Introduction to the Workshop: Identifying and Clarifying Nanoscience Learning Goals

What is the purpose of this workshop?

Nanoscience is a new and emerging field that has made substantial scientific breakthroughs in recent years. New information and technologies resulting from this research will continue to have broad societal implications in many fields, including healthcare, manufacturing, agriculture, food, water, energy, and the environment.

To understand the new discoveries and technologies resulting from nanoscience research, and thus be capable of informed citizenship, we need a population with a high degree of science literacy. It is the responsibility of our national, state and local education leadership to prepare a much larger cross-section of our population with the science and engineering knowledge required to function in a highly technological society and to maintain the momentum of discovery and innovation that will sustain our economic prosperity. Unfortunately, on international studies of educational performance in science and mathematics, U.S. high school graduates ranked near the bottom (AAAS, 1990).

To meet this national need and address this crisis, the National Science Foundation has funded various projects to create materials that can inform children and the public about nanoscience and change the way science education is taught in this country. Developers often struggle as they choose and prioritize the concepts on which to focus, work to frame these concepts in terms of learning goals, align these learning goals with national standards, and sequence these major concepts so 7^{th}-12^{th} grade students in science can develop a deep understanding of these ideas. Teaching nanoscience without a foundation of learning goals is a challenge for practitioners and teachers; therefore, we are convening as leading experts in nanoscience, the learning sciences, and science education to begin to do this work.

Why emphasize learning goals?

We will integrate our learning goals with learning goals based on the national standards in order to help students in grades 7-12 develop a deep understanding over time of scientific ideas related to nanoscience. Accomplishing these goals will support the various national groups who have undertaken the task of developing educational materials and professional development experiences for nanoscience education.

Aligning all parts of the system to learning goals fosters the development of instructional tools and resources, educational experiences for teachers, research studies, and policies that are focused on improving student learning and achievement. Thus, identifying a set of agreed upon learning goals for nanoscience will ensure that all components of the education system, including curriculum, instruction, and assessment, will be aligned.

What will this workshop entail?

At this workshop, we will identify, elaborate and reach a consensus about the core concepts and principles for nanoscience education. Core concepts and principles represent the “big ideas” of the field. Big ideas 1) help learners understand a variety of ideas about nanoscience, 2) provide insight into the development of the field or have a key influence on explaining the major ideas in the domain, 3) provide ideas/models to explain a range of phenomena, and 4) allow learners to intellectually make individual, social, and political decisions regarding science and technology. Together, we will discuss these big ideas and turn them into learning goals that specify what students are expected to learn and be able to do with important concepts.

In the workshop, we will come to a consensus about learning goals as we:

- Identify and clarify the major concepts and principles of nanoscience;
- Clarify the meaning of these core concepts and principles;
- Specify the learning goals that emerge from the major concepts and principles;
- Determine how these learning goals align with national standards; and
- Establish where related national standards do not yet exist.

One of the main tasks at the workshop is for small groups of participants to unpack the nanoscience learning goals. This involves breaking apart, expanding and elaborating on the complex ideas stated in the relatively succinct standards. Unpacking also involves identifying the necessary teacher knowledge, as well as prior knowledge and possible misconceptions that students might have, which ultimately help to provide clarity to the learning goal. As part of our work, we will also identify phenomena that help illustrate the learning goal. One detailed example of what we mean by unpacking a learning goal is provided in the appendix. Aaron Rogat, Joe Krajcik, Yael Shwartz from the University of Michigan, and Jo Ellen Roseman from Project 2061 spent many hours unpacking this benchmark. Although we do not expect this same level of detail to be accomplished at the workshop, we hope to achieve this level eventually. At the conclusion of the workshop, we would like to have rough drafts of 4-6 unpacked learning goals.

Ultimately, we will create a learning progression for each of the nanoscience learning goals developed at the workshop. A learning progression is a sequence of successively more complex ways of thinking about an idea that might reasonably follow one another as students go through school.

What are the projected outcomes?

The documents we will create include the following:

- A Foundations monograph that will speak to teachers and administrators
- A webpage with information for materials developers, members of the NSEC, MRSEC, NISE, NCLT and NSF communities, and researchers
- A journal article that will address the issues of researchers and developers

We will also present our results at various national conferences. Together, these documents and presentations will inform various groups of the major learning goals in nanoscience.

The products of this workshop will address three audiences:

- Classroom teachers and administrators
- Nanoscientists and educators interested in contributing to the development of materials for students
- Researchers in science education/learning sciences

We do not suggest that these documents will be the final word on nanoscience learning goals, nor that the learning progression we propose will be the only one possible. Instead, our efforts will serve to open the conversation on this important work, and will help identify areas of research necessary to support the learning trajectory that is developed.

Appendix

The benchmark below is from the "Flow of Matter and Energy" section of "The Living Environment" (AAAS, 1993). We purposely chose an example unrelated to nanoscience.

Full Benchmark (AAAS 6-8: 5E2):
Over a long time, matter is transferred from one organism to another repeatedly and between organisms and their physical environment. As in all material systems, the total amount of matter remains constant, even though its form and location change.

Idea A (5E2)
Over a long time, matter is transferred from one organism to another repeatedly and between organisms and their physical environment.

What do kids need to understand here?
What are the general interactions that we are talking about here? All living organisms interact with their physical environment in order to survive and function. One of the very basic interactions is the transfer of matter. The substances that get in the organism undergo chemical reactions (which are essential for the organism's survival). In those chemical reactions the arrangement of atoms is changed and new substances are produced (from "old" ones), but the total amount of matter remains constant (see Idea B). Some of the products are transferred out of the organisms' body to the environment.

- What is the matter being transferred here? Carbon, oxygen and hydrogen (should we mention nitrogen?) are all different types of atoms that are transferred between organisms and between organisms and the environment. However, carbon is a central component of all the matter being transferred. Since this transfer of matter happen continuously, repeatedly, and endlessly, it is often described as a cycle. Thus we often refer to this transfer as the carbon cycle. In this idea, we focus mainly on parts of the carbon cycle that involve living systems (any systems involving organisms e.g., a human body, a plant, a marine ecosystem, a land ecosystem). However, if the carbon cycle is mentioned, students would need to realize the part we are looking at is only a piece of the carbon cycle (not the whole thing).
- What are the specific interactions that we are talking about?
  - Photosynthesis: CO_2 gets into plants through the air in the environment via the leaves and H_2O gets into the plant though ground water in the environment via roots. CO_2 and H_2O undergo chemical reaction to produce food for the plant (specifically glucose, $C_6H_{12}O_6$; see 5E1 for more on food) and O_2. O_2, a product of this reaction, is released back into the environment. This chemical reaction requires energy, which is provided by sunlight. The sugars can be used for building plant material or for its energy needs. (refer to 5E1)
  - Eating and digesting: All living organisms need food. Some animals eat only plants, and some eat other animals. The carbon atoms that composed the plant material are now transferred to other animal's body. Digesting food means that the proteins, carbohydrates

and fats are being broken down into simpler and smaller molecules that can be absorbed by the cells. Long chains of proteins are being broken down to small molecules of amino acids, carbohydrates are being broken down to glucose and fats and oils are being broken down to fatty acids. In all organisms (including plants) glucose (that comes from food) and oxygen (inhaled by the respiratory system) are involved in a chemical reaction that supplies the energy needs of all cells. In a series of chemical reactions glucose and O_2 react, and CO_2 and water are produced. The CO_2 is being released to the atmosphere, and there it can be absorbed again by plants for the production of more food.

  - Decaying: When leaves or fruits fall on the earth, and when organisms such as plants or animals die, the various substances in them undergo decomposition reactions (some of which are oxidation reactions – see 5E3). In some decomposition reactions, CO_2 is being released to the atmosphere. Similarly, dead marine organisms sink to the bottom of the ocean and the carbon atoms in their bodies are used to produce sediments rocks.
- Students need to understand not only the particulate nature of matter and the molecular nature of chemical reactions (AAAS5-6: 4D1, & 4D8?, NRC 5-8: B1/2; AAAS6-8), but also the conservation of matter during a chemical reaction: the number of atoms stays the same no matter how they are rearranged (AAAS5-6; 4D7). In a closed system, the mass of all the substances before and after the reaction is the same.
- What time scale are we talking about? Some interactions between organisms could be over a period of days, such as organisms eating other organisms. But for some interactions between organisms and the environment this could be over a period of thousand of years (e.g. transformation of plant and animal matter into sedimentary rocks).

Teachers' background

- One way to demonstrate the continuity of these transfers is the carbon cycle. As this benchmark focuses on organisms, only the "organic" part of the cycle needs to be emphasized. The key chemical reactions are photosynthesis (in plants), glycolysis (in all cells), and decomposition of food to smaller molecules.
- Sometimes the notion of the central idea is being lost in the small details. For example, it is not necessary at this level to describe the chlorophyll, PGA, light phase or dark phase of photosynthesis, but to focus on understating the essence of the reaction.
- The carbon cycle refers to the cycling of carbon in non-living sources as well as living sources. Non-living sources include rocks, fossil fuels, CO_2 in the atmosphere and CO_2 soluble in water, but we will focus on the living components

Prerequisite knowledge

- Atoms and molecules: Atoms form molecules and more than one kind of atom may form molecules. All substances are comprised of molecules (AAAS5-6: 4D1)
- Elements: Atoms of a particular element are the same, and the atoms of different elements are different (4D1). Different atoms have different reactive properties (AAAS5-6: 4D6)
- Chemical reaction: a rearrangement of the atoms and molecules of the reactants to produce new molecules (NRC5-8:B1/2; AAAS5-6, 4D8?). The total amount of atoms of each element remains constant (Conservation of matter, AAAS5-6: 4D7).
- Students much realize this is an open system and must know what an open system vs. a closed system means.
- Chemical reactions involve energy changes. Energy can be released during some chemical reactions, and energy is required in order to enable other chemical reactions to occur.
- Food is needed by all organisms in order to supply energy and as building material.
- Plants make their own food by using CO_2 and sunlight to produce glucose.
- Glucose is used by all other organisms in their cells in order to release energy.

- Different organisms interact with each other in producer/consumer or predator/prey type interactions.

Alternative conceptions/Conceptual challenges

1. Young students tend to think of living systems as disconnected from the natural world (no citation, just informal knowledge from a teacher/researcher)
2. It is difficult for students to describe biological phenomena in terms of chemical substances and chemical reactions. For example, for them respiratory is inhaling and exhaling, but not the oxidation process of glucose. More generally, it was found that kids have difficulties to make the connections between "chemical" knowledge and "biological" knowledge even in cases when they were taught by the same teacher (no citation, just informal knowledge from a teacher/researcher).
3. Students at this age have a very central view; they think as humans as the centre of universe. It is difficult for kids to understand the huge importance of plants (no citation, just informal knowledge from a teacher).
4. Students tend to think that the source of biomass of plants is soil not photosynthesis (no citation, just informal knowledge from a teacher).
5. Students tend to mix between photosynthesis and glycolysis (no citation, just informal knowledge from a teacher/researcher).
6. It is difficult for students to maintain both aspects of chemical reactions, the rearrangement of substances and the energy changes. However, this is crucial to understand why certain chemical reactions take place at all (no citation, just informal knowledge from a teacher).

Idea B (5E2)

As in all material systems, the total amount of matter remains constant, even though its form and location change.

What kids need to know here?

- What does "remains constant" mean? As learned in 7th grade, during a chemical reaction the amount of matter remains constant. This is also true when referring to any chemical reactions that occur in living systems. For example, we can see that all 6 atoms of carbon in glucose become incorporated into 6 molecules of CO_2 in the process of oxidation of glucose (i.e. respiration). Likewise, in the process of photosynthesis the carbon atoms from 6 molecules of CO_2 are incorporated into one molecule of glucose, $C_6H_{12}O_6$. It might be good for students to have a "Lego kit" model, appreciating that the total number of Legos remains essentially constant. Students should appreciate that living organisms can be viewed as open containers in which lots of chemical reactions occur, that if we could keep track of all the atoms entering, leaving, and staying put we would see that the total amount remains constant, even though form and location continually change.
- What matter is being conserved? In living systems and non-living systems this conservation of matter can be illustrated by the carbon cycle. The amount of carbon atoms remains constant; they only change form (they combine to form new arrays of molecules) and location (i.e. the place that matter exists such as in the air, in a plant cell, or in an animal cell, or even in a different location inside of a multicellular organism). The change of form always involves a chemical reaction (see Idea A).
  - For example, during a certain period of time, carbon atoms are deposited in rocks, then dissolve in water, and then are used for photosynthesis by seaweed or algae (that can use CO_2 absorbed from water). These algae can be eaten by another organism and the carbon atoms become part of the food chain and are used for building blocks of the organism body and for producing glucose. Oxidizing glucose (to supply energy) will release CO_2 to the atmosphere; this CO_2 can be used again for photosynthesis. When an organism dies,

some of the carbon atoms will find their way to earth, air and water again. Students can be expected to "follow the bouncing ball."

- Again, students need to understand not only the particulate nature of matter and the molecular nature of chemical reactions (AAAS5-6: 4D1, & 4D8?, NRC 5-8: B1/2; AAAS6-8), but also the conservation of matter during a chemical reaction: the number of atoms stays the same no matter how they are rearranged (AAAS5-6; 4D7). In a closed system, the mass of all the substances before and after the reaction is the same. In the context of photosynthesis, the number of carbon atoms stays the same despite the fact that a new molecule, sugar, is formed from carbon dioxide. However, since this is not a closed system, oxygen gas, a product of the reaction, can leave the plant and diffuse into the atmosphere. In the context of digestion, sugar eaten by animals reacts with oxygen to produce carbon dioxide. Again, the carbon atoms are conserved and some molecules (i.e. carbon dioxide) spread throughout the atmosphere and some dissolve in water because it is an open system.

Teachers' background

- This idea presents conservation of matter (yes, but let's restrict it to carbon) in a global perspective. [In Idea A, emphasis was placed on the role of chemical reactions in matter being transferred, Here, the notion of a total amount of atoms, changing forms and location is the central one].
- Conservation of matter can be described qualitatively in the carbon cycle, but also quantitatively (by counting the number of atoms of each element in the reactants and products of a given chemical reaction). We don't expect students to be able to balance equations but only to realize that the total number of carbon atoms stays the same, even though the distribution in different carbon-containing molecules may change from one time to the next.
- Understanding this notion of conservation of matter in living systems can be challenged by a question: could it be that carbon atoms in my body once were in a dinosaur's body?

Prerequisite knowledge

- Understanding conservation of matter during a chemical reaction (AAAS5-6: 4D7)
- Being able to identify different symbols of elements in a given reaction and to count the number of atoms of each element
- All prerequisite knowledge as described for Idea A

Alternative conceptions/Student challenges

- Understanding this idea requires thinking about the universe including living systems as a united system. This kind of "systematic thinking" is very difficult for kids.

References

American Association for the Advancement of Science (AAAS). (1990). Science for all Americans, Project 2061. New York, Oxford University Press.

American Association for the Advancement of Science (AAAS). (1993). Benchmarks for science literacy, Project 2061. New York, Oxford University Press.