Instructional Segment 1 Teacher Background and Instructional Suggestions:

Many of the Integrated Grade 7 performance expectations and disciplinary core ideas relate to organisms, ecosystems and natural environments. One way to engage students in phenomena related to these topics is to have them sequentially build their understanding of the types of matter and energy interactions, and compare them across different contexts. For example, diagrams of different natural environments can be downloaded for free from WestEd's Making Sense of Science professional development project.[1] Over the course of the first three Instructional Segments, the class as a whole can analyze one environment (e.g., rivers) while they also work in groups on other very different environments (e.g., other environments accessed from the web and/or created by student teams).

Instructional Segment 1 focuses on the matter in these different environments. Using the river diagram as the shared class environment (Figure 2), it is natural to begin by considering the kinds of matter that are living, nonliving, once living, solid, liquid, and gas, and then to focus on the water. Recognizing that water vapor also exists in the air raises physical science concepts related to the molecular structure of water and to the properties and physical states of water.

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[1] http://we-mss.weebly.com/teacher-resources.html Click on "Environment Diagrams."

Figure 2: A river environment with diverse forms of living and nonliving matter. (Illustration from Making Sense of Science *Earth Systems* course, courtesy of WestEd)

The environment diagrams can lead to discussions about air being a mixture of predominantly diatomic gases (nitrogen and oxygen) with varying amounts of water vapor (the familiar H_2O), argon (another mono-atomic inert gas), and carbon dioxide. Through this analysis, six of the most important elements for life (carbon, oxygen, hydrogen and nitrogen) are identified as well as three of the main molecules involved in photosynthesis and respiration (water, carbon dioxide and oxygen).

The environment diagrams also serve as an introduction to the deeper concepts involved in performance expectations MS-LS2-3 (living and nonliving parts of environments) and MS-ESS3-1 (uneven distributions of resources in different environments). In Instructional Segment 1 students begin to research the forms of matter in these environments. In succeeding Instructional Segments these environment diagrams can become more detailed and enriched with **models** of ***cycles of matter, flows of energy***, geoscience processes, and distributions of resources. The identified forms of matter, especially water, serve as the lead-in to the Instructional Segment 1 physical science performance expectations and disciplinary core ideas.

Just as organisms are made of building blocks (cells) that are too small to see with the naked eye, all of matter is made of building blocks (atoms) that are orders of magnitude smaller, and that cannot be seen even with the most powerful light microscopes. The atomic nature of matter underlies almost all of the science that students explore in middle school and high school.

This atomic theory actually includes several features that go beyond merely stating that matter is made of building blocks called atoms. These features include:

* atoms combine with each other to form molecules and other extended structures;
* atoms and molecules are always moving;
* atoms and molecules can attract and/or repel each other; and
* atoms consist of parts that have positive and negative electrical charges.

It should be noted that CA NGSS in middle grades includes the first three of these features, but does not refer to the existence of electrical charges within atoms (or use the terms electrons and protons). Clearly, middle grade science teachers should know these atomic electrical charges, but what about middle school students?

A very relevant consideration is that CA NGSS also does not mention the periodic table of the elements until high school. This omission represents a very significant departure from most current practices, especially in California where the previous science education standards included the periodic table in grades 3, 5 and 8. Instructional Segment 1 in integrated grade seven follows the CA NGSS in not including the periodic table or naming the electrical charges within atoms. However, teachers may choose to include some of these concepts based on their classroom contexts, particularly to answer questions about what makes one kind of atom different from another kind of atom, or the electrical nature of the attractions that happen at the atomic and molecular levels.

These attractions and the movements of atoms are particularly important in **explaining** the nature of solids, liquids, and gases. Since students are familiar with the three states of water and have explored the water cycle in grade 6, H_2O provides a particularly attractive molecule (pun intended) to **model** the relationships among particle kinetic energy, particle attractions, properties of solids/liquids/gases and changes in physical state.

In Integrated Grade 6, students learned to explain that the temperature of a substance is a property that results from the average kinetic energy of the particles of that substance. This statement implies that any given sample of a substance will have particles that have different kinetic energies. Students should be able to demonstrate that understanding by **modeling** in various ways that the particles of a substance at any given temperature have a fairly wide range of kinetic energies. They should then **use these models as evidence** to support claims that the addition or removal of thermal energy (i.e., heating or cooling) changes the temperature of the substance because the average particle kinetic energies have changed.

Using water as an example substance, students can describe the everyday experience that heating water with electricity or gas adds thermal energy, such that the distribution of particle kinetic energies shifts to higher values As a result our bodily sensors (skin and mouth) and our thermometers indicate that the temperature has increased. Note that changes at the invisible particle level are causing changes at our macroscopic level of reality. The crosscutting concepts of both ***cause and effect*** and ***scale*** directly apply to these common experiences of temperature changes.

TABLE 3: Comparing Solids, Liquids and Gases		
Physical State	**Molecular Perspective**	**Macroscopic Properties**
Solid State associated with lowest temperatures and/or highest pressures.	Particles have least freedom of motion. Forces of attraction between particles lock them in their local neighborhood where they vibrate in place.	Solids maintain their volume and keep their shape independent of their container.

Liquid State associated with "moderate" temperatures and/or "moderate" pressures.	Particles have some freedom of motion. Forces of attraction keep each particle associated with nearby particles. Particles have too much kinetic energy for the attraction to lock them in place, so the particles slide past each other and change their neighborhoods.	Liquids flow as a unit and maintain their volume. Liquids adapt their shape to the shape of their container. If the container has more volume than the liquid, then the liquid does not fill the container.
Gas *(3) Students fill in this blank space third.*	*(2) Students fill in this blank space second.*	*(1) Students fill in this blank space first, then the middle and lastly the left column blank space.*

(Table developed by Dr. Art Sussman, courtesy of WestEd)

Changes in particle kinetic energy can have other dramatic effects at our macroscopic level, notably changes in physical state. Table 3 summarizes the particle interactions that happen under different conditions and the resulting macroscopic properties of solids, liquids and gases. Starting with water as the sample substance and temperature as the main variable, students can use everyday experience as **evidence** that as long as ice is not melting; the ice keeps its shape and the amount of space that it takes up (its volume). Similarly, their daily experiences reinforce that liquid water also keeps its volume, but that it will adapt its shape to that of its container. If the container is larger than the volume of water, the liquid does not fill the container. We tend to describe the glass as being half-full.

Students have already investigated the gas state in grade 5 and Integrated Grade 6, so they should have the knowledge to make the claim that the empty space in the unfilled glass actually has matter in the gas state (air consisting mostly of nitrogen gas and oxygen gas). If students have been provided with a copy of Table 3, they can work individually and then in teams to fill in the blank spaces in the bottom row for the gas state. Untying a filled balloon provides **evidence** that a gas does not have a fixed volume, and that it will go into whatever space is available to it. Students can use that and similar evidence to make a claim in the middle column of the bottom row that the gas state results from particles having so much kinetic energy that they break completely free of the attractive force that would keep them in the liquid state.

In the left-hand column of the phase change table, temperature and pressure typically have opposite effects. Mathematically inverse relationships often confuse learners. To **cause** a liquid to evaporate into a gas, we can increase the temperature or decrease the pressure. Students can **explain** this inverse relationship as arising from the competing effects of attractive forces and motion energy at the microscopic particle level. When the temperature is increased, the water molecules have so much kinetic energy that they break free of the attractive forces, and transition from the liquid state to the gas state. Pressure has the opposite effect. Increasing the pressure tends to make a gas condense into a liquid because the higher pressure forces the particles to stay closer together, experience more strongly the force of attraction, and not move away from each other. As a result, higher pressure ***causes*** condensation while higher temperature ***causes*** evaporation.

While this analysis of physical states is interesting for its own sake, it is particularly valuable because it illustrates a key physical science concept that NGSS emphasizes. The properties of materials at our macroscopic level result from the interactions and motions of particles at the level of atoms and molecules. Phenomena that we observe and wonder about result from structures and events that are happening at levels that we cannot see. Science helps us understand the atomic level structures and interactions, and technologies help us use that scientific knowledge to solve problems.
Students can use the crosscutting concept (CCC) of ***cause and effect: mechanism and explanation*** to understand the properties of solids, liquids and gases. As described in the CA NGSS, one feature of this CCC in the middle grade span is that, “Cause-and-effect relationships may be used to predict phenomena in natural or designed systems.” Up until grade 7, students probably have utilized this CCC only in situations that involved purely macroscopic considerations, such as using a force to cause the motion of a visible object to change. In describing that particle behavior ***causes*** the physical

states of water, this causality CCC helps build understanding of the phenomenon that is being studied. A corollary benefit of applying the ***cause and effect*** CCC in this case is that we expand the understanding of the CCC itself***. Cause and effect*** becomes an even more powerful CCC when students realize they can use it to understand and help **explain** phenomena at our level of reality as arising from interactions at the particle ***scale***.

The CCC of ***patterns*** also assists learning in Instructional Segment 1. Students **investigate** the macroscopic patterns of phase changes, such as how solids, liquids and gases behave. They also research the patterns of how temperature and pressure affect changes in these states of matter. In NGSS, the CCC of Patterns at the middle school level is also associated with the concept that, “Macroscopic patterns are related to the nature of microscopic atomic-level structure.” By including this aspect of the Patterns CCC in the instruction, the learning about the roles of particles in determining physical states of matter is assisted AND the understanding of the CCC is broadened. By experiencing the Patterns CCC in this way, students acquire a conceptual tool that they can use in many other contexts. When confronted with a puzzling phenomenon, their new habit of mind may prompt students to look for a ***pattern*** at the atomic level that will help them understand and **explain** the ***causes*** of that macroscopic phenomenon.

Students can apply what they have learned about states of water to predict the behavior of different substances. For example, atoms of helium do not react (attract or repel) with each other or with other atoms or molecules. What would students predict about the states of helium and its phase changes? How would helium compare with nitrogen, the main gas in air?

TABLE 4: Physical States at Normal Atmospheric Pressure			
ELEMENT	**GAS STATE**	**LIQUID STATE**	**SOLID STATE**
Helium	Above -270	Below -270	Never

Nitrogen	Above -196	From -196	Below -210
Copper	Above 2,560	From 1,084	Below 1,084

(Table created by Dr. Art Sussman, courtesy of WestEd)

As shown in Table 4, helium needs to be cooled a lot more than nitrogen in order to transition from the gas state to the liquid state. In addition, further cooling will ***cause*** nitrogen to solidify, but helium will never solidify at normal atmospheric pressure. However, with higher pressure, helium can solidify at about -272^{0}C. Students can make claims about the effects of changing temperature and pressure on the physical states of matter, and use **evidence** from different substances to support or disprove their claims. They should be able to **explain** why changes in thermal energy or pressure have these effects (e.g., higher pressure forces the helium molecules to be closer together so they can actually transition to the solid state). Students could also **argue from this evidence** about the relative strengths of forces of attractions between different molecules or atoms (e.g., that the evidence indicates that nitrogen molecules attract each other more than helium atoms attract each other).

Including the example of copper extends the learning by showing that even a metal will melt or turn into a gas if the temperature is high enough. Further, copper provides the contrasting example of an element whose atoms have a very strong force of attraction for each other. The very strong force of attraction makes it much harder for the particles to overcome that attractive force even when they have a lot of kinetic energy. As a result, copper tends to exist in the solid state even at very high temperatures. Yet, even the metal copper can melt or boil if its particles have enough kinetic energy.

While MS-PS1-4 focuses on changes in state and on temperature, MS-PS1-1 focuses on the atomic/molecular composition of matter. In Instructional Segment 1, students **develop and use a variety of models** to explore and describe the atomic composition of simple molecules. Succeeding Instructional Segments in grade 7 include life science and Earth science contexts that involve extensive discussion of simple molecules such as water, carbon dioxide, oxygen, and also somewhat more complex molecules such as glucose, the sugar product of photosynthesis. MS-PS1-1 also includes the concept of extended structures, referring to a different particle arrangement that is characteristic of metals, salts and many crystalline substances (see snapshot).

Instructional Segment 1 Snapshot:
Extended Atomic and Molecular Structures

This snapshot presents an example of how teaching and learning may look like in the classroom when the *CA NGSS* are implemented. The purpose is to illustrate how a teacher engages students in three-dimensional learning by providing them with experiences and opportunities to develop and use the science and engineering practices and the crosscutting concepts to understand the disciplinary core ideas associated with the topic in the Instructional Segment. A snapshot provides fewer details than a vignette (e.g., the Instructional Segment 2 Vignette “Organism Physical and Chemical Changes”).

Ms. V used lead pencils to introduce the topic of extended structures. She told students that the “lead” in the pencils is actually a form of carbon known as graphite. Ms. V projected a model showing how the carbon atoms in graphite connect with each other (Figure 3). She pointed out that the model just illustrates a tiny section of the structure that actually greatly extends in all three dimensions.

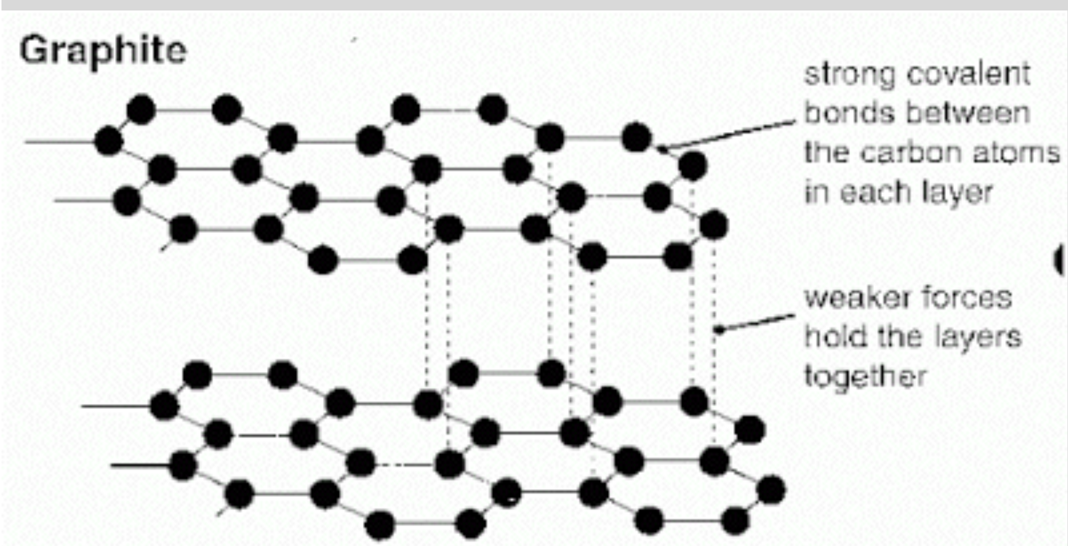

Figure 3: Model of the extended structure of graphite. Black circles are carbon atoms. Solid lines within layers are strong connections. Dotted lines between layers are weak connections. (IGCSE Chemistry Notes 2009)

In small groups, students listed the properties of the lead in their pencil, and discussed how the atomic structure might ***cause*** those properties. Ms. V also instructed the student teams to brainstorm different ways they might create physical models of graphite. Teams shared their discussions that resulted in a consensus claiming that graphite is a solid because of the very many strong connections among the carbon atoms. They also agreed that the weak connections between the layers ***caused*** graphite's ability to break off in flakes that leave marks on paper. As a result of small group and whole class discussions, the class decided on three different types of models that they would work in groups to build the next day.

Ms. V said that they could not work on building the models the next day unless they completed the homework assignment, which was to read and annotate a 1-page handout describing extended structures (Figure 4). The school district emphasized a literacy strategy called "Talk to the Text." By grade 7 students had sufficient experience with this strategy to proceed without further instruction. Ms V knew that many interesting concepts about molecular bonding and structures could emerge from the student reading, annotations and discussions, and she expected to see lots of comments on the handout (Figure 5).

HOMEWORK READING: Extended Structures

Many natural and synthetic solids consist at the atomic/molecular level of extended structures. These structures have repeating units that connect with each other in all three dimensions. As shown in the Table below, the repeating unit can be:

one neutral kind of atom (such as carbon atom);
two or more electrically charged atoms (called ions);
a small molecule such as a water molecule; or
a larger molecule such as a compound made of glucose and fructose.

Substances Made of Extended Structures		
Type of Repeating Unit	**Unit that Repeats**	**Macroscopic Substance**
One Kind of Neutral Atom	Carbon Atom	Graphite Diamond
Two or More Different Ions	Sodium Ion (Na^+) and Chlorine Ion (Cl^-)	Table salt
Small Molecule	H_2O	Ice
Larger Molecule	$C_{12}H_{22}O_{11}$	Packaged Sugar

The properties of the macroscopic substance are directly related to the kind of repeating unit and how the repeating unit is connected to itself within the extended structures. For example, both graphite and diamond are made just of carbon atoms. They are both solids, but graphite is so soft you can write with it, and diamond is one of the hardest known substances. The big difference is how the carbon atoms are interconnected at the molecular level.

Table salt is made of positively charged sodium ions and negatively charged chlorine ions (called chloride). Chlorine is a poisonous green gas and sodium is very explosive – if you put a chunk of sodium in water, it will cause a dangerous, big fire. Yet, the extended structure made of sodium and chloride ions is one of the safest substances. We put it in and on our food.

Packaged sugar and starch are examples of macroscopic substances where the repeating unit is a larger molecule that has more than 20 atoms connected to each other. Of course, the larger extended structure in all these cases has many millions of atoms connected to each other.

Figure 4: Homework handout from Ms. V for students to read and annotate. (Created by Dr. Art Sussman, courtesy of WestEd)

Students read and annotated the “Extended Structures” homework using a “Talk to the Text” Literacy Strategy. Students annotated questions, ideas and other comments that they had while reading and trying to make sense of the text.

Sample Annotated Text

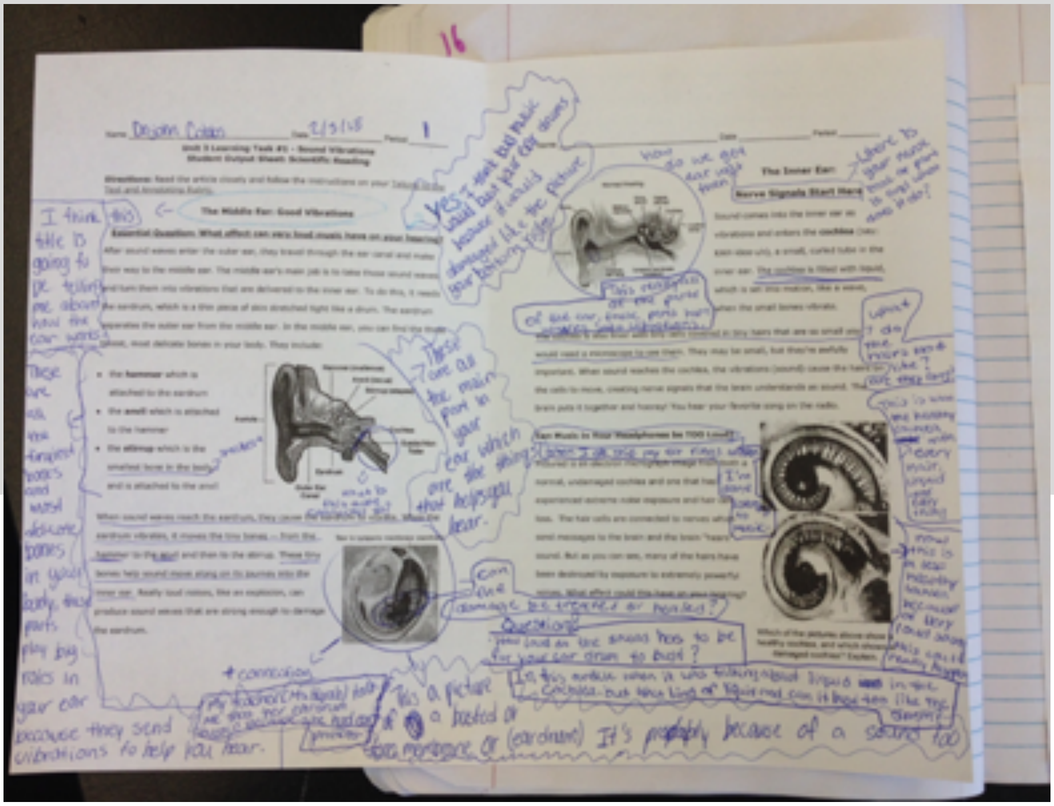

Figure 5: Sample of student annotated text from a different science homework reading. (Illustration courtesy of Oakland Unified School District)

After the students handed in their homework, they worked in teams that focused on building different physical **models** of graphite. One team had researched the structure of diamond and received permission from Ms. V to try to build a diamond model rather than graphite. While the students worked in their teams, Ms. V provided necessary guidance and also had some time to look through the homework to help plan for continuing discussions about substances, molecules and extended structures. She wrote a note to herself to look for and help elicit from the students the ***cause and effect CCC*** and the ***patterns CCC*** about the causal connection from the atomic particle level to the macroscopic level of substances that have distinctive and observable resulting properties.

NGSS Connections in the Snapshot

Performance Expectations

MS-PS1-1. Develop models to describe the atomic composition of simple molecules and extended structures.

Disciplinary Core Ideas

PS1.A: Structure and Properties of Matter

Scientific and Engineering practices

Developing and Using Models

Develop and/or use a model to predict and/or describe phenomena. Develop a model to describe unobservable mechanisms.

Obtaining, Evaluating and Communicating Information

Critically read scientific texts adapted for classroom use to determine the central ideas and/or obtain scientific and/or technical information to describe patterns in and/or evidence about the natural and designed world(s).

Crosscutting Concepts

Patterns

Macroscopic patterns are related to the nature of microscopic and atomic-level structure.

Cause and Effect

Cause and effect relationships may be used to predict phenomena in natural or designed systems.

Scale, Proportion, and Quantity

Time, space, and energy phenomena can be observed at various scales using models to study systems that are too large or too small.

ELD Connections: RST.6–8.1, 10; RI.7.3, 8; SL.7.1