Developing a Learning Progression for the Nature of Matter as it Pertains to Nanoscience

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The Domain

The nature of matter as it pertains to nanoscience-

Nanoscience research is rapidly developing strategies for creating new products and technologies by controlling matter at the nanoscale. New information and technologies from nanoscience research is and will continue to have broad societal implications that will be realized in many fields, including health care, agriculture, food, water, energy, and the environment. Moreover, nanoscience promises to have significantly greater impact on society than previous leaps in scientific knowledge because it represents a convergence of science disciplines on the nanoscale (Stevens, Sutherland, Schank, & Krajcik, 2006).

Nanoscience and nanotechnology incorporate aspects of chemistry, physics, biology and engineering to create highly interdisciplinary fields (Roco, 2001). One of the major challenges for bringing nanoscience and nanotechnology, as well as most emerging science, into the classroom is their interdisciplinary nature, requires students as well as science teachers to be able to integrate ideas from several topic areas in order to explain many nanoscale phenomena. Science is traditionally presented in a discipline-defined rather than cross-disciplinary manner. Thus, introducing nanoscience to the classroom requires changes in instruction, assessment and curriculum development. School curricula must begin to emphasize not only the learning of individual topics, but also the connections between them and assessments must be developed to support such a curriculum. In addition, we need to determine how to embed new ideas from nanoscience that are not traditionally covered in the current science curriculum. Learning progressions, which describe how students build their knowledge over a period of time (NRC, 2007), can help address this challenge. To this end, we are working towards developing a learning progression that can be used to determine (1) how do concepts logically and successively build upon other concepts?, (2) What grade level is appropriate to introduce particular concepts?, and (3) What are the critical connections between ideas that students need to make in order to understand the nature of matter as it pertains to nanoscience?

Nanoscience and nanotechnology are based largely in exploring, explaining and applying the novel, often unexpected properties of matter at the nanoscale. The fact that suspensions of gold nanoparticles are not necessarily gold in color, particles of copper smaller than about 50 nm are no longer malleable, and that a gecko can walk across the ceiling are all examples of nanoscale pheneomena. In order to explain these phenomena, it is necessary to possess a thorough understanding of matter, its properties and how it behaves under different conditions. While atoms are the building blocks for molecules, the building blocks for nanoscale structures and assemblies are atoms, molecules and other nanoscale structures and assemblies. The physical laws that describe the behavior of these building blocks are the same. Therefore, an important aspect of nanoscience literacy must include a robust model of not only the structure of matter, but also its properties and what determines those properties, as well as how matter behaves and interacts under a variety of conditions.

The learners-

The progression that we are building describes grade 7-16 students as they pass through the current science curriculum. We have collected data with students that belong to three distinct populations and have such experienced three different science curricula in quite different contexts. The middle and high school students were all from public school districts that were located in either a diverse, urban community where approximately half of the students were of low SES (N=36) or in suburban and rural, predominantly white middle-class communities (N=14). In addition, we interviewed undergraduates from a large Midwestern research university, both science and non-science majors (N=6).

The majority of middle school students were in seventh grade. The high school students were divided up into two groups, those who were in, or had taken chemistry, and those who had not. The middle and high school students were selected to fill out a 3-D matrix of educational level (middle school-expert), academic ability and gender. The academic ability was determined by their teacher and was not necessarily linked to their academic performance.

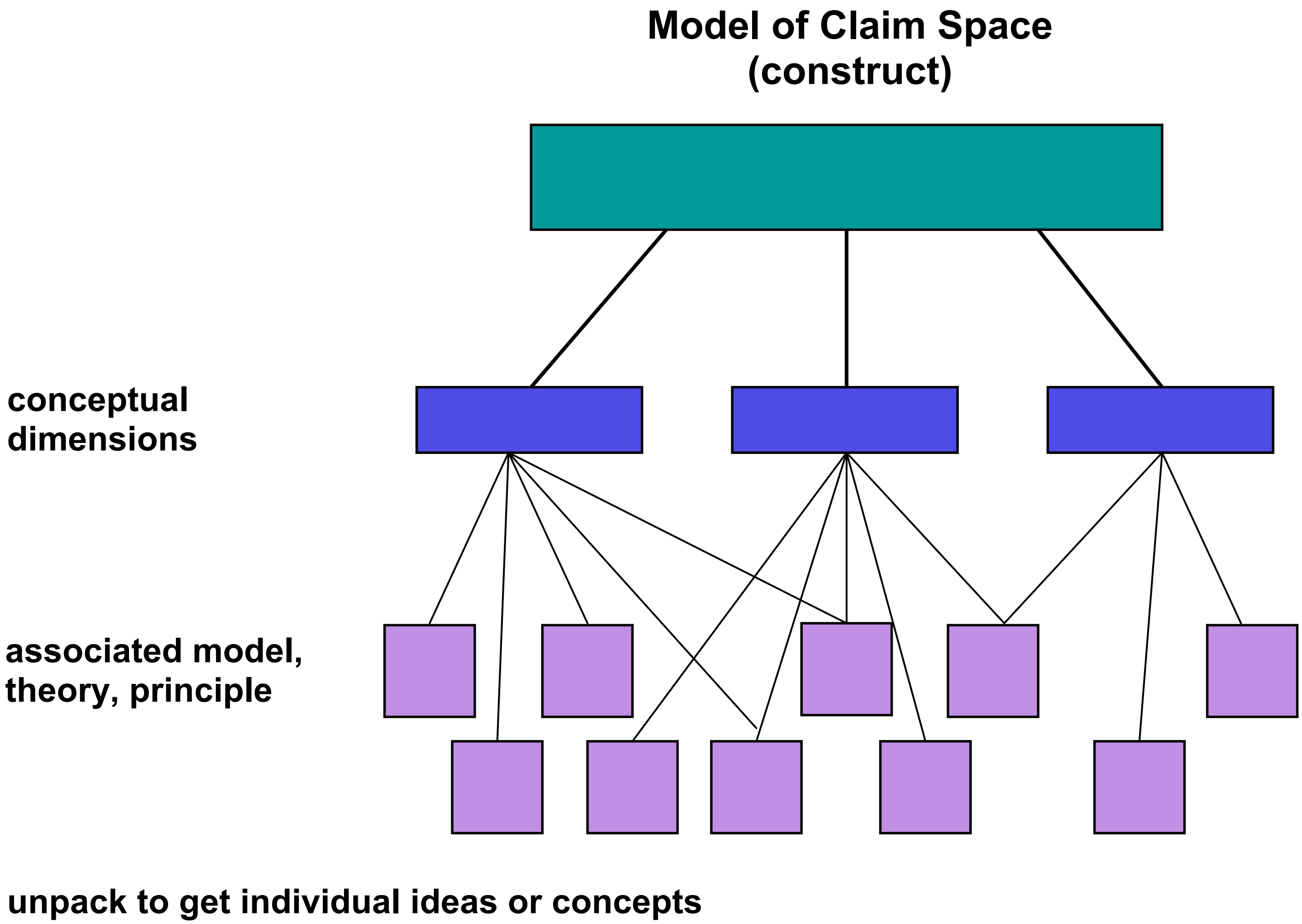
The undergraduates were from a select university and had all completed at least one year of high school chemistry. Those who are science majors had completed some undergraduate-level chemistry courses. Ultimately we will fill out a matrix of both science majors and non-majors, but here just report on a small sample of undergraduates from a select university.

In addition, we have also conducted interviews at a suburban grade 6-12 private school that serves a diverse middle- to middle-upper class community. However, this data is not included in the results reported here.

Process for Characterizing Target (claim space)

Creating a model that describes what the learner should know is the first step toward developing a learning progression (See Figure 1 for model). In our case, we developed a model that represents the set of ideas that defines expert understanding for the "Nature of Matter" as it relates to nanoscience. Similar to the development of the Force Concept Inventory, we divided the space up into four "conceptual dimensions" (Savinainen & Scott, 2002; Hestenes, Wells & Swackhamer, 1992). Each of these dimensions is related to one of the 'big ideas' of nanoscience (Stevens, Sutherland, Schank & Krajcik, 2007): 1) Structure of Matter, 2) Size-Dependent Properties, 3) Forces and Interactions, and 4) Quantum Effects. Ideas that describe principles or theories related to, or necessary for understanding nanoscale phenomena were collected and categorized within these four conceptual dimensions. For example, because electric forces play such an important role at the nanoscale, we are interested in thoroughly probing the continuum of forces that hold nano- and atomic scale objects together. However, we chose not to assess student understanding of the compressibility of a gas because it is much less relevant for working on the nanoscale. Because of the interdisciplinary nature of the field, many ideas fall into multiple dimensions.

Each of the principles and theories were then unpacked to define what it means to understand them. Together, these sets of ideas define the “claim space” (See Appendix A for our claim space).

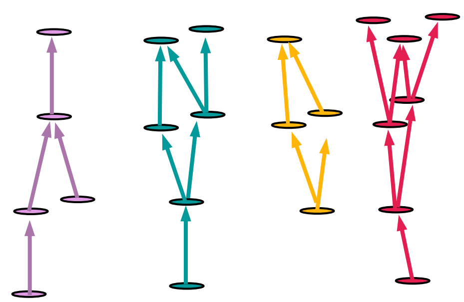


Framework for Describing Knowledge and Practice

Multi-dimensional LP (connections) vs Uni-dimensional LP (complexity)

The integration of knowledge is made more difficult by typical large-scale and classroom assessments ostensibly based on the standards that focus on low levels understanding such as describing and recalling. These assessments commonly focus on targeted, isolated topics that do not require students to connect currently taught concepts with concepts from other science areas that were previously learned (NRC, 2005; Pellegrino, Chudowsky, & Glaser, 2001). Instead, these assessments encourage teachers to focus on isolated bodies of knowledge that ultimately results in compartmentalized application of science concepts. As a result, the traditional curriculum often compartmentalizes the various aspects of the study of matter (e.g. structure of matter, conservation of matter, chemical reactions, phase changes). Thus current assessment and instruction practices can largely be described as linear in nature. A representation of this manner of instruction and assessment is depicted in Figure 2.

Figure 2. Representation of the isolated manner in which topics are typically introduced to students in the classroom. Each color represents a different, but related topic (e.g different chapters in textbook). The arrows indicate progress towards a more sophisticated understanding of the topic.



In order to make progress towards building students' understanding of science and scientific practice, it is necessary to begin thinking about learning with a multi-dimensional model. Conceptual understanding infers that students have the ability to transfer knowledge and apply it to related problems and to make connections between related ideas (Bransford, Brown and Cocking, 2000). The ability to make connections and apply knowledge is especially important as students build understanding within the 'big ideas' of science in general. The very nature of big ideas means that they encompass knowledge from a variety of disciplines, that the ideas can explain a host of phenomena, and that this knowledge must be built up over a number of years (Smith, Wiser, Anderson, & Krajcik, 2006). Thus, a learning progression for a 'big idea' in science should describe a progression of *sets* of ideas instead of isolated strands of knowledge (Figure 3). Therefore, it is important to identify and characterize not only the ways in which students develop understanding of the important concepts within individual, related topics under the umbrella of the big idea, but also how they connect ideas between the related topics.

The authors of documents such as Benchmarks for Science Literacy (AAAS, 1993) and the National Science Education Standards (NRC, 1996) suggested connections between key concepts among multiple disciplines in the sciences. However, these connections have not been borne out in most science curricula nor are they a part of typical assessment practices. As science progresses, it becomes ever more apparent that the scientific disciplines cannot advance in isolation. Likewise, as we begin to address interdisciplinary subject matter in the classroom, such as emerging science or the big ideas of science in general, we can no longer do so. Rather, we define learning progressions as strategic sequencing that promotes both branching out and forming connections between ideas related to a core scientific concept.

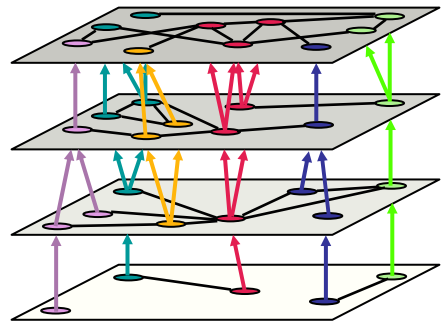


Figure 3. A representation of a progression of sets of ideas within a group of related topics. Each color represents a different topic within the nature of matter. The colored arrows depict progress towards better understanding along a single strand. The black lines represent the connections between the ideas that students should be able to make. The planes designate the sets of ideas in the progression towards building conceptual understanding.

In order to build a deep understanding of the nature of matter, students must be able to connect many related ideas. For example, in order to explain the difference between the formation of a salt (NaCl) and a diatomic gas (Cl_2), they must understand many ideas related to atoms and their structure and how they interact. In particular, students must know that atoms are the fundamental building blocks of matter. In addition, they must know the composition of atoms, and that the configuration of electrons, especially the outermost electrons, influences the manner in which atoms can interact. They must know that the arrangement of atoms is an important determinant of the properties of the substance and that electric forces hold atoms and molecules together and how that affects bond energy. They also must connect those concepts to knowledge of how the electrons behave. In particular, they must understand that the likelihood that an atom accepts or donates an extra electron is predicted by the Periodic Table. The difference in the tendency to accept or donate electrons plays a role in the type of electric forces that govern the interactions between atoms. Thus, students must be able to integrate ideas from several different topics in order to explain the formation of these two substances. These ideas cannot be developed at once but must be built up over time in conjunction with rich experiences. Most importantly, these ideas will only develop if students have developed other important build blocks of understanding.

Because of the complexity and interconnectedness of the concepts, we cannot simply build a learning progression for a concept such as this. First, we must build a more traditional, uni-dimensional progression, which tracks how students build knowledge about the individual ideas. In this case, those ideas are the development of the atomic model, chemical bonding, periodic properties, etc. We develop a learning progression for each of these models or principles. Each learning progression documents how students move from a naive model to one that is more sophisticated and increasingly scientifically accurate.

We build the progressions using cladistics methodology. For example, a progression may consist of six progressively more complex or sophisticated ideas **A**-**F**. The data is analyzed such that if a student understands **D**, then he also understands **A**-**C**, but not **E** or **F**. After we have a set of individual progressions, we work to link them together using a similar methodology to create a multi-dimensional progression.

Defining the Intermediate Steps and Transitions

We have begun to build a preliminary progression that describes how students develop their models of the structure of matter. We grouped several related individual ideas to build up an expert model for the particle model of matter (Table 1). The ideas were sorted by the percentage of total students that held these ideas. The majority of students believe that solids are made of particles (83%). However, fewer (approximately half) were able to express both verbally and through drawings that the particles were arranged in an ordered, compact manner in a solid. Likewise, about half of the total students made the connection that the particles are atoms. We currently cannot tell which idea students tend to hold first. The understanding that the atoms are in constant motion and the importance of their arrangement comes much later in the students' model development. 31 of 35 students fit the progression through the kinetic model. 29 of 35 students fit the entire progression. This means that for 29 of 35 students, if a student understands P6, then she also understands P1-P5.

Table 1.

Particle model of matter (solid)		
Individual Idea		**% of total students**
P1	Particulate model of solids; does not necessarily understand the nature of an atom	83%
P2	Particles are arranged in a compact way	50%
P3	Particles are arranged in an ordered way	44%
P4	The particles are atoms; understands the nature of atoms	42%
P5	The particles/atoms are in constant motion	12%
P6	The arrangement of atoms determines the properties	7%
P7	The arrangement of atoms determines the substance	6%

Since the majority of students held a particle model of matter, we evaluated how they characterized the particles themselves (Table 2). The table describes the percentage of students characterizing the particles/atoms and compares how student understanding differs in relation to whether they have made the connection that the particles are atoms. When students hold a particle model of matter, they may not have made the connection that the particles are atoms. Often students might use the term 'atom' to describe the particles, but really lack an understanding of the nature of atoms (e.g. the dimensionality of atoms, the consistency of size and shape, and the atoms on the edge (surface)

Table 2.

CP Characteristics of particles-		
Individual Idea	**% students particle model**	**% students particles are atoms**
Dimension of particles (2D or 3D)	45%	100%
Particles on the surface vs. bulk particles	25%	86%
Consistency of size	33%	83%
Consistency of shape	29%	80%

versus those in the bulk. This understanding appears to come later (P4), at which point they also seem to have a better conception of the characteristics of the particles that make up matter.

We then sought to characterize how students progress towards building their models of atoms. Table 3 contains the individual ideas that fall within Atomic Model and the percentage of total students that understand them. A majority of students possessed the declarative knowledge that "all matter is made up of atoms". However, only half of those students knew anything about the structure of the atoms. While the electron cloud model appeared to be relatively accessible, discussion of probability to explain electron behavior was rare. 29 of 33 students fit the progression represented in Table 3. Two of the nine students did not state that all matter is made up of atoms even though they used atoms as part of their model of a solid.

Table 3.

Atomic Model		
Individual Idea		**% of total students**
A1	All matter is made up of atoms	72%
A2	Atoms are made of protons, electrons and neutrons	39%
A3	Protons and neutrons make up the nucleus which is surrounded by electrons	39%
A4	Protons and neutrons are approximately of the same mass, which is much greater than the mass of electrons	31%
A5	Electron cloud model	28%
A6	The relative number of protons, electrons and neutrons is important	23%
A7	Probability model for electron behavior; Heisenberg Uncertainty Principle	9%

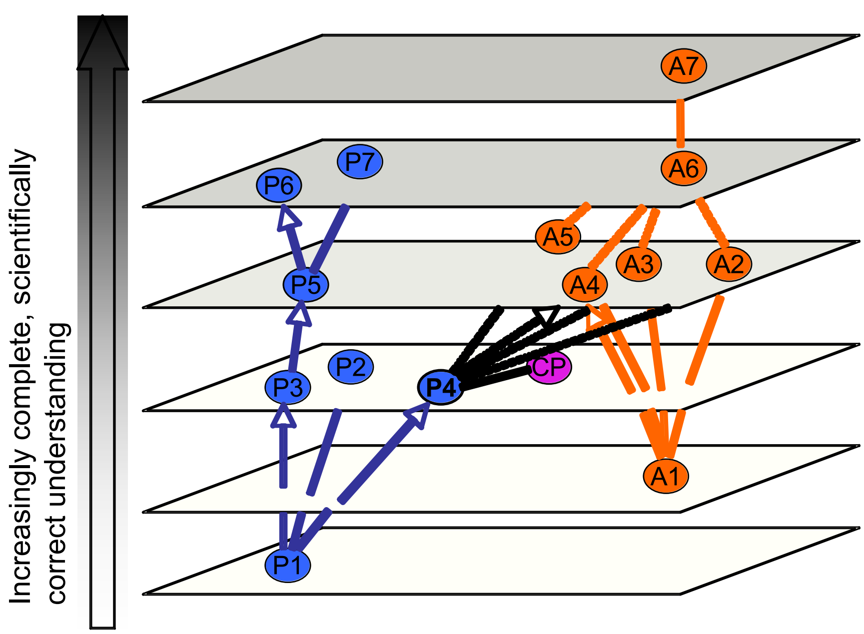


Figure 4. Part of a preliminary multi-dimensional progression of ideas for the 'Structure of Matter' are depicted. Tentative connections are depicted with dashed lines. The connections are tentative because we cannot definitively define the progression between A2, A3, A4 and A5 with our current data set. Most of the students that understand that the particles are atoms are able to begin to understand parts of the structure of atoms. The solid black line depicts a connection within the same plane.

From this data, we can begin to construct a preliminary multi-dimensional learning progression for the Structure of Matter dimension of our model for the Nature of Matter as it relates to nanoscience (Figure 4). We found that students do not hold robust ideas about the characteristics of the particles that make up solids until they make the connection that the particles are atoms. Similarly, from the progression of ideas for the Particle Model of Matter, it appears that the concept of atoms comes in later than students' belief that solids are particulate.

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Appendix A- *Nature of Matter as it pertains to nanoscience- (claim space)*

Particle model

Dimension				Claim
S	P	F	Q	***Students know that:***
				the stuff everything is made of is matter
				matter is made up of particles
				the particles that make up matter are too small to see
				the particles that make up matter are too small to see with a light microscope
				the particles that make up matter are actually atoms

Atoms

Dimension				Claim
S	P	F	Q	***Students know that:***
				atoms make up all of matter
				atoms are the smallest unit of an element and are therefore considered to be the fundamental building block of matter

What about cell vs atom?

Size of atoms

Dimension				Claim
S	P	F	Q	***Students know that:***
				atoms are too small to see with the naked eye
				atoms are too small to see with an optical microscope
				atoms of same type are same size
				all atoms are ~1-2Å in diameter

Composition of Atoms

Dimension				Claim
S	P	F	Q	***Students know that:***
				atoms are made of electrons, neutrons and protons
				neutrons and protons are of similar mass, electron mass is much smaller
				electrons are negatively charged, protons are positively charged, and neutrons are neutral
				the number of protons determines the type of element
				the outermost electrons determine how an atom can interact with other atoms
				an ion is created when an atom or group of atoms has a net surplus or deficit of electrons
				certain atoms (or groups of atoms) have a greater tendency to be ionized than others

Structure of Atoms

Dimension				Claim
S	P	F	Q	***Students know that:***
				atoms consist of a positively charged nucleus surrounded by negatively charged electrons
				electrons are in constant motion
				electrons exist in "orbitals"
				a certain number of electrons are allowed in each orbital at which point the orbital is 'filled'
				the electron orbitals/shells take up the majority of the space of an atom
				the energy of the electrons within an atom is quantized
				electron motion within an atom cannot be predicted by the solar system model
				electrons exhibit particulate and wavelike behavior
				the electron cloud model describes the probability of the electron location
				The position and momentum of an electron cannot be determined simultaneously (Heisenberg's Uncertainty Principle)

Elements

Dimension				Claim
S	P	F	Q	***Students know that:***
				~100 elements make up all matter
				the Periodic Table indicates the number of protons in an atom
				the Periodic Table indicates the number of electrons in a neutral atom
				the Periodic Table indicates the number of electrons in the outermost shell/orbital
				the Periodic Table predicts many properties of elements
				the Periodic Table predicts how a certain type of atom will interact with another atom

Kinetic theory-

Dimension				Claim
S	P	F	Q	***Students know that:***
				particles/atoms are always in motion (except at 0° K)
				the degree of motion of the particles/atoms depends on the temperature (increases with increased temperature, decreases with decreased temperature)
				the degree of motion of the particles/atoms can affect the properties of a substance
				a great number and variety of chemical, biological and physical phenomena can be explained by changes in the motion and arrangement of atoms and molecules

Arrangement of particles

Dimension				Claim
S	P	F	Q	***Students know that:***
				different arrangements of atoms compose all substances
				atoms may stick together to form molecules
				atoms may pack together into large, extended arrays
				the arrangement of particles/atoms determines what the substance is
				the arrangement of particles/atoms is important for determining the properties of a substance
				the arrangement of atoms in a molecule determines the properties of the molecule
				there is empty space between the atoms/particles
				metals have delocalized electrons between atoms

Properties-

Dimension				Claim
S	P	F	Q	***Students know that:***
				objects and substances can be described by physical properties (e.g. color, size, shape, mass, texture, etc.) and that these properties that can change are often called extensive properties*
				more reliable properties for characterizing a substance are properties like melting point, boiling point, density, etc. because they do not change with the amount of substance (macro); these properties are often called intensive properties*
				the properties of the bulk substance are not the same as those of its individual atoms or molecules
				as the amount transitions between the macro- and atomic scales (i.e. the nanoscale), matter can exhibit unique, often unexpected properties that are different than those observed on the macro- or atomic scales.
				properties that depend on volume change out of proportion to properties that depend on area or length
				changing temperature causes changes in the properties of materials
				the properties of the whole may be very different from the properties of its parts

* only true on the macro- or bulk scale

States of matter-

Dimension				Claim
S	P	F	Q	***Students know that:***
				most substances can exist as a solid, liquid or gas depending on temperature
				the atomic and kinetic theories together explain the behavior of substances as they are heated and cooled.
				the particles exhibit different degrees of order depending on the state (solid > liquid > gas)**
				the relative motion of particles/atoms/ molecules changes depending on the state (solid < liquid < gas)** In solids, the particles are closely locked in position and can only vibrate. In liquids, the particles have higher energy, are more loosely connected, and can slide past one another (4D/3); this is why

				liquids flow and can take the shape of the container
				there is empty space between particles; the amount of space is related to the phase it's in (solid < liquid <<gas)
				When a solid is heated until it melts, the atoms or molecules within the material increase their movement, which decreases the order of the particles; there is slightly more space between the particles
				changing temperature causes changes in the properties of materials

** gases are not particularly relevant for nanoscience

Solids-
- maintains shape

Physical and chemical changes-

Dimension				**Claim**
S	P	F	Q	***Students know that:***
				matter is conserved upon melting
				matter is conserved during a physical change
				chemical changes involve rearrangement of atoms; physical changes do not necessarily involve rearrangement of atoms.

Forces

Dimension				**Claim**
S	P	F	Q	***Students know that:***
				four types of forces govern all interactions: gravity, electromagnetic, strong and weak
				every object exerts a gravitational force on every other object; the strength of the interaction is dependent on mass
				the strength of the gravitational force between two objects is dependent on mass and the distance between two objects
				electric forces depend on charge
				because of the small mass of objects on the nanoscale, the strength of the interaction due to

				gravitational forces is negligible on this scale
				there are two types of charge—positive and negative
				opposite charges attract; like charges repel
				electromagnetic forces dominate interactions on the nano- and atomic scales
				even without touching, electrically charged materials attracts all other materials and may either push or pull on other charged materials
				friction is an electric force

Interactions

Dimension				Claim
S	P	F	Q	***Students know that:***
				there is an attraction between particles/atoms/ molecules within a substance
				ionic bonds are classified as bonds that are based on electrostatic forces between two oppositely charged ions
				covalent bonds are characterized by the sharing of one or more electron *pairs* between atoms; this interaction holds molecules together
				the term covalent bonding tends to be used to describe interactions between non-metals that have similar electronegativities.
				covalent bonds often have an ionic character to them and are called polar covalent bonds; all ionic bonds have some covalent character
				the degree of polarity of a polar-covalent bond depends on the electronegativity and polarizability of the atoms involved.
				When a molecule has a permanent electric dipole moment, it is a polar molecule.
				Introducing a non-polar molecule to an electric field can create an induced dipole moment by causing distortions in the electron distribution.
				Instantaneous induced dipole moments occur when the focus of the distribution shifts momentarily, thus creating a partial charge.
				van der Waals forces, or London dispersion forces, result from the attraction between the instantaneous electric dipole moments of neighboring atoms or molecules. Thus, they can be characterized as induced-dipole/induced-dipole interactions.
				van der Waals forces act on *all* types of atoms and molecules, but increase in strength with an increasing number of electrons.

				hydrogen bonds generally occur between H-atoms attached to a highly electronegative element (most commonly O-, N-, or F-atoms) with high electronegativity that have a lone pair of electrons in their outer shell. The influence of less electronegative counterparts than O-, N- or F-atoms significantly diminishes the strength of the interaction.
				hydrogen bonds have both a dipole-dipole and covalent nature to them.
				intermolecular/inter-particle interactions are governed by many of the same electrical forces as the interactions between atoms that are generally described as bonds
				polarizability is a measure of the potential distortion of the electron distribution.
				polarizable atoms and ions exhibit a propensity toward undergoing distortions in their electron distribution.
				greater polarizability is observed for larger atoms and ions due to the decreased influence of the postitively charged nucleus on the outer electrons.
				the outer shell of electrons is involved in inter-atomic interactions
				in metals, free electrons are delocalized and shared among a lattice of atoms
				metallic bonding is an electrostatic attraction between many nuclei of metal atoms, or ions, and the delocalized electrons
				small objects (atoms, molecules, nanoparticles, etc.) can interact in a variety of ways, all of which are electrical in nature; these interactions create a continuum of electric forces that describe all interactions within matter on that scale, the strength of which depends on the entities involved.

Cells shaded grey, are not necessarily relevant to nanoscience.

S Structure of matter
P Properties of matter
F Forces & Interactions
Q Quantum Effects

Appendix B-

The knowledge that students need to understand is clarified by the evidence that is chosen to prove the desired level of understanding—(that students understand the concept the way you want them to understand it). These are excerpts of a more elaborated claim space than that shown in Appendix A.

Atoms

Claim	Evidence	Task
Students know that:	***Students should be able to:***	
All matter is made up of atoms, which are far too small to see directly through a microscope	explain that all matter is made up of atoms and that they are the fundamental building block of matter. This means that if they are broken up, they lose their identity.	Why are atoms important?
	communicate a model of matter that includes atoms as the building blocks.	Imagine that we have an instrument that lets us "zoom in" and see what it's made of – What do you think the surface would look like? Will you draw it for me? Explain to me what I'm looking at.
	provide an explanation of how the student knows that atoms are too small to be seen with a microscope. Optical microscopes are only effective for observing objects greater than ~0.5 µm. Atoms and molecules are not visible using the optical microscope, therefore, they must be smaller than 0.5 µm.	How big are the particles/atoms?
	state that all atoms are ~1-2Å in diameter	
This includes knowledge that:		

- atoms are the smallest unit of an element - atoms are considered to be the fundamental building block of matter - atoms are too small to see with an optical microscope - atoms of same type are same size - all atoms are ~1-2Å in diameter		

Atomic Model

Claim	Learning Performance & Evidence	Task
Students know that:		
The nucleus, a tiny fraction of the volume of an atom, is composed of protons and neutrons, each almost two thousand times heavier than an electron. The number of positive protons in the nucleus determines what an atom's electron configuration can be and so defines the element. 4D/2…	Students communicate their model of an atom and explain it. The model should contain protons, neutrons and electrons. This should establish what they know about the composition of atoms and the level of model to which they adhere (Bohr, electron cloud, probability)	Draw a picture of what you think an atom looks like and explain it.
	Students should describe the relative sizes and masses of the components of an atom.	Is your drawing to scale?
	Students should be able to explain why the relative number of protons, neutrons and electrons is important. Ideally, they should relate it to the Periodic Table—the atomic number represents the number of protons in an atom of a given element. Therefore, changing the number of protons changes they type of atom. Neutral atoms have equal numbers of protons and electrons.	Is the number of protons, electrons, neutrons important? Why?
This includes knowledge that:		
- atoms consist of a positively charged nucleus surrounded by negatively		

charged electrons - electrons are in constant motion - electrons exist in "orbitals" - a certain number of electrons are allowed in each orbital at which point the orbital is 'filled' - the electron orbitals/shells take up the majority of the space of an atom - the energy of the electrons within an atom is quantized - electron motion within an atom cannot be predicted by the solar system model - electrons exhibit particulate and wavelike behavior - the electron cloud model describes the probability of the electron location - The position and momentum of an electron cannot be determined simultaneously (Heisenberg's Uncertainty Principle)		

Appendix C- *Interview protocol*

Structure of matter

Verbally scaffold. DO NOT use the term atom or molecule.

I have this sheet of metal. *(Hand it (4"X6"sheet of flashing) to them so that they can touch it, etc.)* Imagine that we have an instrument that lets us "zoom in" and see what it's made of – What do you think the surface would look like?

Will you draw it for me?
Explain to me what I'm looking at. *(probe as necessary)*

If they don't get down to the atomic/molecular scale, then continue to find out their perception of fundamental structure. (If student doesn't understand, ask him/her to draw what a "speck" of metal looks like from very close, "blow it up big on this paper".)

-OK, now let's zoom in some more. Does the surface still look the same?
-What does it look like?
-Can you draw it for me?
-Describe your picture to me… *(probe as necessary)*

If they draw particles-

- What are those dots (or whatever) you have drawn?
- Tell me about them.
- What do they represent?
- How big are they?
- About how many do you think there are in the whole sheet?

(whatever's appropriate from the picture)
Those particles are in a very regular pattern.

-What makes them arrange like that?
-Do they have to be in that arrangement?
-What makes them stay that way?
-Why don't they fall apart?
-What's in the space between the particles?
-Are they 2D or 3D (like penny or marble)

-How many particles do you think are stacked up to make the metal this thick?

This edge looks looks like it would be lumpy. (point to edge the last row of circles)
-Why does it feel so smooth?

if say cut or polished, etc.--

Would you draw what you think the edge looks like?

Now let's heat the metal and melt it.

-What do you think melting means?
-What is happening when it melts?
-Is anything happening to the particles? (size, shape, number)

Would you draw a picture of what it looks like now?

-Explain what I'm looking at.

Probe as necessary-

You have drawn some difference between the pictures of the liquid and solid form of this substance.

-Is there anything different about the particles in this liquid versus the solid up here?
-Are they the same?

It looks like you drew more space between your particles here than in the solid.

-Why is that?
-What's in that space?

OR

You haven't drawn any particles in the liquid.

-What happened to them?

Change of properties with scale—change in dominant force

Now we're going to talk about a different substance. Here are 3 forms of sugar—a big crystal or rock candy, granulated sugar and powdered sugar.

-Would you still consider these to be the same substance?
If no, -why not?

(note- for 7th grade especially, make sure that they know what a substance is. Define it for them if they don't)

-Which properties do you think are the same? Different?

-Do you think the sugar act the same way no matter what size it is?

Here is a little experiment using our sugar samples.

Pour the granulated sugar and powdered sugar off of the black contact paper. ***Do not tap on table.***

-Do you notice any differences in the behavior of the two samples?
-What differences do you see?
-What do you think causes those differences?

If necessary-

Part of the card is covered with a single layer of powdered sugar, and part has some clumps of sugar.

-What's keeping it from falling down?
-What's keeping the clumps together and stuck to the card?
-How come most of the powdered sugar did fall down?
-Why aren't there any clumps on the regular sugar card?

OK, now powdered sugar is made up of pretty small pieces but we can keep crushing it up even more. How long can I keep crushing it up? What is the smallest piece of sugar there can be?

If get molecules--

-Is there anything different about properties of sugar molecules than the sugar we see here?
-What makes the molecules come together and stay together to make the substance that we can see and use?
-Is this going to be the same for any substance? Even liquids?
- How do water molecules interact? Can you draw 3 of them for me?

If get "disappeared" or "it's gone", etc., probe further.

Do you mean completely gone, or too small to see?

- If the latter, then invoke the special tool to see and another to cut tiny things.

Here is another substance that looks a lot like sugar. However, it came from a chemistry lab. How can we tell them apart?

- probe for properties, tests learned in science class, etc.

Nature of Atoms

Now I'd like to talk about atoms.

If they never mentioned atoms above,

-Do you know what an atom is?

Otherwise, keep going.

-Why are atoms important?

If they say that "atoms make up all of matter, and they didn't use the term in their earlier drawings,
How do atoms relate to the pictures that you drew for me earlier?

Think about what an atom looks like.
  - Would you please draw a picture of an atom for me?
Describe what I'm looking at.

If they get to protons, neutrons and electrons-
Tell me about p, n and e.
  - How do they **compare?**
    - is your drawing to scale?
    -mass, size, charge
    -location (nucleus vs electrons)
    -behavior (movement, etc.)
  - Is the number of p, n, e important?
    (Is there always the same number of each in each element?)

If they draw orbitals, but don't say anything about electron movement-
That looks a lot like a solar system. Do the electrons orbit around like planets?

Electric forces-

Atoms combine to make up all of the substances around us. Two examples are chlorine and sodium chloride.
(give them the periodic table and a paper with formulas written on them.)

-Can you explain why the atoms combine in these ways?
  If necessary can reword as-
    -What determines how atoms can combine?
  Feel free to write on the paper if that's easier for you.

-What is different about how these two substances are formed?

-What would 10 Cl_2 look like? 10 NaCl?