Guest Editorial

Nanotechnology for Everyone

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The growing prevalence of nanotechnology makes it increasingly important that nanotechnology becomes an integral part of all STEM Education. Nanotechnology is science, engineering, and technology conducted where on dimension is 100 nm or less; this includes assembling nanoscale structures into larger materials. One nanometer is approximately the size of single sugar molecule, 1/100,000th the diameter of a typical human hair, or half the diameter of a DNA helix. At the nanoscale, size and shape are key determinants of properties. Some people believe that nanotechnology education is often considered to be only suitable for graduate, and perhaps, undergraduate students. This is similar to the historical view that only these students could engage in engineering activities. Now, engineering is a key part of the Next Generation Science Standards and it is recognized that even kindergartners can perform some level of engineering design (Rogers, 2012). Similarly, everyone including children, undergraduates, graduate students, teachers and the general public can benefit from, and enjoy, learning about nanotechnology. However, for STEM educators to embrace teaching nanotechnology they need to know the answers to two questions: 1) Why should nanotechnology be part of STEM Education?, and 2) How can nanotechnology be incorporated into STEM nanoeducation?

There are multiple reasons why nanotechnology should be incorporated into STEM education. First, modern nanotechnology's impact has been predicted to be comparable to the invention of the automobile or personal computer. Global nanotechnology research is on the order of $9 billion per year and expected to lead to major advances in medicine, transportation, environmental engineering and consumer products (Nanotechprojects.org, n.d.). In fact, nanotechnology is already a part of everyday life. In 2007, $60 billion in nanotechnology-related products were sold. Nanotechnology provides performance properties to consumer products ranging from sporting goods, to low volatile organic compound (VOC) emission paints, to advanced electronics. This number is expected to rise to rise to $150 billion, or 15 percent of total global manufactured goods, by 2015 (Nanotechprojects.org, n.d.). Therefore, educating students in nanotechnology is critical to both the realization of nanotechnology's potential and the students' future employability. In fact, the development of a skilled nanotechnology work force is one of the key goals of the National Nanotechnology Initiative (National Nanotechnology Initiative, n.d.). In modern society, science literacy is an important component of being an enfranchised citizen and consumer (Lane, 2003). Therefore, nanotechnology education is important even for students who do not pursue STEM or nanotechnology related careers.

Second, nanotechnology has become pervasive in pop culture. It is featured in everything from children's cartoons such as the Disney Channel's Phineas and Ferb, to science fiction novels such as Michael Creighton's Prey and Robin Cook's Nano. It is important that average citizens, as well as the current, and future STEM workforce, have the knowledge to distinguish fact from fiction. As with many technological advances, responsible development of modern nanotechnology requires careful consideration of both the potential benefits and the potential risks. Nanotechnology education is important for scientists, engineers, corporations, policy makers and the public to make rational decisions about potential positive and negative implications of our recently found ability to work at the nanoscale.

Third, nanotechnology education includes simply conveying the most current knowledge of our natural and physical world. While our ability to understand nanoscale and exploit nanomaterials and nanoscale phenomena is relatively new, nanotechnology has existed throughout history. Many of the greatest examples of nanomaterials are found in nature. The beautiful iridescent colors in many butterflies and beetles are the result of nanoscale structure, not pigments. Understanding these examples of structural color is expected to lead to new optical devices for solar panels and optical displays. Abalone seashells owe not only their iridescent colors to nanotechnology, but also their mechanical toughness and strength. Like chalk and antacids, abalone is primarily composed of calcium carbonate. Instead of being randomly organized, the calcium carbonate is in the form of nanoscale "bricks" held together by a tough protein "mortar." Understanding how nanoscale structure and composition affects mechanical properties is already leading to higher strength lightweight materials that are promising for a myriad of applications, including more energy efficient vehicles. Even the simple gecko is an example of nanotechnology. Their ability to climb walls is because of the sum of attractive forces created between surfaces and the roughly one billion nanoscale hairs on their toes. Researchers are using their understanding of the attractive forces between these hairs and surfaces to develop dry adhesives. While Nature may still be the consummate nanotechnologist, humans have been practicing nanotechnology for centuries – they just did not have the tools to realize it. For example, the 4th century Roman Lycurgus cup in the British Museum owes its dichroic properties to nanoscale gold and silver which cause it to appear a translucent red when lit from the inside, but an opaque green when lit from the outside. The brilliant colors in medieval stained glass windows are also the result of nanomaterials' interaction with light; the deep reds were because of nanogold and the bright yellows were because of nanosilver. Understanding size dependent optical properties provides a foundation for new cancer detection and treatment methods. Seventeenth century Damascus swords owed their strength and sharpness to cementite nanowires and carbon nanotubes – a material that was not discovered until the late 20th century. Understanding nanotube-metal matrix composites is expected to lead to more durable lighter weight materials for the transportation, electronic and defense industries.

Since nanotechnology has always been a part of nature, art and materials engineering, it should be incorporated into our educational system. How nanotechnology should be incorporated into STEM education and outreach activities depends on the audience. At the K-12 level, nanotechnology can be incorporated into the standard science curriculum. Significant effort has gone into developing fun modules that connect science and other educational standards with nanotechnology. Many of these emphasize inquiry and are therefore readily incorporated into the Next Generation Science Standards. In addition, the interdisciplinary nature of nanotechnology provides ample opportunities for connections between science, math, history, art and writing. Internet searches reveal numerous resources for K-12 nanoeducation content, much of the K-12 content is readily adaptable for higher educational levels and public outreach. One of the larger compilations is the catalog put together by the Nanoscale Informal Science Education (NISE) Network ("Nanoscale," n.d.). The catalog can be searched by topic, audience (age, informal science educators, scientists), and format (including classroom or cart demonstrations). Each module includes the applicable science standards, downloadable resources, reviews and comments. A growing number of the modules are also available in Spanish. The NISE Network also organizes the annual NanoDays event and has completely self-contained kits for nanotechnology activities available. These kits contain not only the materials and instructions, but high quality graphical table-top displays and even plastic tablecloths for covering surfaces. There are also considerable resources on organization and university websites. These are often the result of a National Science Foundation Math Science Partnerships or similar grants, and these web pages evolve with time. Many nanotechnology modules are a new look at activities teachers have been implementing in their classrooms for years. During one teacher training session I was involved with, a teacher expressed trepidation at having to learn to teach AP Chemistry students about nanotechnology. After rotating through a couple of nanotechnology activity stations she exclaimed, "I have been doing some of these activities for years! I just never thought of how they were related to nanotechnology." Developing modules for K-12 and public outreach is itself a valuable STEM educational activity. At Auburn University, undergraduates from science, engineering and education departments have worked on content development. For example, in developing the module "Why are Abalone Seahells So Strong and Shiny?," a chemical engineering undergraduate engaged in self-directed active learning that included types of mechanical properties, forms of calcium carbonate, types of seashells, and how to design inexpensive mechanical testing equipment with readily available items (McGee, Easley, Shannon, & Davis, n.d.). She also had to learn to clearly communicate the activity to a range of audiences ranging from elementary school children to university professors.

Undergraduate and Graduate nanotechnology education tends to still be segregated to specialized electives, even though it is readily incorporated into standard STEM departmental courses and interdisciplinary courses. As previously mentioned, there is considerable nanotechnology in biology and zoology. In chemistry and chemical engineering, colloidal science, surface science, thermodynamics and other core topics can be connected to nanotechnology. Colloid science and nanomaterial dispersions have significant overlap: a colloid is something that has all three dimensions less than 1000 nm dispersed in another phase and a nanomaterial dispersions has entities less than 100 nm in one direction (but potentially much, much bigger in another direction). By this definition, one can consider milk, paints and many other well established products as examples of nanotechnology. Making oleophobic and superhydrophibc surfaces is another key nanotechngology research topic. Our understanding of lotus leaves and other nanostructured self-cleaning materials can be incorporated into lectures on contact angle and how drops sit on or bounce off a surface. Similarly, nanotechnology fits into discussions of how changing the surface affects friction loss and flow through pipes

For public outreach, the key question is how does one reach "the public?" There are some very high quality television shows about nanotechnology broadcast on PBS and available online. These include the Nova Making Stuff Series and several Dragonfly TV episodes, including "What's Nano?" and "Self-Assembly" (PBS Nova, n.d.; PBS Dragonfly TV, n.d.) The websites for these shows also include additional background information and activities. There are also a growing number of nanotechnology related science museum exhibits. Both the exhibits and television shows tend to attract people who already have some interest in science. Science cafés can attract a broad audience depending on the venue. For example, the audience for a science café I led on nanotechnology and art included scientists, artists, children, and senior citizens. However, even science café's will attract a limited audience. The challenge of broad nanotechnology education is similar to that faced by French researchers seeking to educate everyone in quantum physics (Bobroff, 2013). They found that to engage the broader public they had to work with nonscientists to develop creative activities with a "hook" to get people interested. They also found the activities had to be held in truly public venues such as shopping malls, libraries restaurants, and city centers. Teaching the general public about nanotechnology will require a similar approach and expansion of activities such as the NISE Network's annual NanoDays events.

In summary, nanotechnology is a part of everyone's life. In fact, since DNA is a nanomaterial, we can all be considered part of "nanotech." Learning about nanotechnology is important for both STEM workforce development and to enable the public to make informed decisions as citizens and consumers. Thanks to the growing number of nanotechnology education resources, and the fact that much of nanotechnology is a new look on very well established fields, nanotechnology education can be readily implemented in ways that are accessible to everyone.

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References

Bobroff, J.(2013). Quantum physics for everyone. *Physics Today, 66*(9), 60-61.

Lane, N.(2003). Benjamin Franklin, civic scientist. *Physics Today, 56*(10), 41-46.

encece Education Network Nise Network Catalog. (n.d.) Retrieved from http://nisenet.org/catalog.

McGee, S., Easley, C. J., Shannon, C., & Davis, V. A. (n.d.) Abalone Shell Module. Retrieved from http://www.auburn.edu/academic/cosam/departments/chemistry/outreach /MSP_AU_web/MSP-AU.htm.

NanoTechProject.Org (n.d.) Project on Emerging Nanotechnologies Introduction to Nanotechnology. Retrieved from http://www.nanotechproject.org/topics/nano101/introduction_to_nanotechnology/.

National Nanotechnology Initiative (n.d.) Vision, goals, and objectives. Retrieved from http://www.nano.gov/about-nni/what/vision-goals.

PBS Dragonfly TV (n.d.) Matter and motion episodes. Retrieved from http://pbskids.org/dragonflytv/show/mattermotion.html.

PBS Nova (n.d.) Making stuff. Retrieved from http://www.pbs.org/wgbh/nova/tech/making- stuff.html.

Rogers, C. (2012). Engineering in kindergarten: How schools are changing. *Journal of STEM Education, 13*(4), 4-9.

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