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Cumulative Summary of Nanoscience Content

In this document, I'll be explaining what we've learned about nanoscience in this course, particularly about size and scale, surface area to volume ratio, forces and interactions, models, size-dependent properties, and self-assembly. Connections between these themes will be drawn in ways that are accessible to high school students, namely using the context of the future of cell phones - the focus of my group's PBL unit. The ways that this unit incorporates each of the above themes will be discussed, as well as possible misconceptions and how they might be addressed. Finally, I will include some questions that I still have about nanoscience.

**Size and Scale**

The first step to learning anything about nanoscience is comprehending the scale of things. The nanoscale is so small that light doesn't even work right when looking at things in nanometers. That's an exaggeration, but in order to see things at the nanoscale, we can't use optics. We can't use light in the traditional way because the wavelength of visible light is longer than most objects at the nanoscale, so it can't reflect light that we can see. For that reason, in the words of Dr. Ali Shakouri, we have to discuss what it means to "see" at the nanoscale. Having a frame of reference for various objects gives one the chance to make various insights and think creatively. For example, knowing that a carbon nanotubes are smaller than typical transistors is essential to seeing applications of nanoscience to computer processors. This concept connects to others, and will be introduced as they come up as we go.

This concept was illustrated by the How Big Is It Activity and the Nanometer Scaling Activity. These give an idea of the range of sizes of various objects, and most importantly shows how drastically smaller the nanoscale is than the macroscale. The Nanometer Scaling Activity particularly gives an idea of just how small a nanometer is by scaling everything up to the macroscale proportionally.

This concept relates closely to some topics from Dr. Alex Wei's talk, specifically about gold nanorods. The precise size of these nanorods allows them to permeate weakened or unusual blood vessels in tumors. They go through holes in a blood vessel that the blood doesn't go through. Imagine a hole small enough that blood cells can't go through it. That's no problem for our little nanorod friends who just sneak right through it. That's a really small object. That captures the scale of what we're talking about in nanoscience. In the greater field of nanoscience, size and scale is a recurring theme. From new tools and imaging technologies (as discussed above) to the sheer smallness of the objects, this is a central matter in nanoscience.

In our unit specifically, this topic shows up in the How Big Is It? activity and in the scale activity we are considering where students are given an object somewhere on the size spectrum and they have to organize themselves in order. This will help address some misconceptions about how large various objects are, or precisely how small the nanoscale is, and with plant the seed for understanding of nanoscience.

**Surface Area to Volume Ratio**

This is a really fascinating concept in nanoscience, to me. Even as shapes get proportionally smaller, the ratio of volume to surface area decreases. This proportion doesn't stay the same. An excellent illustration of this concept is the dissolution of sugar in water. Sugar dissolves at a rate that is closely tied to how much surface area is exposed. So if a sugar cube is added to water, it will dissolve slower than if that same cube were mashed up and then poured in to dissolve. This is relevant in nanoscience because if you want something that will hold its thermal energy, you should choose an object with a low surface area to volume ratio, whereas if you want an object to dissipate thermal energy quickly, as in the case of gold nanorods that are being excited, you want a high surface area to volume ratio, so that the volume of the particle has proportionally more surface area to send its energy out through.

This concept is very related to size and structure, because as you get smaller and smaller, towards the nanoscale, SA/V increases. It gets truly interesting at the near-atomic end of the spectrum, where material is several molecules thick and has lots of surface area. We included this in our unit via the Excel lab on this topic. This will not only give them a good hands-on way to understand this concept, but it will also support their future research. It could easily apply to our theme though in heat dissipation from processors, in photosynthetic skins, or more. Some likely misconceptions include thinking that a high SA/V ratio is always desirable, or that surface area/volume decrease at the same rate. The former can be addressed by a discussion about when a low ratio is better - such as if you want a medical pill to be dissolved slowly. The latter will be addressed by students' observations in the Excel lab.

**Forces and Interactions**

The nanoscale is a great way to teach students that they cannot always trust their intuition. Nanoparticles interact in a way that we macroscaled humans don't intuitively understand as well as gravity. By far, electrostatic interactions are more significant than gravity at this scale. We saw this in a lab we did on these two types of forces. This is especially relevant because this significance of electromagnetic force opens the doors for scientists to have nanoparticles *repel or attract* each other depending on the charge. This is, of course, very closely related to self-assembly which we'll discuss later. Self-assembly is an excellent illustration of this topic though, as we saw in some of our discussions, because it uses forces other than gravity to pull substances together.

In the cell phone market, this a very relevant topic because you can have strong forces with very little mass. That's a big idea in mobile electronics. Students are liable to have misconceptions about it though. For example they may intuitively think that gravity is still at least somewhat significant on the nanoscale, which in most cases, it really isn't. For this it may be relevant to find out how many Newtons a paperclip applies to someone's arm when resting on it, then figure out how many orders of magnitude smaller gravitational force is at the nanoscale (between two predetermined objects of course).

**Models**

Models are a beautiful depiction of the power of science and also the flaws of science. It is a great way to show students how much we can learn from science but also the limitations of it. For example, use of an AFM produces an image on the atomic scale that can be considered a model, but it definitely has limitations in that you can see generally where atoms are, but it gives the illusion of continuous matter between "adjacent" atoms. This relates closely to size and scale in that we really need models to conceptualize the nanoscale, simply because it is so small.

Students' projects will be a great opportunity for them to experiment with models. They will have to create a mock-up of some sort of their final concept phone, and for many groups, that may include a model of some of the new technology that they see in their concept. Students are very liable to fall into the misconception that models are perfect. We hope that involving them in the inquiry process will activate critical thinking to the degree where they are engaging in critique and analysis of information, including how models work and what they represent.

**Size-Dependent Properties**

Many properties of material actually change when approaching the nanoscale. Boiling points, malleability, color, reactivity, and more can change drastically when the SA/V ratio increases as objects become very small - in the same way that forces abide by "different rules" so to speak. Some things we learned about were from the Does It Pour Out activity, where we saw that the different amounts of water resulted in different properties as far as whether the water would pour out or not. In the talks, we learned about how gold actually is red, not gold, at the nanoscale.

Students have a ton of ways to see this principle at work in cell phones. Many concept phones, such as the Nokia Morph, are citing nanotechnology as allowing materials to stretch or bend in ways that they wouldn't do on the macroscale. We will be using the Does It Pour Out activity in our unit, so students will get a great visual for this concept from that. It will serve as a macro-sized illustration of the concept to further the inquiry process.

Students may have misconceptions about this subject, specifically that size does not change properties of material. However, as gold gets smaller, it loses qualities of conductivity and its melting point lowers (Stevens, et al, p. 39). Particles of zinc oxide also essentially become invisible at small enough sizes. Discussion or demonstrations of these facts would help clear up this misconception, as will research that students conduct.

**Self-Assembly**

Self-assembly is an amazing tool that shows up in nanoscience. Since it is basically impossible to move objects around physically as you would a piece of wood or a nail, scientists have had to come up with other ways to create nanoscale objects. The fact that electromagnetic forces are so significant also plays a part in not being able to physically manipulate objects in whatever way you want. We saw in Dr. Bermel's presentation that constructing such small layers of silicon (2 microns or less) on photovoltaic cells requires the principles of self-assembly.

This was illustrated in the lab about gummy capsules. Although it wasn't true self-assembly, it still gave students the chance to see the principle at work. Similarly, students in our PBL unit will learn about nets in geometry - 2-dimensional shapes that can be perfectly folded into polyhedra - and will connect this concept to self-assembly in nanoscience. They will watch a video of a metal dodecahedron being folded up on its own to show it. They will likely still have a misconception that self-assembly isn't necessary, but just a neat tool at the nanoscale, when in fact it is one of the only ways to construct nanomaterials (or at least the most common). To address this, we could talk about what tools students know of to put together objects that are tens of nanometers in length. They can research it, but the goal would be that they find there are no straightforward tools to put two things together, and in the end, electromagnetic forces will need to be lined up correctly for objects to stick anyway. This may be the toughest misconception for students to clear up in our unit the way it is designed, but they definitely will see the principles of self-assembly in their research on cell phones. For constructing nanoscale memory devices, processors, or pixels, self-assembly is really the only way to go.

**Questions**

I still have a lot of questions that have come up about nanoscience, and I'll list a few here that I may research in the future. Many have come from our researching nanotechnology's applications to the mobile phone market.

* Is there any way to generate images or data about structure at the subatomic level? Are scientists optimistic about creating clearer images of structures at the atomic level?
* Will nanotechnology really be inexpensive enough to be used by businesses? What parts of it are most promising in this regard?
* Is nanotechnology common enough in the marketplace that students would need to be literate in it to be successful in business?

**References**

Stevens, Shawn Y, LeeAnn M. Sutherland, Joseph S. Krajcik. The Big Ideas of Nanoscale Science & Engineering: A Guidebook for Secondary Teachers. NSTApress: Arlington, VA, 2009.