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Abstract The National Research Council's *Framework for K-12 Science Education* and the Next Generation Science Standards (NGSS Lead States in Next Generation Science Standards: For states, by states. The National Academies Press, Washington, 2013) move teaching away from covering many isolated facts to a focus on a smaller number of disciplinary core ideas (DCIs) and crosscutting concepts that can be used to explain phenomena and solve problems by engaging in science and engineering practices. The NGSS present standards as knowledge-in-use by expressing them as performance expectations (PEs) that integrate all three dimensions from the *Framework for K-12 Science Education*. This integration of core ideas, practices, and crosscutting concepts is referred to as three-dimensional learning (NRC in Division of Behavioral and Social Sciences and Education. The National Academies Press, Washington, 2014). PEs state what students can be assessed on at the end of grade level for K-5 and at the end of grade band for 6–8 and 9–12. PEs do not specify how instruction should be developed nor do they serve as objectives for individual lessons. To support students in developing proficiency in the PEs, the elements of the DCIs will need to be blended with various practices and crosscutting concepts. In this paper, we examine how to design instruction to support students in meeting a cluster or "bundle" of PEs and how to blend the three dimensions to develop lesson level PEs that can be used for guiding instruction. We

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provide a ten-step process and an example of that process that teachers and curriculum designers can use to design lessons that meet the intent of the Next Generation of Science Standards.

Keywords Framework for K-12 Science Education · Next Generation Science Standards · Performance expectations · Disciplinary core ideas · Science and engineering practices · Crosscutting concepts

Dimensions Working Together

The National Research Council's *Framework for K-12 Science Education* (NRC, 2012) put forth a new vision of science education where students engage in science and engineering practices to develop and use disciplinary core ideas (DCIs) and crosscutting concepts to explain phenomena and solve problems. These three dimensions work together to help students build an integrated understanding of a rich network of connected ideas. The more connections developed, the greater the ability of students to solve problems, make decisions, explain phenomena, and make sense of new information.

The *Framework for K-12 Science Education* serves as the foundation for the Next Generation Science Standards (NGSS Lead States, 2013). Together, the Framework and NGSS have fundamentally changed the focus of science education. In particular, they call for moving away from learning content and inquiry in isolation to building knowledge in use—building and applying science knowledge.

The Framework and NGSS move teaching away from coverage of many isolated facts to a focus on a smaller number of DCIs and crosscutting concepts that can be used to explain phenomena and solve problems by engaging in science and engineering practices. This integration of core ideas, practices, and crosscutting concepts is referred to as three-dimensional learning (NRC, 2014). DCIs are central to each science field as they provide explanatory power for a host of phenomena. As such, DCIs guide scientists and learners in observing, thinking, explaining phenomena, solving problems, and asking and finding answers to new questions. In chemistry, the core idea *matter and its interactions* explains the diversity of materials that exist. In biology, *evolution* serves to explain the diversity and relationship among all living organisms. Crosscutting concepts serve as intellectual tools for connecting important ideas across all science disciplines. For example, all scientists seek to find *patterns* in data and *cause and effect* relationships. Science and engineering practices are the multiple ways in which scientists and engineers describe the natural and designed worlds. The science and engineering practices build on what we know about inquiry to focus on students asking questions or refining problems, investigating and analyzing data, constructing models, and arguing based on evidence to build and refine explanations to understand the world. All three dimensions—DCIs, science and engineering practices and crosscutting concepts—serve as tools to build understanding. When the dimensions are blended and work together, like strands of a rope, learning is stronger.

Teachers and administrators must recognize that the NGSS call for a shift away from teaching facts, to students constructing explanations of phenomena (Reiser, 2013). By using science and engineering practices in conjunction with DCIs and crosscutting concepts, students build a rich network of connected ideas that serves as a conceptual tool for explaining phenomena, solving problems and making decisions. This network of ideas also serves as the framework for learners to acquire new ideas.

Building Standards from the Dimensions

For a long time, the science education community has talked about the importance of using inquiry in instruction to support students in learning content. But research shows that it actually works in both directions (NRC, 2007, 2012). If we want students to learn the content, they have to engage in the practice. But if we want students to learn the science and engineering practice, then they have to engage in content. Leave one out, and students will not develop proficiency in the other. If we want students to use content, problem-solve, think critically and make statements based on evidence, then we must have all three dimensions working together, linking practice with content. This is the new vision for science teaching and learning painted by the *Framework for K-12 Science Education*, solidly supported by education research.

To support this vision, the Framework committee recommended (Recommendation 5) that standards should be structured as performance expectations (PEs) that blend the three dimensions together in a manner that requires students to demonstrate knowledge in use (NRC, 2012). This structure is the foundation that forms the architecture of the NGSS. The NGSS writing committee used this architecture and blended together DCIs, science and engineering practices, and crosscutting concepts to form PEs. An example of a performance expectation (MS-PS1-5) from the middle school topic *Chemical Reactions* is the following:

> 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.

Notice that the performance expectation includes a science and engineering practice, *develop and use a model*, and an element of a disciplinary core idea, *the total number of atoms does not change in a chemical reaction and thus mass is conserved*. The crosscutting concept in this case is implicit but identified as *energy and matter*. Further articulation of the practice, element of the disciplinary core idea, and crosscutting concept can be found in foundations boxes associated with the performance expectation. However, to develop even further understanding of the three dimensions associated with a performance expectation, the Framework and appendices in the NGSS should be consulted and studied

MS-PS1-5 Matter and its Interactions		
Students who demonstrate understanding can: **MS-PS1-5. 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.** [Clarification Statement: Emphasis is on law of conservation of matter and on physical models or drawings, including digital forms, that represent atoms.] [*Assessment Boundary: Assessment does not include the use of atomic masses, balancing symbolic equations, or intermolecular forces.*]		
The performance expectation above was developed using the following elements from the NRC document *A Framework for K-12 Science Education*:		
Developing and Using Models Modeling in 6–8 builds on K–5 and progresses to developing, using and revising models to describe, test, and predict more abstract phenomena and design systems. • Develop a model to describe unobservable mechanisms. - - - - - - - - - - - - - - - - ***Connections to Nature of Science*** **Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena** • Laws are regularities or mathematical descriptions of natural phenomena.	**PS1.B: Chemical Reactions** • Substances react chemically in characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants. • The total number of each type of atom is conserved, and thus the mass does not change.	**Energy and Matter** • Matter is conserved because atoms are conserved in physical and chemical processes.

Performance expectations are not learning goals for instruction nor are they instructional strategies. As such, PEs do not dictate instruction. However, PEs do provide guidance for what students should learn in the classroom. PEs specify assessment for students in grade levels K-5 and in grade bands 6–8 (MS) and 9–12 (HS). In the example above, students would be assessed on developing and using a model to show conservation of mass in chemical reactions.

Wilson and Berenthal (2006) present a model that shows how standards drive student learning within an educational system. Figure 1 shows how standards guide selection and the development of curriculum materials, choice of instructional strategies, assessment development and teacher professional development. The more specification in a standard, the more guidance it provides. If standards are underspecified, then their guidance becomes unclear.

In addition to specifying student assessment, the PEs also provide guidance for teachers and curriculum developers on planning for instruction. In this paper we examine how NGSS PEs integrate all three dimensions from the *Framework for K-12 Science Education* and why PEs are important for *K-12* science learning. We then explore how to design instruction to support students in meeting a cluster or “bundle” of PEs and how to blend the various dimensions to develop lesson level PEs that can be used in teaching (NGSS Lead States, 2013). We end by discussing and providing an example of a ten-step process that teachers can use to design lessons that match the intent of the Next Generation of Science Standards.

The Value of Performance Expectations

The NGSS are expressed as “Performance Expectations” (PEs). PEs are statements that describe student proficiency in science—end of grade or grade band student outcomes for demonstrating their ability to apply the knowledge described in the DCIs. The PEs integrate all three dimensions, requiring demonstration of knowledge in use. As such, the NGSS PEs differ from standards as expressed in previous documents. Often standards were expressed as “students will know…” or “students will understand that…” But “know” and “understand” are vague terms.

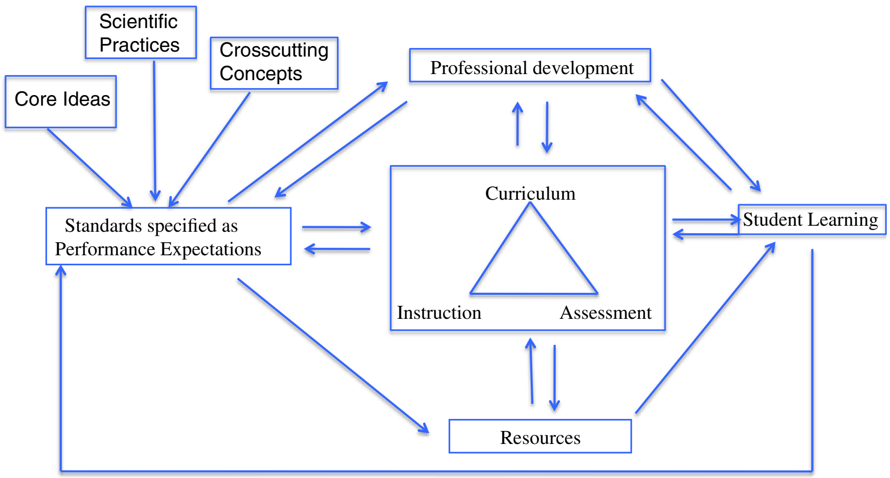

Fig. 1 Standards' impact on the educational system (Figure modified from Wilson & Berenthal (2006))

What does it mean to know or to understand? The PEs form standards by blending science and engineering practices, DCIs and crosscutting concepts; they clearly specify how students should make use of science content knowledge. The PEs call, not for memorizing isolated terms, but for focus on students applying ideas to explain phenomena, solve problems, and make decisions.

Let's examine how the three dimensions—DCIs, science and engineering practices, and crosscutting concepts—are blended together in the NGSS to develop PEs. Returning to our example above, MS PS1-5[1]—a middle school performance expectation in the *Chemical Reactions* topic states "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." Notice how only a portion or element of the DCI *PS1 Matter and Its Interactions* relates to the PE. This element is part of

> *PS1.B: Chemical Reactions* – Substances react chemically in characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants. The total number of each type of atom is conserved, and thus the mass does not change.

A full discussion of this DCI is included in the *Framework for K-12 Science Education*. This element of the DCI is blended with the practice element "*Develop a model to describe unobservable mechanisms*" and with the *Energy and Matter* crosscutting concept element "*Matter is conserved because atoms are conserved in physical and chemical processes.*"

[1] MS-PS1-5, refers to middle school, physical science Disciplinary Core Idea 1 (Matter and Its Interactions) and the fifth Performance Expectation associated with this DCI (MS-PS1-5 is one of 3 PEs in the Topic Chemical Reactions).

Table 1 Blending the dimensions to form performance expectations (MS-PS1-5)

Practice crossed with element of DCI and crosscutting concept gives performance expectations

Practice	DCI	Crosscutting concept	PE
Developing and using models	PS1.B: chemical reactions—substances react chemically in characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants. The total number of each type of atom is conserved, and thus the mass does not change	Energy and matter: matter is conserved because atoms are conserved in physical and chemical processes	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

Table 1 shows a graphic representation of how PE MS-PS1-5 was built from the three dimensions.

Designing Instruction to Build Understanding of Performance Expectation(s)

A standard expressed as a performance expectation specifies what students are expected to know and do for assessment purposes at the end of instruction. PEs provide guidance for designing instruction and curriculum materials. Teachers and curriculum designers need to plan instruction to provide learning opportunities for all students to meet the PEs. Developing the proficiency described in a PE, students will need to experience the DCIs through a number of science and engineering practices and crosscutting concepts. Similarly for students to gain proficiency in the use of science and engineering practices, they need to use the practices with a variety of DCIs and crosscutting concepts. In this way students will build useable, integrated understanding of the DCIs and crosscutting concepts and proficiency in using the practices. To ensure these experiences, we define "lesson level PEs" to guide instruction toward meeting the PEs as specified in NGSS. Teachers design lessons that call for students to meet the lesson level PEs using combinations of practices and DCIs beyond those specified in individual PEs.

Although one lesson will begin to help students build understanding, one lesson will not build the depth and integration of usable understanding required to achieve the performance expectation. In other words, we need to scaffold the development of understanding expressed in the PEs. The ideas expressed in a bundle of PEs (several related PEs) need to be carefully developed in multiple lessons over time. At Michigan State University, along with colleagues from the Michigan Department of Education, and members of Michigan's NGSS Lead State Internal Review Team (see section "Appendix" for a list of individuals contributing to the ideas described below), we have developed a ten-step process to guide teachers in developing a sequence of lessons to build student proficiency in a bundle of PEs. While the steps are listed in a linear fashion, in practice the lesson development process is much more iterative.

Step 1: Select PEs that work together—a bundle—to promote proficiency in using the ideas expressed. Often the bundle will include PEs from a single NGSS topic (see topic arrangement) or DCI (see DCI arrangement), but a bundle could draw in PEs from other topics or DCIs.
Step 2: Inspect the PEs, clarification statements, and assessment boundaries to identify implications for instruction.
Step 3: Examine DCI(s), science and engineering practices, and crosscutting concepts coded to the PEs to identify implications for instruction.
Step 4: Look closely at the DCI(s) and PE(s). What understandings need to be developed? What content ideas will students need to know? What must students be able to do? Take into consideration prior PEs that serve as the foundation for cluster of PEs the lessons will address.
Step 5: Identify science and engineering practices that support instruction of the core ideas. Develop a coherent sequence of learning tasks that blend together various science and engineering practices with the core ideas and crosscutting concepts.
Step 6: Develop lesson level PEs. Lesson level expectations guide lesson development to promote student learning; they build to the level of understanding intended in the bundle of PEs.
Step 7: Determine the acceptable evidence for assessing lesson level performances, both formative and summative.
Step 8: Select related Common Core Mathematics Standards (CCSS-M) and Common Core Literacy Standards (CCSS-L).
Step 9: Carefully construct a storyline to help learners build sophisticated ideas from prior ideas, using evidence that builds to the understanding described in the PEs. Describe how the ideas will unfold. What do students need to be introduced to first? How would the ideas and practices develop over time?
Step 10: Ask: How do the task(s)/lesson(s) help students move towards an understanding of the PE(s)?"

An Illustrated Example of the Process

We will look at an example for teachers and curriculum developers to illustrate this process. The example we have chosen comes from middle school and focuses on students developing understanding of chemical reactions.

Step 1: Select PEs that Work Together: A Bundle—to Promote Proficiency in Using the Ideas Expressed

First, carefully examine the PEs to see which ones fit together to allow students to explain some phenomena and develop a set or "bundle" of PEs. Think of a bundle as a cluster or related set of PEs that work together to support students in explaining phenomena. Use the NGSS website to search for related PEs. With our focus on developing understanding of chemical reactions in the middle school band, three related PEs that could create a coherent set include: MS-PS1-1 (Middle School, Physical Science, DCI 1, first performance expectation, in NGSS Topic Structure and Properties of Matter), MS-PS1-2 (Middle School, Physical Science, DCI 1, second performance expectation, in NGSS Topic Chemical Reactions), MS-PS1- 5, (Middle School, Physical Science, DCI 1, fifth performance expectation, in NGSS Topic Chemical Reactions). Table 2 presents these three PEs as listed in their NGSS Topic Arrangement pages.

MS.Structure and Properties of Matter	
Students who demonstrate understanding can:	
MS-PS1-1.	**Develop models to describe the atomic composition of simple molecules and extended structures.** [Clarification Statement: Emphasis is on developing models of molecules that vary in complexity. Examples of simple molecules could include ammonia and methanol. Examples of extended structures could include sodium chloride or diamonds. Examples of molecular-level models could include drawings, 3D ball and stick structures, or computer representations showing different molecules with different types of atoms.] [Assessment Boundary: Assessment does not include valence electrons and bonding energy, discussing the ionic nature of subunits of complex structures, or a complete depiction of all individual atoms in a complex molecule or extended structure.]

MS.Chemical Reactions	
Students who demonstrate understanding can:	
MS-PS1-2.	**Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred.** [Clarification Statement: Examples of reactions could include burning sugar or steel wool, fat reacting with sodium hydroxide, and mixing zinc with hydrogen chloride.] [Assessment Boundary: Assessment is limited to analysis of the following properties: density, melting point, boiling point, solubility, flammability, and odor.]
MS-PS1-5.	**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.** [Clarification Statement: Emphasis is on law of conservation of matter and on physical models or drawings, including digital forms, that represent atoms.] [Assessment Boundary: Assessment does not include the use of atomic masses, balancing symbolic equations, or intermolecular forces.]

Step 2: Inspect the Performance Expectations

Carefully read and study each selected PE to understand the intent of each. Examine the clarification statements and assessment boundaries written in the red letters following each PE. The clarification statement and assessment boundary will help guide the scope of our instruction. For example, MS-PS1-1 (see Table 2) states that students will be expected to develop models to describe the atomic composition of simple molecules and extended structures. The clarification statement provides further information to explain what this means for middle school students. The clarification statement for MS-PS-1 provides examples of various molecules that would be appropriate for students to develop at this level as well as the types of models students might build. The assessment boundary tells what is not assessable at this level for all students. At the middle school level students are not expected to know about valance electrons, bonding energy, or structure of complex molecules and ionic subunits.

Step 3: Examine the DCIs, Science and Engineering Practices, Crosscutting Concepts

The third step involves carefully examining DCIs, science and engineering practices, and crosscutting concepts associated with the selected PEs. Understanding the DCIs, science and engineering practices and crosscutting concepts is essential for developing instruction that proceeds coherently across time and allows students to develop explanatory accounts of phenomena. The foundation boxes help

Table 2 A bundle of performance expectations

MS-PS1-1. Develop models to describe the atomic composition of simple molecules and extended structures. [Clarification Statement: Emphasis is on developing models of molecules that vary in complexity. Examples of simple molecules could include ammonia and methanol. Examples of extended structures could include sodium chloride or diamonds. Examples of molecular-level models could include drawings, 3D ball and stick structures or computer representations showing different molecules with different types of atoms]. [Assessment Boundary: Assessment does not include valence electrons and bonding energy, discussing the ionic nature of subunits of complex structures, or a complete depiction of all individual atoms in a complex molecule or extended structure]
MS-PS1-2. Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred. [Clarification Statement: Examples of reactions could include burning sugar or steel wool, fat reacting with sodium hydroxide, and mixing zinc with HCl]. [Assessment Boundary: Assessment is limited to analysis of the following properties: density, melting point, boiling point, solubility, flammability, and odor]
MS-PS1-5. 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. [Clarification Statement: Emphasis is on law of conservation of matter, and on physical models or drawings, including digital forms that represent atoms]. [Assessment Boundary: Assessment does not include the use of atomic masses, balancing symbolic equations, or intermolecular forces]

Table 3 Elements of the DCI for MS-PS1-2

PS1.A: structure and properties of matter Each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) that can be used to identify it
PS1.B: chemical reactions Substances react chemically in characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants

to identify the element (or part) of the DCIs, practices, and crosscutting concepts associated with each PE. For example, the DCI elements associated with MS-PS1-2, include an element of PS1.A, The Structure and Properties of Matter, and PS1.B, Chemical Reactions. Table 3 identifies these elements.

In addition to examining the elements from the Foundation Boxes, examine the description of the DCI in the *Framework for K-12 Science Education* (NRC, 2012). In particular, look carefully at the grade band endpoints for PS1.A and PS1.B. Use NGSS Appendix E – Progressions within NGSS, to examine closely a summary of what students should know about the DCI by the end of the grade band. A portion of the grade band endpoint for middle school for PS1.A reads:

> All substances are made from some 100 different types of atoms, which combine with one another in various ways. Atoms form molecules that range in size from two to thousands of atoms. Pure substances are made from a single type of atom or molecule; each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) that can be used to identify it (NRC, 2012 p. 108).

For PS1.B the grade band endpoint for middle school states:

> Substances react chemically in characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different

> molecules, and these new substances have different properties from those of the reactants. The total number of each type of atom is conserved, and thus the mass does not change. Some chemical reactions release energy, others store energy (NRC, 2012 p. 111).

In a similar fashion the science or engineering practices and crosscutting concepts need to be examined. The foundation boxes associated with the PEs also help to clearly articulate what is expected of students. For instance, the practice associated with MS-PS1-2, Analyzing and Interpreting Data, is more clearly described in the foundation box. The foundation box states:

> Analyzing data in 6–8 builds on K–5 and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis. [The element related to MS-PS1-2 reads] Analyze and interpret data to determine similarities and differences in findings (NGSS Lead States, 2013, MS. Chemical Reactions).

The element of the practices specifies that students need to look for similarities and differences in the findings.

The crosscutting concept is typically implicit in the performance expectation. The crosscutting concept element for a given PE can be identified from the foundation box. The crosscutting concept element for MS-PS1-2 is:

> Patterns: Macroscopic patterns are related to the nature of microscopic and atomic-level structure (MS-PS1-2)

MS-PS1-2 Matter and its Interactions

Students who demonstrate understanding can:

MS-PS1-2. **Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred.** [Clarification Statement: Examples of reactions could include burning sugar or steel wool, fat reacting with sodium hydroxide, and mixing zinc with hydrogen chloride.] [*Assessment boundary: Assessment is limited to analysis of the following properties: density, melting point, boiling point, solubility, flammability, and odor.*]

The performance expectation above was developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Analyzing and Interpreting Data Analyzing data in 6–8 builds on K–5 and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis. • Analyze and interpret data to determine similarities and differences in findings. - - - - - - - - - - ***Connections to Nature of Science*** **Scientific Knowledge is Based on Empirical Evidence** • Science knowledge is based upon logical and conceptual connections between evidence and explanations.	**PS1.A: Structure and Properties of Matter** • Each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) that can be used to identify it. **PS1.B: Chemical Reactions** • Substances react chemically in characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants.	**Patterns** • Macroscopic patterns are related to the nature of microscopic and atomic-level structure.

Connections to other DCIs in this grade-band:
MS.PS3.D ; MS.LS1.C ; MS.ESS2.A

Articulation of DCIs across grade-bands:
5.PS1.B ; HS.PS1.B

Common Core State Standards Connections:
ELA/Literacy -

RST.6-8.1	Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.*(MS-PS1-2)*
RST.6-8.7	Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table). (MS-PS1-2)

Mathematics -

MP.2	Reason abstractly and quantitatively. (MS-PS1-2)
6.RP.A.3	Use ratio and rate reasoning to solve real-world and mathematical problems. *(MS-PS1-2)*
6.SP.B.4	Display numerical data in plots on a number line, including dot plots, histograms, and box plots. *(MS-PS1-2)*
6.SP.B.5	Summarize numerical data sets in relation to their context. (MS-PS1-2)

Step 4: Look Closely at the DCIs

The fourth step requires an even closer examination of the DCI(s) and PE(s) to determine what student understandings need to be developed. This step requires an "unpacking" of the ideas in each of the PEs. This step takes into consideration prior PEs that serve as the foundation for the current PEs. Think of unpacking as a process of determining which ideas are critical for the learner. Unpacking involves breaking apart and expanding the various concepts to elaborate the various content statements (Krajcik, McNeill, & Reiser, 2008). MS-PS1-2 requires that students understand properties of substances and that matter is made up of atoms. The ideas of properties and atoms are both developed from 5th grade PEs on the Structure and Properties of Matter: 5-PS1-1. *Develop a model to describe that matter is made of particles too small to be seen*, and 5-PS1-3. *Make observations and measurements to identify materials based on their properties*. Part of the instructional process would be to assess whether students understand what is expected in these PEs and to help those who have not yet developed an understanding of this content to do so. The unpacking process also requires a careful examination of Appendix E, Progressions within NGSS, to identify other prior ideas students might need. Appendix E identifies that students should develop the following understanding by the end of 5th grade for PS1.A Properties and Structure of Matter:

> Matter exists as particles that are always conserved even if they are too small to see. Measurements of a variety of observable properties can be used to identify particular substances (NGSS Lead States, 2013, p. 7).

For students entering middle school, we would expect the science teacher to build from this level of understanding of the ideas. Using various forms of assessment, the teacher needs to assess students' level of understanding and, if not attained, support students in developing these foundational ideas before engaging students in more advanced ideas. For understanding chemical reactions in middle school, determine if students understand particles and properties, which are ideas referred to in various PEs in the fifth grade. It is critical to ask, "What prior knowledge and experiences about the DCIs and scientific practices did students develop in previous grade levels?" (See progressions of DCIs, practices, and crosscutting concepts in NGSS Appendices E, F, and G.)

Step 5: Select Additional Science and Engineering Practices

In this step, determine which of the practices work best with the elements of DCI and crosscutting concepts. To support students in building proficiency in the bundle of PEs, and in the components in the PEs, the elements of the DCI need to be blended with various science and engineering practices. This will ensure that students develop deep understandings of the elements as well as build proficiency in all the practices. However, not all the practices will necessarily work with all of the DCIs. In selecting the various practices, refer to Appendix F, Science and Engineering Practices in NGSS.

For our chemical reactions example, in addition to *Developing and Using Models* and *Analyzing and Interpreting Data*, practices coded to the bundled PEs, three additional practices might work well to scaffold instruction to the selected PEs:

1. Planning and Carrying Out Investigations: "Plan an investigation individually and collaboratively, and in the design: identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how much data are needed to support a claim" (NGSS Lead States, 2013, Appendix F, p. 7).
2. Construct Explanations and Design Solutions: "Construct a scientific explanation based on valid and reliable evidence obtained from sources (including the students' own experiments) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future" (NGSS Lead States, 2013, Appendix F, p. 11).
3. Engage in Argument from Evidence: "Construct, use, and/or present an oral and written argument supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon or a solution to a problem" (NGSS Lead States, 2013, Appendix F, p. 13).

In selecting the practices, it is also critical to understand the various aspects involved. For instance, constructing an argument involves stating a claim and providing evidence and reasoning to support that position (McNeill & Krajcik, 2012).

Step 6: Develop Lesson Level Performance Expectations

Lesson level PEs guide lesson development to promote student learning. Lesson level performances (written as knowledge in use statements) are similar to PEs in the standards in that they blend core ideas, practices, and crosscutting concepts, but at a smaller grain size. They will support teachers in designing lessons and assessments. For instance, in unpacking MS-PS1-2—*Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred* – and in the associated element of the DCI:

> PS1.A – *Structure and Properties of Matter: Each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) that can be used to identify it* – it is critical that students understand that characteristic properties identify a substance before they can develop proficiency in MS-PS1-1.

As such, we would want to develop a sequence of lessons focusing on this idea blended with various practices and crosscutting concepts. We could create a lesson level performance expectation by blending together the practice of engaging in argument from evidence with the PS1.A element we are addressing. The crosscutting concept would again be assumed. We could, for instance, focus on Patterns: Macroscopic patterns are related to the nature of microscopic and atomic-level structure. (MS-PS1-2). The lesson would help build towards this practice.

Table 4 shows the lesson level performance expectation resulting from blending the various elements together.

This lesson level performance expectation will guide lesson and assessment development. The expectation calls for students to engage in constructing an argument using evidence that pure substances have characteristic properties. This might involve students measuring properties of substances such as boiling point and density. The blending of practices, the DCI element and the crosscutting concept is important at the lesson level and will support students in developing knowledge in use that can be used to explain phenomena and solve problems. In meeting NGSS PEs, several related lesson level expectations must be developed.

Step 7: Determine the Acceptable Evidence for Assessing Lesson Level Performances

Step 7 involves determining acceptable evidence that students have met lesson level performances (Shin, Steven, & Krajcik, 2011). This is a critical step as it allows teachers to monitor students' developing understanding. For instance, for the lesson level performance expectation: *Construct an argument that pure substances have characteristic properties*, we would expect students to write a claim regarding which samples are the same substances and provide at least two forms of evidence supporting this claim (the density and melting point are the same) and reasoning (that if two samples were the same substance, they would have the same properties). Once we specified the evidence, we could design assessments that would elicit evidence of meeting the lesson level learning performances, for example as illustrated in Table 5.

Joe wasn't sure if the any of the materials described in the data table below were the same substance. He was confused because two samples had the same mass, but different melting points. Some of the other samples had the same density but different mass. Using the data below, write an argument supporting an explanation of whether any of the samples are the same substance.

In responding to this assessment item, students would need to make the claim that samples 2 and 4 are the same materials because they have the same density and melting points. Density and melting point are properties that don't change with the amount of sample. That the masses of the two samples are different does not matter. Samples 2 and 3 are not the same materials even though samples have the same mass. Mass is not a characteristic that can be used in an argument to identify materials that are the same.

Step 8: Select Related Common Core Mathematics Standards (CCSS-M) and Common Core Literacy Standards (CCSS-L)

The NGSS identifies CCSS-M and CCSS-L that align with various PEs. Related CCSS-M and CCSS-L are found in the connections boxes just below the foundation/

Table 4 Creating lesson level performance expectations

Practice crossed with element of DCI and crosscutting concept gives lesson level performance expectations

Practice	DCI	Crosscutting concept	Lesson level expectation
Argument from evidence	Each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) that can be used to identify it	Patterns	Construct an argument that pure substances have characteristic properties

dimensions boxes. The Common Core Literacy Standards that align with MS-PS1-2 include:

- RST.6-8.1 Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.
- RST.6-8.7 Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table).

The Common Core Mathematics Standards that align with MS-PS1-2 include:

- MP.2 Reason abstractly and quantitatively.
- 6.RP.A.3 Use ratio and rate reasoning to solve real-world and mathematical problems.
- 6.SP.B.4 Display numerical data in plots on a number line, including dot plots, histograms, and box plots.
- 6.SP.B.5 Summarize numerical data sets in relation to their context.

Develop lesson level expectations and performance tasks, and select resources that scaffold learning to meet the PEs, while applying and reinforcing literacy and mathematics standards.

Step 9: Carefully Construct a Storyline

The storyline should show how the DCIs, science and engineering practices, and crosscutting concepts develop overtime. It should also show how learners build sophisticated ideas from prior ideas, using evidence that builds to the understanding described in the PEs as students engage in the practices to explain phenomena. Here we present one possible storyline that shows how student understanding could develop over time to reach the level of proficiency expected in the bundle of PEs discussed above (MS-PS1-1, MS-PS1-2 and MS-PS1-5).

Instruction should begin with students exploring the questions: How can we identify a substance? How can we distinguish one substance from another? Answering these questions engages students in developing an explanation. Students need to apply ideas that substances have characteristic properties that distinguish

Table 5 Example of assessment of the lesson level performance

Sample	Density (g/ml)	Color	Mass (g)	Melting point (°C)
1	1.0	Clear	8.2	0.0
2	0.89	Clear	4.2	38
3	0.93	Clear	4.2	14
4	0.89	Clear	12.6	38

them from other substances, and that properties characteristic of a substance are independent of the sample size (i.e., density, boiling point, melting point). Understanding and explaining answers to these questions is critical for students to answer the later question "What happens to materials when they undergo a chemical reaction?" Here students will need to build an explanation that the properties of new substances (the products) differ from the properties of the initial substances (reactants). To do so, students conduct investigations to collect data on the properties of substances before and after they interact, and analyze data to determine the properties of materials before and after the interaction has occurred. Investigations might start with the macroscopic level that students can measure and observe and then move to a molecular level that students cannot see but can use to develop and use models to explain the phenomena they observe. In exploring these ideas, the crosscutting concept of patterns is called out as an organizing concept necessary to identify trends in the data. Students use the science practices of analyzing and interpreting data and building explanations to demonstrate understanding of the DCIs in the PEs [specifically, MS-PS1-2].

By exploring the properties of materials and learning how properties change when materials interact at the macroscopic level, students begin asking questions such as: Why do substances have characteristic properties? And, why do new substances (products) have different properties than reactants in chemical reactions? To answer the first question, students build models that show that substances are composed of molecules and that molecules of the same substance have the same chemical composition (i.e., made up of the same type and number of atoms) and structure [MS-PS1-1]. They learn that it is the same chemical composition and structure that gives a substance its characteristic properties. This leads to questions related to what happens at the molecular level when materials react chemically. Here students build models to provide a causal account showing that the atoms that make up the molecules in the reacting materials rearrange to form new molecules with different compositions. This causal account needs to show that while the composition of molecules of the starting materials is different from the composition of molecules of the products, the type of atoms that make up the initial molecules and the number of atoms does not change. This leads students to an explanation of why the mass in a chemical reaction is always conserved – the number and types of atoms are the same in the reactants as they are in the products [MS-PS1-5]. The crosscutting concepts of energy and matter; cause and effect; scale, proportion and quantity; and patterns are essential in answering these questions and building understanding. As they progress through the lessons developed to address this bundle of PEs, students build proficiency in developing and using models to show causal accounts and in analyzing and interpreting data.

Step 10: Ask: How Do the Tasks/Lessons Help Students Move Towards an Understanding of the PE(s)?"

At the end of the lesson development, it is critical to go back and re-examine the tasks and lessons we have designed to confirm that they help to move students towards an understanding of the PEs we have bundled together. This question will best be answered based on observations and monitoring students in the classroom; however, it is critical to check our unpacking, development of lesson level expectations, and resulting tasks and lessons.

Reflections on the Ten-Step Process

Here we reflect on some of the decisions we used in developing the process to design lessons aligned with NGSS. We acknowledge that others will develop additional strategies for developing lessons to meet PEs and that our ten-step process represents one possible avenue for constructing lessons aligned with the intent of NGSS. Our primary recommendation is to build a series of lessons that focus on a bundle or cluster of closely related PEs. We do not recommend developing lessons that focus only on one performance expectation. Focusing on a bundle helps students see connections among the elements of DCIs and the various scientific and engineering practices that would not be seen by focusing on one performance expectation at a time. Focusing on one performance expectation could contribute to learners developing compartmentalized understanding that the *Framework for K-12 Science Education* was trying to avoid. Building useable, integrated understanding of the DCIs and crosscutting concepts by engaging in scientific and engineering practices requires a much richer set of experiences than can be accomplished in one lesson. Building understanding of the core idea(s) described in the performance expectation will require working with other scientific and engineering practices and crosscutting concepts than those contained in the performance expectation. Similarly, developing useable understanding of practices will require that students engage in other core ideas. This point is echoed in the National Research Council report, *Developing Assessments for the Next Generation Science Standards* (2014), which states that instruction will need to use multiple practices to support students in developing a particular core idea and will need to apply each practice in the context of multiple core ideas.

One place to start with the bundling/clustering of PEs is with the topic organization of the NGSS PEs. This approach is consistent with the work of the NGSS writers. The NGSS writers began by eliminating redundant statements across the DCIs, finding natural connections among the DCIs, and developing PEs across the grades that correspond to this smaller, tighter set of ideas. The resulting performances fit well into a topic clustering that aligns with the DCI arrangement in the Framework. In addition to topic or DCI clustering/bundling, selecting PEs from various topics would provide a more interdisciplinary arrangement.

We have not yet conducted a systematic testing of this ten-step process to evaluate its effective use by teachers or to determine if the process results in lessons that increase student learning of the PEs. Teacher leaders, however, from throughout Michigan used this process to develop a variety of skeletal lessons as part of a day-long workshop to introduce the NGSS. See http://create4stem.msu.edu/ngss/intro for some example lessons. We acknowledge that the teachers who used the process represent a select group familiar with the NGSS. As such, showing that the process is usable by a much wider range of teachers and examining whether the resulting lessons help students meet the PEs based upon various external measures would be of value. We are only at the first stage of a research-based design approach for developing a process for constructing a valid and workable method for designing materials that align with NGSS. We need to examine how teachers make use of the process to develop lessons and investigate whether teachers and students can use the materials and learn from them. Some additional work with teachers indicates that the process is much more iterative than linear. With careful analysis of our observations, we will modify the process and test it again. It is through the use of this iterative design process that we will develop at least one valid and workable process for developing lessons that support students in building understanding of a cluster/bundle of PEs.

Finally, we recognize the importance of teacher education, both inservice and preservice, to support teachers in learning the vision proposed by the *Framework for K-12 Science Education* and the NGSS PEs, and how to plan for instruction that builds to the level of the PEs. The Framework and NGSS present a new vision based on research (NRC, 2006, 2012) for conceptualizing standards, one that is needed to help our students develop understanding that can be use to solve problems, propose explanations of phenomena, and learn more. We encourage the use of the materials in inservice professional development as well as in preservice experiences. We are designing a series of workshops and corresponding materials that facilitators can use to introduce teachers to NGSS and to the ten-step process. These materials are available at http://create4stem.msu.edu/ngss. We invite others to use the materials and help in the modification and development of a process that supports teachers in constructing materials that support students in building understanding of the NGSS.

Conclusions

The NGSS require that teachers move away from simply presenting information to supporting students building explanations of phenomena and proposing solutions to problems. This requires that students develop explanatory models, shows chains of reasoning that provide explanations, and use evidence to justify their ideas. In doing so, students demonstrate knowledge in use by using DCIs with science and engineering practices and crosscutting concepts. The PEs in the NGSS present only the performances on which students can be assessed at the end of a grade level for K – 5 and end of grade band for middle school and high school. To support students in developing proficiency in the PEs, the elements of the DCI will need to be blended with various practices and crosscutting concepts. In this paper, we proposed one strategy for supporting teachers and curriculum developers through a ten-step process for developing a series of lessons that focus on a related set or bundle of PEs, and integrated lesson level PEs and assessments. Determining the quality of this process will depend on studying the process carefully through systematic implementation and data collection.

Building core ideas, scientific and engineering practices, and crosscutting concepts across time will support the development of scientific dispositions so that students know when and how to seek and build knowledge. A scientific disposition will arm students with the intellectual tools to ask questions such as "Hmm, what do I need to know?" "I wonder if…" "How can I explain…" and "Do I have enough evidence to support my ideas?" To help ensure that the intent of the NGSS and the Framework are enacted in the classroom, we need curriculum materials and professional development to support teachers, and we need research that extends over time to determine their effectiveness. We have much work in front of us, but like the vista we see when we climb a tall mountain, our efforts will be worth it.

Appendix

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