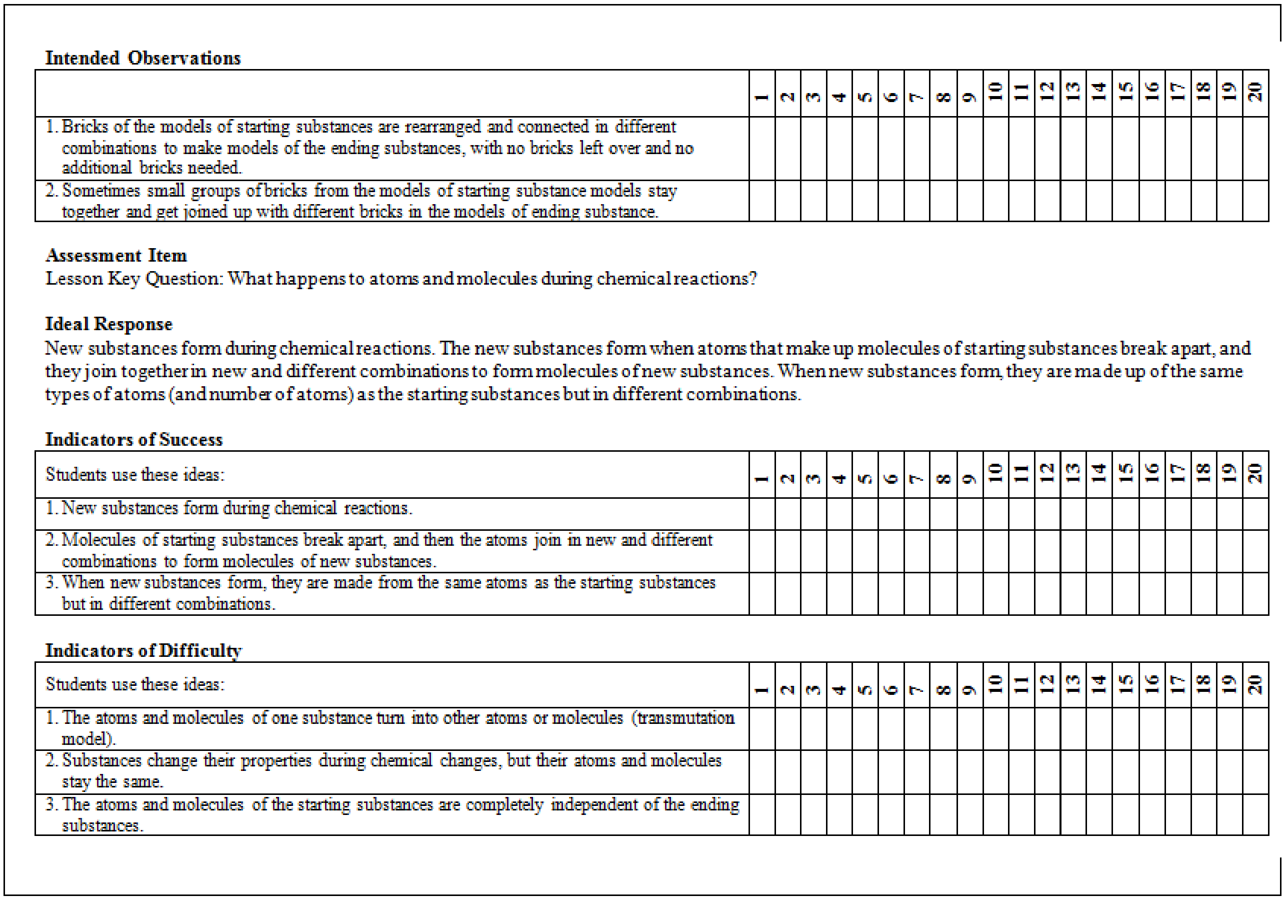
Step 2. Read the embedded assessment analysis chart for the assigned question. Read the ideal student response, the indicators of success (features of the ideal response), and indicators of difficulties (features consistent with common student ideas/incomplete ideas).

Step 3. Compare each of your target student's responses to the possible features of student responses on the embedded assessment analysis chart. Each column from 1 to 20 represents one of your target students. In each column place check marks to indicate all the features included in that particular student's response.

Step 4. Look at the pattern of check marks across the class and for each student. Write a reflection addressing the following questions:

1. What science ideas seem to be well understood by your students? Give specific evidence from the embedded assessment analysis chart or from your students' written responses that supports your assessment.
2. What science ideas might be causing some difficulty or confusion for students? Give specific evidence from the embedded assessment analysis chart or from your students' written responses that supports your assessment.
3. Optional: Are you unsure about where students are at this point? Do you have conflicting evidence from this analysis and other things you have observed in class? If so, please explain.

Teachers used provided embedded assessment analysis charts to analyze a small but representative set of target students' written responses for selected assessment tasks items. Using these analysis charts provides both diagnosis of an individual student's thinking at the end of a lesson, as well as a way to track the development of the individual's understanding over the course of the unit. The charts also provide a visual for quickly and easily identifying patterns in student thinking across the larger sample of students. These tools are intended to support teachers in developing analysis and reflection skills as described in the Pedagogical Support for Student Learning framework (Table 2). A blank embedded assessment analysis chart is provided in Figure 2 for the **Lesson Analysis Task #2 (Lesson 5)**: Analyze the target students' responses to the lesson key question (*Summarize, Reflect, and Connect* question 1, p. 40): What happens to atoms and molecules during chemical reactions?



Intended Observations

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1. Bricks of the models of starting substances are rearranged and connected in different combinations to make models of the ending substances, with no bricks left over and no additional bricks needed.																				
2. Sometimes small groups of bricks from the models of starting substance models stay together and get joined up with different bricks in the models of ending substance.																				

Assessment Item
Lesson Key Question: What happens to atoms and molecules during chemical reactions?

Ideal Response
New substances form during chemical reactions. The new substances form when atoms that make up molecules of starting substances break apart, and they join together in new and different combinations to form molecules of new substances. When new substances form, they are made up of the same types of atoms (and number of atoms) as the starting substances but in different combinations.

Indicators of Success

Students use these ideas:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1. New substances form during chemical reactions.																				
2. Molecules of starting substances break apart, and then the atoms join in new and different combinations to form molecules of new substances.																				
3. When new substances form, they are made from the same atoms as the starting substances but in different combinations.																				

Indicators of Difficulty

Students use these ideas:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1. The atoms and molecules of one substance turn into other atoms or molecules (transmutation model).																				
2. Substances change their properties during chemical changes, but their atoms and molecules stay the same.																				
3. The atoms and molecules of the starting substances are completely independent of the ending substances.																				

Figure 2. Embedded Assessment Analysis Chart

Toward Goal 2, the TE also provides other embedded resources to support teachers' ability to anticipate, diagnose, and respond to student difficulties and common ideas in their daily planning and teaching of the unit. The TE includes information about commonly held student ideas from research literature and data from previous AAAS assessment projects to alert teachers to the ideas students are likely to bring to the classroom. These and other common ideas noted in the pilot study are included in the *Student Misconceptions* document by chapter, as well as in lesson guides as "Anticipated Student Responses" to student edition questions. "Follow Up Questions" intended to reveal student thinking and guide student reasoning are linked to specific anticipated student responses, often those indicating incomplete ideas, misunderstandings, or use of fuzzy language.

The TE identifies a specific embedded assessment task in each lesson, strategies for its use, and indicators of success and difficulty for assessing student progress and difficulty. Usually these assessment tasks are identified from a short number of questions in the *Summarize, Reflect, and Connect* segment of a lesson that requires students to summarize the key idea(s) from the lesson, practice using the key idea in a new context, and/or link the idea to a previous, but often future, lesson (e.g., think about whether/how atom rearrangement might have something to do with the digestion of food).

Select Findings and Implications for Revisions for Year 3

A field test was conducted with a relatively small but diverse sample of eight teachers and their 677 students in the East Coast and in the West. The purpose of the field test was to understand whether the fundamental structure of the program was feasible to implement in a variety of ordinary classroom settings, to conduct preliminary tests of impact on student achievement and teacher learning, and to collect data to further inform revisions. The data sources and analyses included the following:

- **Quality of the student materials.** A subset of Project 2061's Textbook Evaluation Criteria were used to analyze the student materials. Findings of the analysis of coherence and content alignment to learning goals are described by Roseman *et al.* (2013).
- **Quality of the teacher materials and professional development.** A subset of Project 2061's Textbook Evaluation Criteria were used to analyze the coherence and quality of support for teacher learning that are provided by teacher materials (TE) and professional development (PD). A teacher pre-, mid-, posttest assessed teachers' knowledge needed to teach the unit across the subscales of content coherence and pedagogical support for student learning. The measure and findings are described by Flanagan *et al.* (2013).
- **Feasibility of use.** Teacher pacing logs, student work, and teacher online reports of their students' progress were used to find out what lessons and activities teachers are using and how much time it is taking them. Findings are summarized in Roseman *et al.* (2013). We also videotaped four lessons in one of each teacher's classes and analyzed them according to the criteria and accompanying indicators that best predicted student learning in AAAS' previous IERI study: Guiding student interpretation and reasoning (Wilson & Roseman, 2012).
- **Student pretests and posttests.** A multiple choice assessment was developed and piloted that aligned with the articulated learning goals, boundaries, and common and persistent misconceptions. The measure and findings are described by Herrmann Abell *et al.* (2013).
- **Student interviews.** A small number of students were interviewed during and after the unit to assess how consistent their performance on the student test is with their oral performance on interview questions.
- **Student classwork.** Students' written work is analyzed to determine what lessons and activities were actually completed and serve as an indicator of what students understand.

The remainder of the paper will illustrate how the various data sources and findings produced from these measures have informed the iterative development process of the teacher support materials in Year 3, including 1) the redesign of the suite of teacher support materials that addressed these findings, including a print teacher edition that better connected SE and TE; 2) a restructuring and expansion of online resources (instructional videos, online tutorials and how-to videos, and lesson analysis tasks); and 3) teacher professional development that included three days of face-to-face PD and a webinar, both of which have a significant focus on pedagogical support. The following provides more details regarding findings and how they were addressed in revisions of the suite of teacher support materials during Year 3.

Format and structure of the digital teacher edition

Analytics and teacher feedback regarding their use of the digital TE indicated that teacher use was limited primarily to accessing instructional media and for completing lesson analysis tasks. Teachers cited the following as areas for further improvement. Teachers generally found the format and organization of the digital TE too complex, with different components required for planning, teaching, and analyzing teaching layered in different expandable menus of the CCS online portal rather than all in one place. Even when printed, the format of the lesson guides did not closely resemble the format of the student edition, nor were they connected proximally to the student edition answer key (as a typical wrap-around version would provide, for example). Finally, the student edition answer key included a range of typical student responses (some accurate, some incomplete, some reflecting confusion or misconceptions), not just the ideal response, making it difficult for teachers to discern where they might reasonably expect students to be at a given point in the curriculum.

The revised teacher edition consists of 400+ pages of printed text (also available online) providing teachers with information about the unit and in support of the enactment of the unit at the unit, chapter, and lesson levels. The following are new to the TE:

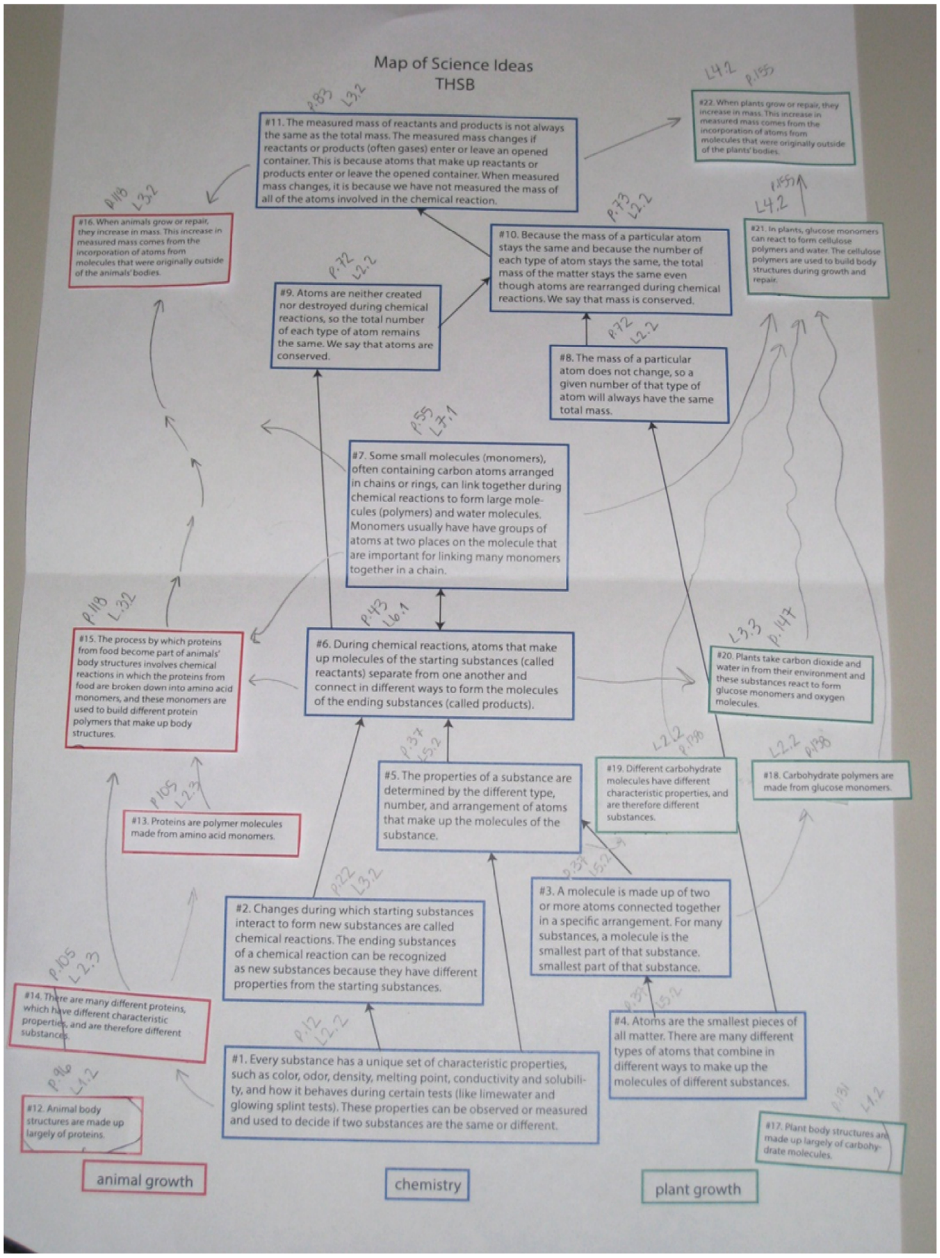
Each **Lesson Guide** now consists of facing (alternating) student edition answer key and teacher facilitation notes pages, providing a clear link between the student and teacher materials. Each student edition answer key page includes the student edition page plus the ideal student response we would expect from the "average" student at that point in the lesson. The teacher facilitation notes pages include *Teacher Talk and Actions*, strategies for facilitating each page of the student edition, including partner/small group work, prompts for whole-class discussion, science ideas to highlight and strengthen visibility of the content storyline, and science notes addressing issues for the teacher to be aware of. The teacher facilitation notes pages also include less-than-ideal *Anticipated Student Responses* (e.g., student responses that use "fuzzy" language, include misconceptions, or suggest other confusions) and *Possible Follow-Up Questions* the teacher can pose to clarify what students are trying to communicate or for moving students toward more-accurate ideas.

The teacher facilitation notes are not intended as a script, but provide the essence of the developers' intent for enactment of lessons, "typical" student responses, and reasonable ways for teachers to productively respond to student thinking and adjust the curriculum to their students and classroom situations in service of that intent.

Unit and Lesson Storylines

Asking teachers to individually identify the primary science concept for each lesson and chapter and then negotiate these concepts with the group requires them to take a more analytical stance in their review of the student materials, considering how ideas develop from activities and identifying places in which they might anticipate students will need additional support. However, during the Year 2 PD we acknowledged the tension that exists between wanting teachers to construct their understanding versus time constraints of the three-day PD. First, the process of teachers' constructing their understanding is inherently more successful when they can first experience lessons *in their entirety* just as their students will. Due to time constraints, teachers only experienced key activities from each chapter, and often these experiences significantly informed their identification of the lesson concepts. Teachers tended to neglect important contributions of the rest of each lesson that they had not experienced. Second, teachers bring with them their own experiences and ideas about how content should be sequenced and presented to students for many of the fundamental concepts of the unit. As teachers were negotiating the lesson concepts with the group, we observed teachers sometimes relying on their past experiences and ideas rather than on the materials themselves. PD leaders expended much time in challenging teachers to identify where their identified concept was developed (often they misinterpreted the pedagogical purpose of an activity or question) and then to examine particular activities and/or questions more carefully. Sometimes this involved additional time for the unanticipated modeling of activities and/or questions to better illustrate lesson concepts.

In Year 3, we took the stance that teachers would benefit more from opportunities to interact with the *intended* key lesson concept as well as the supporting science ideas developed in each lesson than with their constructed understandings. Rather than using the process outlined previously for creating the CFGs, we revised the process to focus on mapping the content storyline through preprinted cards containing lesson concepts and science ideas. After experiencing key activities from each lesson in a chapter as learners, the PD leaders highlighted other important activities and questions from segments of the lessons teachers had not experienced. Teachers were provided with preprinted cards, each containing a lesson concept. Teachers were asked to assign each concept card to a lesson in the sequence and then draw arrows to show connections and building of concepts between and among lessons. After completing this for each of the four chapters, teachers were provided with preprinted cards, each containing a science idea. Teachers were asked to create a sequenced map of the science ideas (in major subsets of chemistry, animal growth, and plant growth) presented in the unit and then draw arrows to show connections between and among science ideas. Figure 3 shows an example of such a map. In the map, the more basic and foundational concepts are at the bottom and the more complex ideas at the top. The hierarchical organization shows a clear building of ideas. By including the science ideas for chemistry, animal growth, and plant growth on the same map, teachers can more clearly visualize the foundational chemistry ideas and their contextualization for the living contexts.



Map of Science Ideas
THSB

#22. When plants grow or repair, they increase in mass. This increase in measured mass comes from the incorporation of atoms from molecules that were originally outside of the plants' bodies.

#11. The measured mass of reactants and products is not always the same as the total mass. The measured mass changes if reactants or products (often gases) enter or leave an opened container. This is because atoms that make up reactants or products enter or leave the opened container. When measured mass changes, it is because we have not measured the mass of all of the atoms involved in the chemical reaction.

#16. When animals grow or repair, they increase in mass. This increase in measured mass comes from the incorporation of atoms from molecules that were originally outside of the animals' bodies.

#10. Because the mass of a particular atom stays the same and because the number of each type of atom stays the same, the total mass of the matter stays the same even though atoms are rearranged during chemical reactions. We say that mass is conserved.

#21. In plants, glucose monomers can react to form cellulose polymers and water. The cellulose polymers are used to build body structures during growth and repair.

#9. Atoms are neither created nor destroyed during chemical reactions, so the total number of each type of atom remains the same. We say that atoms are conserved.

#8. The mass of a particular atom does not change, so a given number of that type of atom will always have the same total mass.

#7. Some small molecules (monomers), often containing carbon atoms arranged in chains or rings, can link together during chemical reactions to form large molecules (polymers) and water molecules. Monomers usually have have groups of atoms at two places on the molecule that are important for linking many monomers together in a chain.

#15. 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 different protein polymers that make up body structures.

#6. During chemical reactions, atoms that make up molecules of the starting substances (called reactants) separate from one another and connect in different ways to form the molecules of the ending substances (called products).

#20. Plants take carbon dioxide and water in from their environment and these substances react to form glucose monomers and oxygen molecules.

#5. The properties of a substance are determined by the different type, number, and arrangement of atoms that make up the molecules of the substance.

#19. Different carbohydrate molecules have different characteristic properties, and are therefore different substances.

#18. Carbohydrate polymers are made from glucose monomers.

#13. Proteins are polymer molecules made from amino acid monomers.

#2. Changes during which starting substances interact to form new substances are called chemical reactions. The ending substances of a chemical reaction can be recognized as new substances because they have different properties from the starting substances.

#3. A molecule is made up of two or more atoms connected together in a specific arrangement. For many substances, a molecule is the smallest part of that substance. smallest part of that substance.

#14. There are many different proteins, which have different characteristic properties, and are therefore different substances.

#1. Every substance has a unique set of characteristic properties, such as color, odor, density, melting point, conductivity and solubility, and how it behaves during certain tests (like limewater and glowing splint tests). These properties can be observed or measured and used to decide if two substances are the same or different.

#4. Atoms are the smallest pieces of all matter. There are many different types of atoms that combine in different ways to make up the molecules of different substances.

#12. Animal body structures are made up largely of proteins.

#17. Plant body structures are made up largely of carbohydrate molecules.

Figure 3. Map of Science Ideas

Pedagogical Purpose

Feasibility measures (e.g., teacher logs, student work, and classroom video) indicated that the unit was too long for the five-week timeframe allotted. Curriculum developers made suggestions as to activities that could be cut with minimal impact on the coherence of the content storyline. Furthermore, teachers made some additional cuts due to unforeseen time losses. Some teachers did not reach the end of the unit. One teacher did not reach the biology lessons, and two teachers did not reach the lessons on photosynthesis and plant growth. Our data suggest that teachers generally followed the curriculum script for the chemistry lessons. As it became clear that they would not complete the biochemistry lessons if they maintained the intended pace, teachers either kept that pace and didn't finish, or they rushed through making significant cuts. Some teachers' cuts did not preserve coherence, suggesting lack of awareness of or attention to the pedagogical purpose of activities (or other phases of a lesson) during planning and in-the-moment decision making.

At the lesson level, the **Lesson Guide** provides a two-page overview of the lesson, including the key question, target sciences ideas and practices, materials and advance preparation, and a summary chart describing key phenomena, data, and models used, intended observations, and their pedagogical purpose. The summary also provides rationale, including common ideas that are challenged, and other helpful notes to the teacher (e.g., (de)emphasize idea, accept certain ideas at this time). Table 3 provides a sample from *Lesson 6: Using Models to Represent Chemical Reactions*. The intent of the summary table is to provide teachers with stronger understanding of unit and lesson storylines and pedagogical purpose of specific tasks.

Table 3. Lesson Guide Summary Table for Lesson 6

Phenomena, Data, or Models	Intended Observations	Purpose	Rationale and/or Notes
Activity 1: LEGO models representing two chemical reactions: • Steel wool (iron) and air (oxygen gas) • Baking soda and vinegar	• Bricks of the models of starting substances are rearranged and connected in different combinations to make models of ending substances, with no bricks left over and no additional bricks needed. • Sometimes small groups of bricks from the models of starting substances stay together and get joined up with different bricks in the models of ending substances.	Students visualize rearrangement of atoms (and forecast conservation of atoms) of starting substances to account for new substances that form during chemical reactions.	The modeling activity challenges common ideas that atoms are created, destroyed, or turned into new atoms during chemical reactions. The modeling activity represents the stoichiometric (lowest whole number) relationships between reactant and product molecules, but it is not an explicit focus of the activity.
Activity 1: Space-filling models representing methane gas and oxygen gas and possible ending substances	• Starting substances (methane and oxygen molecules) are collectively made up of combinations of H, C, and/or O atoms. • Water, carbon dioxide, and carbon monoxide are collectively made up of combinations of H, C, and/or O atoms. Ammonia is made up of N and H atoms.	Students use accurate models of molecules to predict possible ending substances given the atom composition of starting substances.	The context challenges the misconception that atoms are not created, destroyed, or turned into new atoms during chemical reactions.
Pulling It Together: Descriptions of substance properties and LEGO-model images representing two changes involving the formation of gases: • Chemical reaction of hydrogen peroxide forming oxygen gas and water • Dissolution of carbon dioxide gas from carbonated water	• Description of substance properties suggest a new substance (a gas) is formed • LEGO models indicate atoms are rearranged when hydrogen peroxide forms oxygen gas and water (chemical reaction) • LEGO models indicate atoms are NOT rearranged when carbon dioxide gas leaves carbonated water (physical)	Students use accurate models of atoms and molecules of the starting and ending substances to decide that a chemical reaction has/has not occurred and justify their decision based on the ideas. An ideal explanation would include a) one or more differences formed/did not form using the same atoms as those that made up the starting substances and b) according to the definition of a chemical reaction, the formation/lack of formation of one or more molecules from the original atoms means that a chemical reaction did/did not occur.	The contexts challenge the misconception that gas formation during a change always is the result of a chemical reaction.

Supporting the Science Practices

Unlike traditional textbooks, the curriculum does not merely state the central concepts students should know and expect them to memorize them; rather, students develop their understanding of these concepts through observing and interpreting phenomena and data sets, reasoning about models that represent underlying molecular changes, and constructing and critiquing verbal and written explanations of the phenomena. This is likely a shift in some teaching and learning routines in traditional classrooms, and teachers need support in making these shifts.

Findings of the pre/posttests showed that students included more correct science ideas in their written explanations (Herrmann Abell *et al.*, 2013). However there was little improvement in the students' ability to construct scientific explanations. Few students included all parts of a scientific explanation; that is, they did not include a claim, evidence, and reasoning (McNeill & Krajcik, 2012). The measure of teacher knowledge indicated similar findings (Flanagan *et al.*, 2013). The Year 2 unit included four lessons dedicated to instructing students on how to construct and evaluate scientific explanations. However, feasibility measures indicate that these lessons were among the activities eliminated due to the time constraints, providing the most logical reason why both students and their teachers made little improvement in this practice.

Findings of the feasibility measures indicated that in general teachers were engaging students in the modeling activities. However, several teachers enacted the modeling tasks in Chapters 3 and 4 (with ball-and-stick models) almost exclusively as teacher-led demonstrations after a challenging experience with protein digestion (e.g., some students completely dismantled the protein model instead of breaking and making a few connections to make amino acids; other students could not accurately reconnect the amino acids to build the protein models for the next period). In informal conversations between classes and during planning periods, two teachers suggested that these kinds of tasks require more class time and more extensive scaffolding than was found in the SE.

For the Year 3 revisions to the student edition, we made the decision to cut some of the learning goals that were not as central to the overarching goal of growth and repair of living things (for example, building proteins in plants and building carbohydrates in animals) so that the explanation activities could be added back in. Additionally, instead of having only four formal explanation activities, the Year 3 version of the unit includes additional opportunities to practice constructing scientific explanations in 11 of the 20 lessons We also revised the student materials to increase the frequency that students engage in identifying monomeric units from ball-and-stick model images of polymer segments. And we increased the level of scaffolding when ball-and-stick physical models are used to ensure greater success in manipulating the models. For example, students were provided step-by-step routines for

- building large carbon-based molecules,
- contemplating manipulations with photographs of the models before conducting them with the physical models, and
- checking with the teacher for an "OK" to proceed with manipulating the models.

Revisions to the suite of teacher support materials also reflect the central role explanations and models serve in the Year 3 curriculum.

The online tutorials included in the Year 3 online resources provide teachers with additional support for apprenticing students in the science practices using models and constructing explanations. Each online tutorial consists of an animated PowerPoint presentation with narration converted to a 10–15 minute video. The tutorials include an introduction to the science practice, key features of the practice, examples from the curriculum illustrating how the practice is used, and strategies for supporting students in using the practice in THSB and beyond.

The online resources also include **how-to videos** that demonstrate and narrate activities as they are presented in the student edition. The intent of the how-to videos is to provide teachers with opportunities to observe phenomena and, especially, manipulations of models prior to their teaching in the classroom. This allows teachers to "watch" activities that were not included in face-to-face professional development and think through what their students will observe and do in the classroom and how they as teachers can best support students. Though it is not our preference, most of these videos may also be used as instructional media in classroom contexts where hands-on manipulation of models is challenging for the teacher to enact. As these videos can be projected, they are a better alternative to 28–32 students crowded around a teacher demonstration the modeling.

Furthermore, during face-to-face PD teachers spend 6–8 hours investigating modeling and explanations tasks. Teachers experience most of the modeling activities as learners. Then, for each chapter, teachers examine explanation tasks and scaffolding provided, then practice evaluating and/or constructing their own explanation for a specific task in partners or small groups. The webinar that occurs during teachers' implementation of the unit affords teachers with an addition opportunity to reflect on the quality of their own students' explanations using the criteria established in the curriculum (below):

- Claim should answer the question.
- Evidence should include all available evidence that is relevant to the claim.
- Scientifically accurate models can be cited as evidence for atomic molecular changes.
- The science ideas relevant to the claim must be stated and all of the available evidence must be consistent with these science ideas.

During the webinar, teachers use student work to identify progress and challenges associated with student-developed explanations and consider what additional support is needed for students moving forward.

Lesson Analysis Tasks

As developers, we intended that teachers would use the lesson analysis tasks and embedded assessment analysis charts to contemplate how they would productively respond to problematic student thinking and/or use student thinking as rationale for any adaptations made the next day and/or for future lessons. For example, if the teacher notes evidence of difficulty, she can look for evidence of the same difficulty in later, related lessons and plan questions or tasks to challenge the idea. Or if a teacher notes evidence that many students share the same difficulty, he may conclude that conducting an interactive lecture demonstration of a previous activity is warranted to ensure students are making the appropriate observations and, through his questions, guide students' reasoning. Unfortunately, we found that generally teachers did not use lesson analysis tasks as tools for informing instruction in the ways intended.

Findings from the lesson analysis task data and from teacher feedback indicated several areas for improvement with lesson analysis tasks. First, teachers generally found lesson analysis tasks time consuming given their frequency and other demands from the field test. Rather than complete a lesson analysis task immediately after teaching the lesson from which the task came, teachers tended to complete them over the weekend or complete all tasks associated with a chapter at the end of the chapter. Some teachers waited until the end of the unit to complete a majority of the lesson analysis tasks. This negated the use of lesson analysis tasks in informing instruction "the next day". In Year 3, we reduced the number of lesson analysis tasks from 14 to 4, selecting them from lessons in which key ideas (the concept central to the chapter) were developed and likely used again in next/future lessons.

Second, we also found teachers generally treated the lesson analysis tasks academically, completing them primarily as a tool to inform the research, not as a tool to help them uncover and attend to problematic student thinking in next/future lessons. In the Year 3 iteration of the teacher support materials, an additional reflection question has been added to provoke such reflection on plans for responding to student thinking in next/future lessons:

> Review the next lesson (and if possible, the next chapter). Where will the difficulties from this lesson cause problems later in the unit? Where and how in coming lessons will you challenge student difficulties or confusion that you observed in this lesson?

Teachers also used the analysis charts mechanistically: 1) looking very literally for students' use of specific phrasing and vocabulary rather than considering the ideas revealed in students' responses and 2) looking only for the ideas listed in the charts rather than treating charts flexibly and adding other pertinent ideas that emerged from students' writing. This finding was consistent with teachers' ability to recognize only 1–2 misconceptions on the teacher knowledge measure with no noticeable improvement after PD or after teaching the unit. We surmised that if teachers do not recognize misconceptions challenged in the unit, they will fill in the chart mechanistically. To better prepare teachers for completing and learning from these analyses, more explicit attention was paid to misconceptions in the face-to-face PD and in the TE. In the final iteration of the lesson analysis tasks, teachers are directed to use a 2-1-0 scoring system to reflect use, partial/incomplete use, or no use of ideas, rather than a system of check mark or no check mark. Teachers are also provided with customizable charts in a Word file and an additional suggestion has been added to further encourage flexible use:

> Students may use different words than those used in the features. Look for the *ideas* represented, not the specific words used. If students use ideas that are not listed in the indicators of difficulty table (e.g., misconceptions, confusions, "fuzzy" language), please add these to the table.

Conclusions

This paper reported on the iterative development process of a suite of teacher support materials (teacher edition and professional development) designed to support teachers' enactment of a research-based curriculum intervention. Here we described the Year 2 suite of teacher support materials and, specifically highlighted how it enacts its seven research-based design principles. We illustrated how findings from a variety of teacher and student data sources informed revisions in the final year of the project.

The project has broader impacts for the field of science education at a critical time. As science educators begin to incorporate the recommendations in the National Research Council's *Framework for K-12 Science Education* and to prepare for the final release of the *Next Generation Science Standards*, this curriculum intervention serves as one of few models in which teacher support materials have been created to support teachers in engaging students in important scientific practices and their application of crosscutting themes and in their understanding of core science ideas such as those identified in the NRC *Framework*. The knowledge and experiences developed and the findings from this project may help inform the design and study of curriculum, assessment, and professional development that is aligned to the goals expressed in these documents.

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