PS1 LEARNING MAP MODEL NEIGHBORHOOD RESEARCH NARRATIVES

Innovations in Science Map, Assessment, and Report Technologies

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Physical Science 1 Essential Elements

The DLM® Science Essential Elements for PS1.A Structure and Properties of Matter (Table 1) provide a grade 3-12 progression for what students with the most significant cognitive disabilities should know and be able to do.

Grades 3-5

In elementary school, students examine the effects of physical changes (e.g., cutting, grinding, melting) on weight. Elementary students also measure and observe characteristic properties of materials (e.g., weight for size, response to a magnet, ability to conduct heat or electricity, ability to dissolve in water, etc.). Elementary students use skills of comparing, measuring, and observing to explore conservation of weight and material identity.

Grades 6-8

The middle school Essential Elements build on the skills developed in Grades 3-5. Middle school students analyze and interpret differences in substance properties. Knowledge of properties is expanded to include more complex properties (e.g., density, boiling point). Middle school students use skills of analysis and interpretation of data to examine familiar chemical changes, such as burning and rusting.

Grades 9-12

The high school Essential Elements build on middle school content. In high school, students explain change using patterns of characteristic properties and the range of properties is expanded to include chemical properties (e.g., dissolving and exemplary reactions). High school students develop explanations, using a model of matter to explain observed chemical phenomena.

Table 1: Essential Elements for PS1 - Structure and Properties of Matter

5th Grade	Middle School	High School
EE.5.PS1-2; Measure and compare weights of substances before and after heating, cooling, or mixing substances to show that weight of matter is conserved.	EE.MS.PS1-2; Interpret and analyze data on the properties of substances before and after chemical changes have occurred.	EE.HS.PS1-2; Make a claim supported by evidence to explain patterns of chemical properties that occur in a substance during a common chemical reaction.
EE.5.PS1-3; Make observations and measurements to identify materials based on their properties.		

(From DLM Science Essential Elements; DLM Science Consortium, 2014)

Physical Science 1 Narratives

Overview

The following narratives summarize the research that was used to create the learning map model neighborhoods for the four Physical Science 1 Essential Elements. First, the science core idea and science and engineering practice components for the Essential Element are described. Then the research on how students learn this content is presented, organized by grade span and topic.

Essential Element EE.5.PS1-2

Measure and compare weights of substances before and after heating, cooling, or mixing substances to show that weight of matter is conserved.

Disciplinary Core Idea and Science and Engineering Practice Components

In this section, the concepts and skills needed to master Essential Element EE.5.PS1-2 are listed. Developmental progressions for each concept and skill described in this section were considered in this neighborhood map.

Disciplinary Core Idea

The disciplinary core idea is *PS1.A Structure and Properties of Matter*. Several science concepts are needed to master Essential Element EE.5.PS1-2. Two larger science concepts are: (1) the amount [weight] of matter is conserved when it changes form, regardless of what reaction or change in properties occurs, and (2) the total weight of the substances does not change. Several smaller science concepts are embedded within the two larger concepts, such as weight, measurement of weight, conservation of weight, effects of heating/cooling substances, effects of mixing substances, states of matter, and changes in states of matter.

Science and Engineering Practices

The science and engineering practice is *Using Mathematics and Computational Thinking*, which includes measuring and comparing quantities such as weight to address science and engineering questions and problems. Mathematics allows people to representation relationships using numbers, variables, or symbols. Computational thinking is the use of tools and strategies to collect, analyze, model, or represent complex data (National Research Council, 2012). Tools and strategies include spreadsheets and simulations. For EE.5.PS1-2, students measure and compare weight to address questions about conservation of matter.

Research on Student Learning (by grade span)

Preacademic

Before students can understand conservation of matter, they must understand weight. By kindergarten, students notice how different objects feel when they are held (felt weight or heft) or how objects press down on something else; however, students perceive weight as subjective (Smith & Wiser, 2013; Wiser, Frazier, & Fox, 2013; Keeley, 2016).

Grades K-2

Weight

In K-2, most children develop the understanding that weight is an objective, measurable quantity (Smith & Wiser, 2013). Children learn to weigh objects with a scale and understand that this measurement is more accurate than heft (AAAS, 2007g; Wiser et al., 2013). Students may have a variety of misconceptions about weight, including that light objects (e.g., air or polystyrene foam) do not have weight (Keeley, 2016), which can persist until late elementary school. After students understand that weight measurement is more accurately accomplished with a scale, they can explore conservation of weight.

Conservation of Weight

In early elementary school, students learn that things are made of parts. They then learn about conservation of weight by comparing the weight of a whole to the weight of the parts (American Association for the Advancement of Science [AAAS], 2007f; Keeley, 2015b). Less complex examples include cases in which the appearance of the material does not change (e.g., taking apart a tower of blocks to compare the tower to the blocks; AAAS, 2007d; Wiser et al., 2013). More complex examples include situations in which the shape of material changes (e.g., comparing a ball shape to a pancake shape; Keeley, 2015b; Wiser et al., 2013).

Effect of heating and cooling

In early elementary school, students should develop understanding that heating or cooling substances can cause changes that can be observed but do not affect weight (Wiser et al., 2013). Heating or cooling may cause a change in state. In early elementary school, students learn about state changes (AAAS, 2007a). The misconception held by many young children that liquids do not have the same properties as solids, such as weight, contributes to complexity. After children understand that weight is an inherent property of solids and liquids, they can explore its conservation during phase changes between the solid and liquid states.

Measuring and comparing weight

Use of mathematics and computational thinking begins in early elementary school with recognizing that math is useful for describing attributes of objects. In K-2, students learn to measure and compare weights of objects (NGSS Lead States, 2013). In early elementary school, students learn to use an equal-arm balance to weigh objects (AAAS, 2007e; Wiser et al., 2012). Children tend to measure weight by heft (Wiser et al., 2012).

Grades 3-5

Weight

Most children develop the understanding that air and very small objects have weight in late elementary or early middle school (Wiser et al., 2013). Students work on developing the understanding that any piece of material, regardless of size, has weight (Smith & Wiser, 2013). The term matter is abstract, and understanding of this term is not expected until late elementary school (Wiser et al., 2013).

Conservation of weight

Contexts are more complex, and include situations where the appearance of the material changes drastically.

Grinding

Many young children believe that powders do not have the same properties, such as weight, as solid materials. This misconception increases the difficulty of comparing wholes to parts when the parts are powder (e.g., comparing a piece of wood to sawdust). Students work on understanding that if a solid material is ground into a powder, the weight is conserved (Smith & Wiser, 2013).

Heating and cooling

Students may confuse the concepts of weight and volume (Smith & Wiser, 2013). Students should have opportunities to compare weights when size changes due to heating or cooling. Context should include materials that follow typical patterns of expansion or contraction with heating and cooling. Freezing water can be a confusing context because the expansion of water as it freezes is an exception to the typical pattern. Students may think that weight is lost when ice melts because ice takes up more space than liquid water (Keeley, 2015a). Students should have opportunities to collect data that show weight is conserved during phase changes. Elementary students are not ready to apply conservation of weight to the phase change from the liquid to the gas state until they understand that things that cannot be seen or felt have weight (Smith, Wiser, Anderson, & Krajcik, 2006). Students develop the understanding that all objects, no matter how small, have weight through experiences weighing ground materials and hollow objects before and after they are filled with air.

Mixing

Later in elementary school, students learn that when different kinds of matter are mixed, there are several possible results (e.g., a substance can dissolve, both substances can remain visible, a new substance can form). Students should gain experience with weighing substances before and after mixing to compare the weights and determine if weight is conserved. Students should compare the sum of the weights of the individual components to the weight of the mixture. Contexts should also include situations in which the resulting substance looks very different than the initial substances (e.g., making cake batter) to show that even when the resulting substance looks different, weight is conserved.

Dissolving

Dissolving is often misunderstood because children believe weight is reduced when a solute dissolves (Driver, Squires, Rushworth, & Wood-Robinson, 1994). Situations in which one substance dissolves into another are more complex because students may think the dissolved substance has disappeared (Keeley & Tugel, 2009). Most students understand that weight is conserved when sugar dissolves in water by the end of elementary school (Keeley & Tugel, 2009).

Weight for size

Students develop understanding of weight as an extensive property of materials. By comparing weights of different-size objects of the same material, students can develop understanding that weight depends on and is proportional to amount. This idea is needed for students to use properties to identify materials (EE.5.PS1-3) because weight is not a property that can be used to identify a material. Density is a property, related to weight, that can be used to identify materials. Weight for size is a precursor concept for density (Smith & Wiser, 2013). Elementary students are not yet ready to understand density, but they can prepare to understand density by exploring "weight for size" of different materials.

Measuring and comparing weights

Students' practice of measuring and comparing weights expands to science applications in grades 3-5 (NGSS Lead States, 2013). Students learn that weight can be measured with a balance scale and that scale measurement is more reliable than felt weight (e.g., our senses cannot distinguish small differences in weight, but a scale can). Students should be able to accurately measure weight using an appropriate device (AAAS, 2007g). By the end of elementary school, students should be able to use simple computation to compare weights before and after heating, cooling, or mixing (AAAS, 2007c; NGSS Lead States, 2013; Wiser et al., 2012). Children weigh objects with a balance scale, using non-standard and standard units, and rank objects by weight using weight lines, which are similar to number lines (Wiser, Smith, & Doubler, 2012). Students begin to use mathematical reasoning (i.e., subtraction or division) to infer weights when something cannot be weighed alone (e.g., subtracting weight of an empty container from the weight of the full container to find the weight of the contents). Students use weight data as evidence to explain that gases are matter, which builds on inference skills. Students should be familiar with standard units for measuring weight (e.g., ounce or pound). At this level, students are not expected to differentiate between weight and mass and may use grams as a weight unit.

Middle School

Extension of the principle of conservation of weight to situations that involve gases, such as evaporation and condensation, generally occurs in middle school (Smith et al., 2006). By middle school, students should understand that no matter what the result looks like, the weight of matter is conserved before and after an interaction (AAAS, 2007d). Extension of conservation of matter to chemical reactions occurs in middle school, after students understand atoms, closed systems, and gases (AAAS, 2007b; Rogat, 2011). In middle school, most students develop understanding of density, which is an intensive property that can be used to identify materials (Smith et al., 2006).

References

American Association for the Advancement of Science. (2007a). Changes of state. Retrieved from Science Literacy Maps website: http://strandmaps.dls.ucar.edu/?id=SMS-STD-1333

American Association for the Advancement of Science. (2007b). Changing vs. constant properties. Retrieved from Science Literacy Maps website: http://strandmaps.dls.ucar.edu/?id=SMS-STD-1334

American Association for the Advancement of Science. (2007c). Computation. Retrieved from Science Literacy Maps website: http://strandmaps.dls.ucar.edu/?id=SMS-STD-2492

American Association for the Advancement of Science. (2007d). Conservation. Retrieved from Science Literacy Maps website: http://strandmaps.dls.ucar.edu/?id=SMS-STD-2425

American Association for the Advancement of Science. (2007e). Making accurate measurements. Retrieved from Science Literacy Maps website: http://strandmaps.dls.ucar.edu/?id=SMS-STD-2508

American Association for the Advancement of Science. (2007f). Parts and wholes. Retrieved from Science Literacy Maps website: http://strandmaps.dls.ucar.edu/?id=SMS-STD-1335

American Association for the Advancement of Science. (2007g). Using tools and devices. Retrieved from Science Literacy Maps website: http://strandmaps.dls.ucar.edu/?id=SMS-MAP-2507

Driver, R., Squires, A., Rushworth, P., & Wood-Robinson, V. (1994). *Making sense of secondary science: Research into children's ideas*. New York, NY: Routledge.

Keeley, P. (2015a). Ice cubes in a bag. *Science & Children*, *52*(5), 20–22.

Keeley, P. (2015b). Snap blocks. *Science & Children*, *52*(9), 26–28.

Keeley, P. (2016). Uncovering students’ concept of matter. *Science & Children*, *53*(5), 26–29.

Keeley, P., & Tugel, J. (2009). Sugar water. In *Uncovering student ideas in science: 25 new formative assessment probes* (Vol. 4, pp. 11–16). Arlington, VA: NSTA.

NGSS Lead States. (2013). *Next Generation Science Standards: For states, by states*. Washington, DC: The National Academies Press.

Smith, C. L., & Wiser, M. (2013). Learning and teaching about matter in the elementary grades: What conceptual changes are needed? In S. Vosniadu (Ed.), *International handbook of research on conceptual change* (pp. 159–176). New York, NY: Routledge.

Smith, C. L., Wiser, M., Anderson, C. W., & Krajcik, J. (2006). Implications of research on children’s learning for standards and assessment: A proposed learning progression for matter and the atomic-molecular theory. *Measurement: Interdisciplinary Research & Perspective*, *4*(1–2), 1–98. http://doi.org/10.1080/15366367.2006.9678570

Wiser, M., Frazier, K. E., & Fox, V. (2013). At the beginning was amount of material: A learning progression for matter for early elementary grades. In G. Tsaparlis & H. Sevian (Eds.), *Concepts of matter in science education* (pp. 95–122). Dordrecht, The Netherlands: Springer.

Wiser, M., Smith, C. L., & Doubler, S. (2012). Learning progressions as tools for curriculum development: Lessons from the Inquiry Project. In A. C. Alonzo & A. W. Gotwals (Eds.), *Learning progressions in science* (pp. 359–404). Rotterdam, The Netherlands: Sense.

Essential Element EE.5.PS1-3

Make observations and measurements to identify materials based on their physical properties.

Disciplinary Core Idea and Science and Engineering Practice Components

In this section, the concepts and skills needed to master Essential Element EE.MS.PS1-2 are listed. Developmental progressions for each concept and skill described in this section were considered in this neighborhood map.

Disciplinary Core Idea

The disciplinary core idea is *PS1.A Structure and Properties of Matter*. Several science concepts are needed to master Essential Element EE.5.PS1-3. Two larger science concepts are: (1) materials can be identified by a set of characteristic properties and (2) knowledge of properties of materials. Several smaller concepts are embedded within the two larger concepts, such as such as the material construal and knowledge of a wide range of physical properties.

Science and Engineering Practices

The broad science and engineering practice is *Planning and Carrying Out Investigations*. The skill of making observations and measurements to produce data to serve as the basis for evidence for an explanation of a phenomenon is the focus of the EE. Observing is defined as careful exploration of *all* of the properties of an object or substance with the senses and instruments that extend the senses (Bass, Contant, & Carin, 2009; Rezba, Sprague, & Fiel, 2003). Properties that can be observed include, but are not limited to: color, texture, odor, shape, weight, volume, temperature, and sounds that are made when the object is manipulated. Observation of a specific property may present a barrier to students with a specific sensory impairment, but all students should be able to observe some properties with their senses. Measurements are observations made with instruments that provide information about quantity, such as a number or amount (Rezba, et al., 2003).

Research on Student Learning (by grade span)

Preacademic

Identification of Materials

Infants do not yet understand the concept of material, but can recognize familiar non-solid materials (e.g., water, milk, sand; Wiser, Frazier, & Fox, 2013).

Material Construal

Children think of solids as objects rather than materials (Wiser et al., 2013). Children apply the concept of material to some familiar non-solids, but may have difficulty distinguishing the concepts of object and material (Ngai, Sevian, & Talanquer, 2014).

Grades K-2

Identification of Materials

Identification tasks become more complex over time. By the end of second grade, students should develop the understanding that specific materials have specific properties and that material identity is maintained over reshaping and cutting (AAAS, 2007d; Wiser et al., 2013).

Properties

Young children begin to associate familiar properties with materials (e.g., smell, taste, hardness, bitterness; Wiser et al., 2013). Once children become familiar with a property, they can observe the property in unfamiliar materials (AAAS, 2007d). Students should observe properties such as smell, hardness, flexibility, and breakability (AAAS, 2007a). Students should be able to match materials that share these physical properties.

Material Construal

Children are developing the concept of material, but apply it inconsistently to solid objects (AAAS, 2007c; Wiser et al., 2013).

Planning and Conducting Investigations

Children develop observation skills (AAAS, 2007e). Elementary children often do not write down their observations or label drawings because they think they will remember. Children need instruction on making and recording observations that include details, accurately reflect observations, and can be read by others (Arias & Davis, 2016). They make qualitative comparisons and build knowledge of measurement as iteration of fixed units, as well as knowledge that measurements are more reliable than our senses. Young children tend to miss relevant details (Bass, Contant, & Carin, 2009). Early investigations are descriptive. In early elementary school, children use the idea of fair tests to conduct simple investigations that support science explanations. Planning of early investigations is guided by the teacher, and students gradually take more responsibility in planning decisions. The observations and measurements that children make become more sophisticated over time. In early elementary school, children learn to make accurate observations and descriptions (AAAS, 2007b). They record their observations and descriptions with pictures and can compare the number, shape, texture, size, weight, color, and motion of objects (AAAS, 2007e).

Grades 3-5

Identification of Materials

Gradually, elementary students develop understanding that materials have consistent properties. By the end of fifth grade, students should understand that material identity is maintained before and after dissolving, mixing, and grinding into powder (Wiser et al., 2013). Fifth grade students should be able to measure and observe these properties to identify a material. At this stage, students are not expected to select which properties should be used to identify the material, but students are expected to know that materials must share multiple properties to be the same. Students use a macroscopic compositional model to understand properties of a material as caused by the material itself and that a material is composed of many small pieces with consistent properties (Wiser & Smith, 2013).

Properties

Properties that cannot be observed with senses

Students begin to measure properties that they cannot observe with their senses, such as hardness, strength, weight for size, flammability, ease of conducting heat or electric current, response to a magnet, and solubility in water (American Association for the Advancement of Science [AAAS], 2007d; NGSS Lead States, 2013).

Characteristic and Non-characteristic properties

Students explore how weight increases with the size of an object, but are not yet ready to formally distinguish between characteristic and non-characteristic properties. Whereas weight changes with size, density is independent of size. Elementary students are not yet ready for the proportional reasoning required to understand the concepts of density (or buoyancy) and are likely to incorrectly attribute buoyancy to the weight of the object rather than density (Rogat, 2011), which may interfere with using buoyancy to identify a material. By fifth grade, students should have enough experience with melting and freezing of substances to understand that the melting and freezing temperatures are characteristic properties of a substance.

Material Construal

Children accurately apply the concept of material to solid objects and expand their use of the concept to include gases (Wiser et al., 2013).

Planning and Conducting Investigations

Students make measurements with instruments such as scales and rulers. Students learn that measurements have error and that we can see things that are too small to see with our eyes using tools. By fifth grade, students should be able to make accurate observations. Students may confuse inferences and observations (Arias & Davis, 2016). By late elementary school, students should be able to make observations and measurements to obtain data that allow a material to be identified (NGSS Lead States, 2013). Students make some choices in the planning of investigations. In late elementary school, students develop skills in record keeping and some quantitative properties are measured with tools (AAAS, 2007e). Properties that can be observed in late elementary school include strength, hardness, flexibility, durability, resistance to water and fire, and ease of conducting heat (AAAS, 2007d).

Middle School

Identification of Materials

By middle school, students should be able to select the properties that can be used to identify a substance from available properties (AAAS, 2007d). Students should recognize that some substances may only be distinguishable using properties that require experimental testing, such as determining melting point (AAAS, 2007d; Ngai et al, 2014). Once students understand that weight and size vary with the amount of material, they can understand that these data are not useful for identifying materials. Middle school students learn to describe changes using a particle model that describes materials as made up of very small particles that cannot be seen. This idea helps students to provide reasoning to explain why material identity does not change during physical changes (Wiser & Smith, 2013).

More Complex Characteristic (Intensive) Properties.

Knowledge of properties expands to include more complex characteristic properties. Students begin to formally distinguish between characteristic properties (e.g., density and melting point; AAAS, 2007d) and non-characteristic properties (e.g., size and weight) in middle school. Students should develop an understanding of density as a characteristic property (AAAS, 2007d; Wiser & Smith, 2013). Density is a challenging concept that is connected to proportional reasoning (used in mathematics in Grade 7). After students understand density, they can begin to understand buoyancy. After middle school students recognize gases as a state of matter, they are ready to understand boiling point as a characteristic property (AAAS, 2007d). Middle school students should have experiences measuring a variety of characteristic properties (e.g., density, melting point, and solubility) for different amounts of material to develop understanding that some properties are independent of the amount of material (AAAS, 2007d).

Extensive Properties

Students should understand that weight and volume alone are not useful for identifying a material. The understanding that weight and size (volume) vary with the amount of material develops over multiple experiences observing and measuring properties of objects and materials (Smith & Wiser, 2013).

Substance Construal

In middle school, students learn that a substance has characteristic properties and is made of specific compounds (Smith et al., 2006). Students begin to learn about the atoms and molecules that make up compounds (AAAS, 2007a).

Planning and Conducting Investigations

Students take more responsibility in planning investigations. Students learn that some properties are measured indirectly or using powerful tools. Students use a wider range of measuring tools.

References

American Association for the Advancement of Science. (2007a). Basic ingredients. Retrieved from Science Literacy Maps website: http://strandmaps.dls.ucar.edu/?id=SMS-STD-1350

American Association for the Advancement of Science. (2007b). Communication Skills. Retrieved from Science Literacy Maps website: http://strandmaps.dls.ucar.edu/?id=SMS-MAP-2531

American Association for the Advancement of Science. (2007c). Materials. Retrieved from Science Literacy Maps website: http://strandmaps.dls.ucar.edu/?id=SMS-STD-1616

American Association for the Advancement of Science. (2007d). Physical properties. Retrieved from Science Literacy Maps website: http://strandmaps.dls.ucar.edu/?id=SMS-STD-1605

American Association for the Advancement of Science. (2007e). Record-keeping. Retrieved from Science Literacy Maps website: http://strandmaps.dls.ucar.edu/?id=SMS-STD-1210

American Association for the Advancement of Science. (2007f). Scientific investigations. Retrieved from Science Literacy Maps website: http://strandmaps.dls.ucar.edu/index.html?id=SMS-MAP-1207

American Association for the Advancement of Science. (2007g). Using tools and devices. Retrieved from Science Literacy Maps website: http://strandmaps.dls.ucar.edu/?id=SMS-MAP-2507

Arias, A. M., & Davis, E. A. (2016). Making and recording observations. Science & Children, 53(8), 54–60.

Bass, J. E., Contant, T. L., & Carin, A. A. (2009). Teaching science as inquiry (11th ed.). Boston, MA: Pearson.

Ngai, C., Sevian, H., & Talanquer, V. (2014). What is this substance? What makes it different? Mapping progression in students' assumptions about chemical identity. International Journal of Science Education, 36(14), 2438–2461. http://doi.org/10.1080/09500693.2014.927082

NGSS Lead States. (2013). Next generation science standards: For states, by states. Washington, DC: The National Academies Press.

Rezba, R. J., Sprague, C., & Fiel, R. L. (2003). Learning and assessing science process skills (4th ed.). Dubuque, IA: Kendall Hunt.

Rogat, A. D. (2011). Developing learning progressions in support of the new science standards. New York, NY. Retrieved from http://www.cpre.org/sites/default/files/researchreport/1286_lpsstandardscprerevised.pdf

Smith, C. L., & Wiser, M. (2013). Learning and teaching about matter in the elementary grades: What conceptual changes are needed? In S. Vosniadou (Ed.), International Handbook of Research on Conceptual Change (pp. 159–173). New York, NY: Routledge.

Smith, C. L., Wiser, M., Anderson, C. W., & Krajcik, J. (2006). Implications of research on children's learning for standards and assessment: A proposed learning progression for matter and the atomic-molecular theory. Measurement: Interdisciplinary Research & Perspective, 4(1–2), 1–98. http://doi.org/10.1080/15366367.2006.9678570

Wiser, M., Frazier, K. E., & Fox, V. (2013). At the beginning was amount of material: A learning progression for matter for early elementary grades. In G. Tsaparlis & H. Sevian (Eds.), Concepts of matter in science education (pp. 95–122). Dordrecht, The Netherlands: Springer.

Wiser, M., & Smith, C. L. (2013). Learning and teaching about matter in the middle-school years: How can the atomic-molecular theory be meaningfully introduced? In S. Vosniadou (Ed.), International Handbook of Research on Conceptual Change (pp. 177–194). New York, NY: Routledge.

Wiser, M., Smith, C. L., & Doubler, S. (2012). Learning progressions as tools for curriculum development: Lessons from the Inquiry Project. In A. C. Alonzo & A. W. Gotwals (Eds.), Learning progressions in science (pp. 359–404). Rotterdam, The Netherlands: Sense.

Essential Element EE.MS.PS1-2

Interpret and analyze the data on the properties of substances before and after chemical changes have occurred.

Disciplinary Core Idea and Science and Engineering Practice Components

In this section, the concepts and skills needed to master Essential Element EE.MS.PS1-2 are listed. Developmental progressions for each concept and skill described in this section were considered in this neighborhood map.

Disciplinary Core Idea

The disciplinary core idea is *PS1.A Structure and Properties of Matter*. Several science concepts are needed to master Essential Element EE.MS.PS1-2. Two larger science concepts are: (1) effects of chemical change on substance identity and (2) explanatory models of matter. Several smaller concepts are embedded within the two larger concepts, such as the substance construal, knowledge of a wide range of physical properties, and knowledge of familiar chemical and physical changes.

Science and Engineering Practices

The broad science and engineering practice is *Analyzing and Interpreting Data.* The skills of interpreting and analyzing data to identify similarities and differences in properties is the focus of the Essential Element. Analysis is the organization and of data through making tables or graphs, and using mathematics that allows patterns and relationships to be identified (National Research Council, 2012). Interpretation is the process of making meaning from data and determining relevance (National Research Council, 2012). Analysis skills build on mathematics instruction, whereas interpretation skills are linked to students' understanding of models for matter.

Research on Student Learning (by grade span)

The narrative for EE.5.PS1-3 describes the development of knowledge of properties and substance identity in elementary school. The narrative for EE.5.PS1-2 describes the development of knowledge of changes of state and weight.

Preacademic

Effect of Physical Changes on Material Identity

Most young children think in terms of objects rather than materials because they do not yet understand the concept of material (Wiser, Frazier, & Fox, 2013). Many children do not yet understand that material identity stays the same when an object is cut into pieces. Some students may understand that material identity stays the same after cutting when the cut pieces maintain all the perceptual properties of the object (Rogat, 2011).

Grades K-2

See the narratives for EE.5.PS1-3 on properties and EE.5.PS1-2 on conservation of weight for descriptions of development.

Effect of Physical Changes on Material Identity

Nodes in the EE.5.PS1-2 neighborhood address physical changes, including changes in shape. As students examine conservation of weight during simple physical changes, they can also examine material identity before and after the change (Rogat, 2011). Examples should be limited to cases in which the perceptual properties of the material do not change.

Analyzing and Interpreting Data

Experiences include gathering data from observations in the form of pictures, drawings, and writing (American Association for the Advancement of Science [AAAS], 2007c). Analyses are limited to similarities or differences, and simple patterns. Interpretations of data are limited to comparisons of material identity for simple transformations (e.g., cutting in half, reshaping) in which perceptual properties stay the same (Rogat, 2011).

Macroscopic Compositional Model of Matter

Rogat (2011) describes a *macroscopic compositional* model of matter as appropriate for K-2. Matter can be touched or felt, and objects can be divided into smaller parts that maintain material identity.

Grades 3-5

See narrative for EE.5.PS1-3.

Physical Change

In elementary school, instruction focuses on material properties and identity, physical changes, and the effects of physical changes on material properties (Wiser, Smith, & Doubler, 2012). Physical changes such as freezing and melting are explored in grades 3-5.

Effect of Physical Changes on Material Identity

Nodes in the EE.5.PS1-2 neighborhood address physical changes, including grinding and melting. As students examine conservation of weight during more complex physical changes, they can also examine material identity before and after the change (Rogat, 2011).

Analyzing and Interpreting Data

In elementary school, experiences with interpreting and analyzing data include analyzing pictures, drawings, and writing (NGSS Lead States, 2013). Elementary students should be able to describe patterns and relationships and use them to answer science questions (NGSS Lead States, 2013). Elementary students build skills in recording information, using observations, and answering questions (NGSS Lead States, 2013). An interpretation is an explanation of what the data mean. Students learn that different sets of properties are caused by differences in materials.

Microscopic Compositional Model for Matter

Wiser and Smith (2013) describe a *microscopic compositional* model, learned in grades 3-4, that is a precursor to more complex models for matter. The microscopic compositional model explains that materials are made up of very tiny pieces that have the same properties as the whole (Rogat, 2011; Wiser & Smith, 2013). Students learn that the pieces are so tiny that a sensitive instrument, such as a microscope, is needed to see them (AAAS, 2007a). Students use the concepts of amount of material, weight, and identity to explain science phenomena, such as mixing and dissolving (Rogat, 2011). Students may confuse microscopic and macroscopic ideas (Merritt & Krajcik, 2013).

Middle School

Properties of Substances

In middle school, students should learn that each pure substance has characteristic properties that can be used to identify it (NGSS Lead States, 2013). By the end of middle school, students should be able to interpret and analyze data on the observable characteristic properties that were learned in grades 3-5 (e.g., heaviness for size, flammability, conductivity, response to magnetic force, solubility in water), as well as more complex properties that are explored during middle school (e.g., melting point, freezing point, density, boiling point; AAAS, 2007b; Wiser, Frazier, & Fox, 2013). Students should learn to use properties that describe how materials respond to mechanical, thermal, or electrical changes (e.g., response to energy transfer or the presence of other materials). Properties are more effective for distinguishing among materials than surface features and can be used to conduct tests to identify substances (AAAS, 2007b; Ngai, Sevian, & Talanquer, 2014).

Identification of Substances

The use of properties to compare substance identities builds on the skill of identifying materials that was developed in elementary school. Students need to be able to compare properties of two substances to determine if the substances are the same or different. Task complexity increases as properties become more complex and students must select properties that can be used to identify the substances. The neighborhood map of EE.MS.PS1-2 has significant overlap with the neighborhood map of EE.5.PS1-3.

Chemical Changes

Students should learn that new substances created in chemical processes have different properties from those of the reactants (NGSS Lead States, 2013). Chemical changes explored in middle school are limited to familiar, simple reactions, such as rusting and burning (Rogat, 2011; Smith, Wiser, Anderson, & Krajcik, 2006). Observations of burning and rusting lead to the finding that the products of these chemical reactions have different properties than the original substances. Students know from elementary school that the material is the cause of its properties. In middle school they apply this knowledge to interpret differences in properties to mean that a different material was formed during the reaction. The idea that a new substance is formed during a chemical reaction may contradict students' ideas. For example, many students think that the substance retains its identity but changes state or properties due to the chemical process. Or students may think that the product (i.e., rust) is already inside the reactants (i.e., iron) and the chemical reaction merely brings the product to the outside. Other students may believe a reactant is transformed or that reactants get used up (Driver, Squires, Rushworth, & Wood-Robinson, 1994).

Effect of Chemical or Physical Changes on Substance Identity

Instruction focuses on the effects of physical and chemical changes on substance identity, building on what students learned in elementary school. A key idea is understanding the types of changes for which substance identity is conserved. Analyses should begin with situations that are familiar to the student, such as reshaping, cutting, grinding, melting, and freezing, and should progress from least to most complex (Rogat, 2011). These familiar physical changes build from transformations that are included in nodes in the EE.5.PS1-2 neighborhood; however, the focus has shifted to examining the effect of these changes on substance identity instead of weight. The phase change between the liquid phase and gas phase is examined in middle school, which depends on students' understanding of gas as matter (AAAS, 2007a). After students understand that identity does not change during physical changes, they explore chemical changes to see that identity does change (Rogat, 2011).

Analyzing and Interpreting Data

Analyzing Data

Students analyze data on the properties of substances to determine if they are similar or different. Middle school students should be able to represent data in tables and bar or line graphs. In middle school, the type of data that students can be asked to analyze becomes more complex, including tables and graphical displays. The types of analyses also become more complex. Middle school students should be able to identify patterns or discuss similarities and differences in substance properties (NGSS Lead States, 2013).

Interpreting Data

Students interpret analyses of properties to make sense of substance identity before and after the change. An important concept for making sense of change is a model of matter. The microscopic compositional model that was learned in elementary school does not help students make sense of the changes during chemical reactions. In middle school, students are introduced to the particle model and use the model to describe how new substances are formed by the rearranging of particles (AAAS, 2007a; Rogat, 2011; Wiser & Smith, 2013).

Particle model for matter

Wiser and Smith (2013) describe a basic particle model, learned in grades 5-6, that is a successor to the microscopic compositional model and a precursor to the atomic-molecular model. The basic particle model helps students interpret changes in properties and explain the effect of changes on identity. The basic particle model explains matter as made of particles that are always moving. In solids, particles are tightly packed and bound to each other. In liquids, particles move faster and are farther apart. In gases, particles move even faster and are the farthest apart. Phase changes can be described by the addition of heat energy, making particles move faster and increasing the distance between the particles, or the removal of heat energy, making particles move slower and decreasing distance between the particles. Merritt and Krajcik (2013) developed a sixth-grade curriculum to help students understand the particle model and use it to explain phenomena, such as how an odor is smelled from a distance.

Chemical changes can be described as particles rearranging to form new substances that have different properties (AAAS, 2007d). In middle school, students use a particle model to explain that particles rearranged to create new substances during a chemical reaction (Rogat, 2011; Wiser & Smith, 2013). However, students are not expected to explain *why* different chemical reactions happen until they learn about atoms.

High School

Chemical Changes

Nonfamiliar chemical reactions (e.g., displacement reactions) are introduced in high school (Smith et al., 2006). Students are not expected to explain why chemical reactions happen until high school, when they learn about atoms (Rogat, 2011). Chemical properties are formally introduced in high school.

Atomic-Molecular Model of Matter

Wiser and Smith (2013) describe a basic atomic-molecular model, learned during grades 7-9, that is a successor to the basic particle model and explains why chemical reactions occur. Students think of particles as molecules that are in constant motion. Attractive forces and energy affect how the molecules interact. Students distinguish between atoms, elements, molecules, substances, and mixtures (Rogat, 2011). The atomic-molecular model is needed to adequately explain chemical changes and properties (Rogat, 2011) that are caused by the internal structure of the particles. The development of the atomic-molecular model occurs over several years, across middle school and high school. At the most basic level, the atomic-molecular model begins with the knowledge that different atoms have different properties, and that different substances are made from different atoms (AAAS, 2007d; Wiser & Smith, 2013). The concept of atoms is typically introduced in middle school (AAAS, 2007a).

Subatomic Model of Matter

In grades 10-12, students learn a subatomic model of matter (Rogat, 2011). Students learn that atoms have internal structure (i.e., protons, electrons) that affects interactions (AAAS, 2007a; Rogat, 2011).

References

American Association for the Advancement of Science. (2007a). Atoms and molecules. Retrieved from Science Literacy Maps website: http://strandmaps.dls.ucar.edu/?id=SMS-MAP-1325

American Association for the Advancement of Science. (2007b). Physical properties. Retrieved from Science Literacy Maps website: http://strandmaps.dls.ucar.edu/?id=SMS-STD-1605

American Association for the Advancement of Science. (2007c). Record-keeping. Retrieved from Science Literacy Maps website: http://strandmaps.dls.ucar.edu/?id=SMS-STD-1210

American Association for the Advancement of Science. (2007d). Scientific understanding. Retrieved from Science Literacy Maps website: http://strandmaps.dls.ucar.edu/?id=SMS-STD-2341

Driver, R., Squires, A., Rushworth, P., & Wood-Robinson, V. (1994). Making sense of secondary science: Research into children's ideas. New York, NY: Routledge.

Merritt, J., & Krajcik, J. (2013). Learning progression developed to support students in building a particle model of matter. In G. Tsaparlis and H. Sevian (Eds.), Concepts of Matter in Science Education (pp. 11–46), New York, NY: Springer.

National Research Council. (2012). A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas. Washington, DC: National Academies Press.

Ngai, C., Sevian, H., & Talanquer, V. (2014). What is this substance? What makes it different? Mapping progression in students' assumptions about chemical identity. International Journal of Science Education, 36(14), 2438–2461. http://doi.org/10.1080/09500693.2014.927082

NGSS Lead States. (2013). Next Generation Science Standards: For states, by states. Washington, DC: The National Academies Press.

Rogat, A. D. (2011). Developing learning progressions in support of the new science standards. New York, NY. Retrieved from http://www.cpre.org/sites/default/files/researchreport/1286_lpsstandardscprerevised.pdf

Smith, C. L., Wiser, M., Anderson, C. W., & Krajcik, J. (2006). Implications of research on children's learning for standards and assessment: A proposed learning progression for matter and the atomic-molecular theory. Measurement: Interdisciplinary Research & Perspective, 4(1-2), 1–98. http://doi.org/10.1080/15366367.2006.9678570

Wiser, M., Frazier, K. E., & Fox, V. (2013). At the beginning was amount of material: A learning progression for matter for early elementary grades. In G. Tsaparlis & H. Sevian (Eds.), Concepts of matter in science education (pp. 95–122). Dordrecht, The Netherlands: Springer.

Wiser, M., & Smith, C. L. (2013). Learning and teaching about matter in the middle-school years: How can the atomic-molecular theory be meaningfully introduced? In S. Vosniadou, International Handbook of Research on Conceptual Change (pp. 177–194). New York, NY: Routledge.

Wiser, M., Smith, C. L., & Doubler, S. (2012). Learning progressions as tools for curriculum development: Lessons from the Inquiry Project. In A. C. Alonzo & A. W. Gotwals (Eds.), Learning progressions in science (pp. 359–404). Rotterdam, The Netherlands: Sense.

Essential Element EE.HS.PS1-2

Make a claim supported by evidence to explain patterns of chemical properties that occur in a substance during a common chemical reaction.

Science Core Idea and Science and Engineering Practice Components

In this section, the concepts and skills needed to master Essential Element EE.HS.PS1-2 are listed. Developmental progressions for each concept and skill described in this section were considered in this neighborhood map.

Science Concepts

The science core idea is *PS1.A Structure and Properties of Matter*. Several science concepts are needed to master Essential Element EE.HS.PS1-2. Two larger science concepts are: (1) chemical properties, and (2) explanatory models of matter. Several smaller concepts are embedded within the two larger concepts, such as such as the substance construal, knowledge of a range of physical and chemical properties, and knowledge of chemical changes.

Science and Engineering Practices

The broad science and engineering practice is *Constructing Explanations and Designing Solutions*. The skills of constructing and revising explanations based on evidence obtained from a variety of sources (including observations, models, and theories) is the focus of the Essential Element. "Scientific explanations are accounts that link scientific theory with specific observations or phenomena… they explain observed relationships… and describe the mechanisms that support cause and effect… (National Research Council, 2012, p. 67). The practice of constructing explanations includes students offering causal explanations that are appropriate to their level of scientific knowledge (National Research Council, 2012). The practice of constructing explanations builds on English language arts instruction (i.e., use of evidence) and is integrated with students' understanding of matter. Students use models of matter to explain phenomena involving changes in matter. The kinds of phenomena that students can explain are limited by the features of the conceptual model for matter that they will use. Students' models for matter develops gradually from elementary to high school, and increase in complexity as well as explanatory power. A five-level model sequence that corresponds to specific grade bands (K-2, 3-4, 5-6, 7-9, 10-12; Rogat, 2011) is described in this narrative.

Research on Student Learning (by grade span)

Preacademic

See the narratives for EE.5.PS1-3 and EE.MS.PS1-2 for descriptions of development regarding properties the effect of physical changes on material identity, respectively.

Grades K-2

See the narratives for EE.5.PS1-3 and EE.MS.PS1-2 for descriptions of development regarding properties and the macroscopic compositional model for matter, respectively.

Constructing Explanations

In Grades K-2, students learn to explain the effect of simple transformations on material identity using a macroscopic compositional model for matter. Students learn to make a claim based on a given piece of evidence and to identify evidence that supports a given claim (Zembal-Saul, McNeill, & Herschberger, 2013). Students learn that scientists use multiple pieces of evidence to support claims.

Macroscopic Compositional Model for Matter

In K-2, students learn a *macroscopic compositional* model for materials. Matter is something that can be touched or felt. Objects can be broken down into parts and still keep their material identity. Students should be able to explain why material identity is maintained after reshaping or cutting with this model (Rogat, 2011).

Grades 3-5

See the narratives for EE.5.PS1-3 on properties and EE.MS.PS1-2 on microscopic compositional model for matter.

Chemical Properties

By the end of elementary school, children should have observed some chemical properties, such as reactions between common household solids and liquids and dissolving (Lee, Cite, & Hanuscin, 2014). Children have had a variety of personal experiences with burning, such as candles, paper, food on a barbeque, and sunburned skin (Rahayu & Tytler, 1999). However, elementary-aged children are not ready to describe or explain chemical reactions (Rogat, 2011; Wiser & Smith, 2013). Elementary-aged children do not understand that burning and rusting are chemical reactions and may think that the substances are destroyed or undergo physical changes that change their properties (Driver et al., 1994). Young children may believe that physical changes are chemical changes because they do not understand that substance identity stays the same during a change of state (Driver et al., 1994).

Constructing Explanations

In Grades 3-5, students learn to explain the effect of physical transformations on material identity using a revised model of matter, the microscopic compositional model (Wiser & Smith, 2013). Students become more proficient in constructing explanations, using multiple pieces of evidence to support claims (Zembal-Saul et al., 2013) Students learn that reasoning is used to show how the evidence supports the claim. Students learn to use science concepts as reasons in explanations.

Microscopic Compositional Model of Matter

In Grades 3-5, students learn a *microscopic compositional model* for materials as made of many small, pieces that are too small to seen without tools, have size and weight, have some characteristic properties that are the same as the material, and can be rearranged without changes in volume or weight. They develop a sense of material identity and conservation through experiences with increasingly more complex phenomena and properties. Students begin to use tools to measure materials properties that cannot be observed with the senses. Exploration of transformations such as grinding help them understand that perception is not a reliable indicator of physical properties. Grades 3-5 students should be able to explain why physical transformations such as grinding or melting do not affect material identity using the microscopic compositional model (Rogat, 2011).

Middle School

See the narrative for EE.MS.PS1-2 for descriptions of development regarding properties of substances, chemical changes, effect of chemical and physical changes on substance identity, and particle model for matter.

Chemical Properties

In middle school, students examine two common chemical reactions (i.e., burning and rusting; Smith et al., 2006). Students are likely to begin middle school with inconsistent, contextually-specific understandings of burning (Rahayu & Tytler, 1999). Burning is difficult to understand because it involves gases as reactants and as products. Sixth grade students use the idea of particles to describe how burning and rusting can occur through the rearrangement of particles, but they cannot explain why some substances react and some do not. Students can begin to develop causal explanations for chemical properties and reactions in grades 7-8 as they learn about atoms (Rogat, 2011; Wiser & Smith, 2013)[1].

Constructing Explanations

In middle school, students explore different transformations to distinguish chemical changes from physical changes by comparing substance identities before and after the change[2]. Explanations become more sophisticated in middle school. Students learn that evidence should be appropriate and sufficient to support the claim (McNeill & Krajcik, 2012).

Basic Particle Model of Matter

In Grades 5-6, students learn a basic particle model in which they understand materials as continuous, but able to be divided into tiny, invisible, preexisting particles that are in motion have many of the same properties as the object (Rogat, 2011). Students should be able to use the particle model to explain conservation of identity across phase changes, but the particle model cannot account for why a new substance is created in a chemical change (Rogat, 2011).

High School

The transition from middle to high school in the EEs is marked by increasing depth of knowledge (e.g., from analyzing to explaining) and the addition of chemical properties to students' repertoire of properties. In other words, the expectations for student performances shift from the description of change to causal explanations of change. However, explaining chemical change requires some knowledge of the atomic-molecular model (Rogat, 2011). To meet the expectation of constructing an explanation for this EE, students learn about atoms and

[1] The NGSS introduce atoms in middle school.

[2] The NGSS require students to differentiate chemical changes from physical changes in middle school, while the EEs require students only to examine changes before and after chemical reactions.

molecules, and use these concepts to explain why physical and chemical transformations are different.

Chemical Changes

Students learn that that each pure substance (atom) has characteristic chemical properties that identify it (NGSS Lead States, 2013)[3]. Chemical properties include solubility (AAAS, 2007b) and exemplary reactivities (AAAS, 2007c). Students use the concept of atoms to explain chemical properties, such as solubility and chemical reactions. Typically, students develop understanding of the components of the atomic-molecular model over an extended time period from middle to high school (Rogat, 2011). Students learn about more complex types of chemical reactions that involve a wider variety of elements. Unfamiliar chemical reactions (e.g., displacement reactions) are introduced in high school (Smith et al., 2006). Students are not expected to explain why chemical reactions happen until they learn about atoms (Rogat, 2011).

Constructing Explanations

In middle school, students explore chemical properties. Students' explanations become more sophisticated as students learn that reasons can have multiple components (McNeill & Krajcik, 2012). In high school, explanations become more causal. The substances that will react with each other and those that won't can be predicted by patterns of chemical properties (NGSS Lead States, 2013). Products of chemical reactions have different chemical properties than the original substances. High school students use properties of atoms or molecules to explain why chemical reactions occur. Students should learn that different atoms or molecules react chemically in characteristics ways. Knowledge of the chemical properties of atoms or molecules can be used to describe and predict chemical reactions[4].

Atomic-Molecular Model of Matter

Wiser and Smith (2013) describe a basic-atomic molecular model, learned during grades 7-9, that is a successor to the basic particle model and explains why chemical reactions occur. The concept of atoms is typically introduced in middle school (AAAS, 2007a). Students learn that atoms exist in many different kinds and can combine to make different molecules. Substance properties are determined by the kinds of atoms or molecules and the forces that hold them together. Atoms or molecules are in constant motion. Attractive forces and energy affect how the molecules interact. Students learn to distinguish between atoms, elements, molecules, substances, and mixtures (Rogat, 2011).

The atomic-molecular model is needed to adequately explain chemical changes and properties (Rogat, 2011). Instruction focuses on the internal structure of the particles that were introduced in the particle model. The development of the atomic-molecular model occurs over several years, across middle and high school. At the most basic level, the atomic-molecular model

[3] The NGSS include chemical properties in middle school, while the EEs introduce chemical properties in high school.

[4] The NGSS introduces prediction and causal explanations of chemical reactions in high school.

begins with the knowledge that different atoms have different properties, and that different substances are made from different atoms (AAAS, 2007c; Wiser & Smith, 2013).

Subatomic Model of Matter

In grades 10-12, students learn a subatomic model of matter (Rogat, 2011) that describes the internal structure of atoms (i.e., protons, electrons) that affects interactions (AAAS, 2007a; Rogat, 2011).

The focus of the Essential Element should be making an evidence-based claim about chemical reactions and patterns of chemical properties. The types of claims that students could make include:

(1) Predict which substances will react (or not react) based on chemical properties (e.g., exemplary reactivities and solubility; SCI-196),
(2) Explain how new substances are formed during a chemical reaction (e.g., atoms recombine; SCI-197; SCI-166),
(3) Identify a substance based on patterns of chemical properties (SCI-132; SCI-195),
(4) Explain substance behavior based on patterns of chemical properties (SCI-128).

Each of these types of claims are represented in the EE.HS.PS1-2 neighborhood map.

In the middle school Essential Elements, students have examined properties before and after chemical changes to determine that new substances are formed. A logical next step is to use the Basic Particle Model to describe how new substances are formed. A node for this skill is included in the neighborhood for EE.MS.PS1-2 (SCI-166). The middle school neighborhood contains additional nodes to describe the development of concepts that support understanding the effect of chemical change on substance identity. The kinds of changes for which students examine properties before and after were expanded to include physical changes because students have difficulty distinguishing between the two kinds of changes (Rogat, 2011). For example, students may believe that new substances are created during melting or boiling. The neighborhood for EE.MS.PS1-2 includes several nodes and connections for these skills. The link to the high school PS1 content could be enhanced by including chemical properties as characteristic properties. The use of knowledge of chemical properties builds on the neighborhood maps for EE.5.PS1-2 and EE.MS.PS1-2, which already include nodes for observations of chemical properties, such as dissolving, burning, and rusting.

References

American Association for the Advancement of Science. (2007a). Atoms and molecules. http://strandmaps.dls.ucar.edu/?id=SMS-STD-1325

American Association for the Advancement of Science. (2007b). Physical properties. http://strandmaps.dls.ucar.edu/?id=SMS-STD-1605

American Association for the Advancement of Science. (2007c). Scientific understanding. http://strandmaps.dls.ucar.edu/?id=SMS-STD-2341

Driver, R., Squires, A., Rushworth, P., & Wood-Robinson, V. (1994). Making sense of secondary science: Research into children's ideas. New York, NY: Routledge.

Lee, E. J., Cite, S., & Hanuscin, D. (2014). A traditional mystery-powders lesson is modified to emphasize argumentation. Science and Children, 52(1), 46–52.

McNeill, K. L., & Krajcik, J. S. (2012). Supporting grade 5-8 students in constructing explanations in science. Upper Saddle River, NJ: Pearson.

Merritt, J., & Krajcik, J. (2013). Learning progression developed to support students in building a particle model of matter. In G. Tsaparlis and H. Sevian (Eds.), Concepts of Matter in Science Education (pp. 11-46), New York, NY: Springer.

National Research Council. (2012). A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas. Washington, DC: National Academies Press.

NGSS Lead States. (2013). Next Generation Science Standards: For states, by states. Washington, DC: The National Academies Press.

Rahayu, S., & Tytler, R. (1999). Progression in primary school children’s conceptions of burning: Toward an understanding of the concept of substance. Research in Science Education, 29(3), 295–312. http://doi.org/10.1007/BF02461595

Rogat, A. D. (2011). Developing learning progressions in support of the new science standards. New York, NY. Retrieved from http://www.cpre.org/sites/default/files/researchreport/1286_lpsstandardscprerevised.pdf

Smith, C. L., Wiser, M., Anderson, C. W., & Krajcik, J. (2006). Implications of research on children’s learning for standards and assessment: A proposed learning progression for matter and the atomic-molecular theory. Measurement: Interdisciplinary Research & Perspective, 4(1-2), 1–98. http://doi.org/10.1080/15366367.2006.9678570

Songer, N. B., & Gotwals, A. W. (2012). Guiding explanation construction by children at the entry points of learning progressions. Journal of Research in Science Teaching, 49(2), 141–165. http://doi.org/10.1002/tea.20454

Wiser, M., & Smith, C. L. (2013). Learning and teaching about matter in the middle-school years: How can the Atomic-Molecular Theory be meaningfully introduced? In S. Vosniadou, International Handbook of Research on Conceptual Change (pp. 177-194), New York, NY: Routledge.

Zembal-Saul, C., McNeill, K. L., & Hershberger, K. (2013). What's your evidence: Engaging K-5 students in constructing explanations in science. Upper Saddle River, NJ: Pearson.