Nanoscale Science and Engineering Education (NSEE) – the Next Steps

Workshop Report
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Dr. James Murday
University of Southern California

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Organizing Committee

Dr. James Murday, University of Southern California, Chair
Dr. Lisa Friedersdorf, National Nanotechnology Coordination Office
Dr. Christopher Cannizzaro, Department of State, NSET liaison to OECD
Mr. Larry Bell, Boston Museum of Science
Ms. Deb Newberry, Dakota County Technical College (DCTC) and Nano-Link
Dr. Patricia Simmons, NC State Univ. and National Science Teachers Association (NSTA)
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Dr. Lars Montelius, Univ. of Lund, Sweden and International Nanotechnology Laboratory, PT
Dr. Ana-Rita Mayol, University of Pennsylvania (formerly University of Puerto Rico-Rio Piedras)

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The workshop was sponsored by the National Science Foundation (NSF):

Dr. Mihail Roco
Senior Advisor for Nanotechnology
National Science Foundation

Dr. Mary Poats
Engineering Education and Human Resource Development
Division of Engineering Education and Centers
National Science Foundation

Contributing Authors

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Executive Summary

The importance of education to the U.S. efforts in nanotechnology development has been recognized by the R&D community and is clearly acknowledged in the third goal of the National Nanotechnology Initiative (NNI): *Develop and sustain educational resources, a skilled workforce, and a dynamic infrastructure and toolset to advance nanotechnology*. This *Nanoscale Science and Engineering Education (NSEE) – the Next Steps* workshop brought together experts from global stakeholder communities interested in Science, Technology, Engineering, and Mathematics (STEM) education broadly and NSEE more specifically. The two day workshop built upon the knowledge gained from previous workshops and addressed the NSEE needs for all the stages of education: K-12, Community College/Technical College (CC/TC), College/University, Graduate Degree, Continuing Education, and Informal. This integrated approach is necessary because the stages of education build on one another.

Participants in the workshop were selected in order to provide perspectives on NSEE from various stakeholder communities, including Federal agencies with STEM activities, state and local governments, teachers and researchers from different levels of education, professional science and engineering organizations, industry, and international education perspectives. There was a balance between those with primary knowledge of NSE and others involved in STEM education. A session, open to the public, was included to showcase the many teaching aides that have been developed for NSEE.

The workshop consisted of a plenary session where the current state-of-the-art in nanoscale education was presented followed by breakout sessions, one each for the six education stages: K-12, Community College/Technical College, College/University, Graduate Degree, Continuing Education, and Informal. Each group considered a list of concepts; those discussions have provided a wealth of insightful ideas. They are reported in the breakout session section, along with a list of top actionable items. The workshop closed with a plenary session where those top actionable items from each of the breakout sessions were presented. Subsequently, participants provided a global prioritization of the items. The top priorities by stage are:

<u>K-12</u>

- Identify and leverage insertion points that can be linked across grade levels for NSE concepts in existing standards and curricula.
- Create a central, searchable NSEE portal repository for teachers (possible models and/or partners included nanoHUB and the National Science Teachers Association).

<u>CC/TC</u>

- Create a best practices manual which builds on the efforts of the Nanotechnology Applications and Career Knowledge (NACK) Network, Nano-Link, and others to help with nationwide translation, replication, and tailoring of programs to specific local and regional needs. This manual should reflect the multitude and diversity of approaches.

<u>Undergraduate</u>

- Create and promote interdisciplinary cooperation and professional development opportunities among educators.
- Promote the interdisciplinary nature and societal impacts of NSE in order to increase diversity in the student population.

<u>Graduate</u>

- Address the pipeline for students entering graduate education with special attention to building and maintaining trusted relationships with institutions which traditionally serve underrepresented groups in order to encourage underrepresented populations in STEM and NSE.

<u>Continuing</u>

- Identify the resources already available, for example from the ATE Centers or courses on nanoHUB, and make it easy for anyone to assemble these into learning packages tailored to specific curricula need.

<u>Informal</u>

- Refocus NSE outreach efforts around specific applications that address societal Grand Challenges in order to increase relevance and interest for the public.
- Expand the reach of the Nanoscale Informal Science Education (NISE) Network beyond museums and research centers to youth-serving, community based national organizations that reach a broad demographic including underserved and underrepresented audiences.

Consideration of all the recommendations leads to a number of key findings that cut across the stages (the following list is not prioritized):

- Identify, develop, and evolve the NSEE workforce skillset requirements (and the education stages necessary to acquire those skills).
- Review the existing NSEE efforts to identify and disseminate best practices. (As a start, the existing web accessible K-12 teaching aides have been collated in Appendix D.)
- Identify, evolve, and/or develop NSEE materials with well-defined links to appropriate standards and curricula. Additionally, promote that material scale-up and widespread use of those materials.
- Establish a central, searchable, e-portal that identifies and provides links to vetted NSEE materials, is readily accessible, designed for intuitive use, and sustainable.
- Develop a national network of regional education hubs that effectively utilize the diverse stakeholder communities, leverage national forums, and address the challenges identified in the other recommendations.
- Establish clearly defined, nanotechnology-enabled approaches toward the solution of societal Grand Challenges in order to engage students, underrepresented populations, and general public interest.

The Commonwealth of Virginia and the state of Colorado recently incorporated nanotechnology into their new K-12 Science Standards of Learning. As they work to implement those standards, there is an immediate opportunity for the NSEE community to assist.

The National Nanotechnology Coordination Office (NNCO) has an interest and charter in promulgating NSEE at a national scale. Workshop funds were used to procure selected teaching aides that were displayed at the workshop exhibition. The NNCO will use those materials in its national level NSEE efforts.

Introduction

Nanoscale science and engineering (NSE) provides a timely, interdisciplinary aspect of science and engineering that incorporates biology, chemistry, physics, materials sciences, and engineering/technology. Thus, it is an ideal topic to teach students the connected nature of STEM disciplines. Additionally, the impact of nanoscale science and engineering education (NSEE) extends across the education spectrum, including K-12, technician training/community college, undergraduate, and graduate programs as well as in informal and continuing education. These qualities require new approaches to teaching NSE concepts. Beyond the education community, potential stakeholders with vested interest in NSEE include government agencies, economic development authorities, industry leaders, professional societies and non-governmental organizations, and the general public (to enable informed decisions regarding the benefits and potential risks of nanotechnology).[1]

President Obama has emphasized the importance of science, technology, engineering and mathematics (STEM) education to the future competitiveness of the United States.[2] The importance of education to the U.S. efforts in nanotechnology development has been clearly recognized by the R&D community and is clearly acknowledged in the third goal of its National Nanotechnology Initiative (NNI): *Develop and sustain educational resources, a skilled workforce, and a dynamic infrastructure and toolset to advance nanotechnology*.[3] The goal of up-to-date STEM education, however, is a moving target as the global investment in science and engineering research leads to continual development of new knowledge. For instance, nanoscale science and engineering (NSE) continues to produce broad ranging breakthroughs of both scientific and technological importance.[4] The latter point is buttressed by a recent study that shows the dramatic penetration of nano-enabled products into the commercial marketplace.[5] Further, the success of NSE is now being extended to a broader vision of Converging Technologies (the intersection of bio-, info-, cogno-, and nano- technologies) and can be viewed as an opportunity to identify more effective mechanisms for timely incorporation of new science and engineering knowledge into the education ecosystem.[6]

A recent National Research Council report on STEM education highlighted the challenges for integrating the traditional science/engineering disciplines into K-12 education:[7]

> "Education for students in science, technology, engineering, and mathematics (STEM) has received increasing attention over the past decade with calls both for greater emphasis on these fields and for improvements in the quality of curricula and instruction. In response, numerous new instructional materials, programs, and specialized schools are emerging. While most of these initiatives address one or more of the STEM subjects separately, there are increasing calls for emphasizing connections between and among the subjects."
>
> "Advocates of more integrated approaches to K-12 STEM education argue that teaching STEM in a more connected manner, especially in the context of real-world issues, can make the STEM subjects more relevant to students and teachers. This in turn can enhance motivation for learning and improve student interest, achievement, and persistence. And these outcomes, advocates assert, will help address calls for greater workplace and college readiness as well as increase the number of students who consider a career in a STEM-related field."

> "Programs that prepare people to deliver integrated STEM instruction need to provide experiences that help these educators identify and make explicit to their students connections among the disciplines."

These challenges could certainly be met with the application of NSEE, as it may be incorporated or infused into the various traditional disciplines.[8] Some examples include infusion into:

- *chemistry* by pointing out the natural evolution in material building blocks from atoms to molecules to nanostructures;
- *physics* by pointing out different physical properties inherent at the nanoscale due to the importance of surfaces (e.g. catalysts), quantum effects (e.g. quantum dots), and collective forces (e.g. para versus ferro-magnetism);
- *biology* by pointing out that the molecular "machinery" in cells are examples of functional nanostructures;
- *mathematics* by providing the framework to develop models that help us understand behaviors and phenomena at the nanoscale; and
- *engineering/technology* where NSEE, as an inherently interdisciplinary enterprise and an enabler of innovative technologies, can provide examples of contemporary and pending solutions to real world problems such as the use of nanostructures in point-of-care medical diagnostics and therapeutics (enabled by engineering clever integration of nanoscale biology, chemistry, engineering, and physics) or application of nanomaterials to enhance photon capture and conversion in solar cells or nanostructured electrodes for advanced batteries to address future energy needs.

The issues surrounding the need for evolving science and engineering content within the various stages of education is not new with the nanoscale, nor is it unique to the United States. Progress in updating curricula is slow and hard to attain. For instance, over the past fifty years the traditional fields of biology and geology have been struggling with this challenge as they evolved from predominately taxometric disciplines into a formulation based in the physical/mathematical sciences. One piece of evidence for success in this endeavor has been the incorporation of life sciences, earth and space sciences, and engineering, technology, and applications with the physical sciences in the new K-12 *Next Generation Science Standards* (NGSS).[9] As a contrapositive, which highlights the difficulty in inserting newly developed science and engineering into K-12 standards, the NGSS did not formally incorporate either computer or nanoscale science and engineering. NSE has, however, been formally incorporated into the Virginia[10] and Colorado[11] standards in the U.S. and into standards in Australia[12] and Taiwan[13].

Much has happened in the years since the previous two NSF-funded workshops that addressed NSEE - *Partnership for Nanotechnology Education* in 2009[14], and *International Benchmark Workshop on K-12 Nanoscale Science and Engineering Education* in 2010[8]. This includes the continued exponential growth in NSE; nanotechnology-enabled products topping $1T per annum[5]; many fledgling NSEE efforts around the world; the U.S. Next Generation K-12 Science Standards; the Commonwealth of Virginia incorporating nanoscale into its K-12 standards (as Taiwan and Australia did more than five years ago); the growth of the National Nanotechnology Infrastructure Network (NNIN) and Nanoscale Informal Science Education (NISE) Network; and a U.S. national STEM education initiative. The reports from the two prior workshops assessed the state-of-the-art at the time, and provided some guidance to investment strategies, both in the U.S. and abroad. It is even clearer now that developments in nanotechnology will have a significant commercial impact, accompanied by the need for a skilled workforce and knowledgeable public. Attention to the environmental, health, and safety issues at the nanoscale (nanoEHS) has also continued, with the attendant need for informed benefit/risk judgments by the business, governmental, and societal communities as well as the general public.[15,16,17] Furthermore, it has been recognized that there are growing symbioses among the nanoscale, the pervasiveness of information technology and its impact in education, the reframing of biology and medicine in terms of the physics/chemistry of nanoscale materials and processes, and the focus on understanding how the brain works (cognition) - resulting in a convergence of technologies.[6] Other, but related, developments have been the creation of the National Network for Manufacturing Innovation (most of which have critical NSE aspects) and the announcement of the National Materials Genome Initiative.[18,19] NSE will play a critical role in this last initiative, which seeks to establish models and simulations to accelerate materials development. There is now an opportunity to extend and refocus the development of NSE in education.

The *Nanoscale Science and Engineering Education (NSEE) – the Next Steps* workshop brought together experts from various global stakeholder communities, including representatives from schools and universities, various professional communities, industry, foundations, state/local education authorities, and pertinent national agencies. The two day workshop built upon the knowledge gained from the previous workshops and addressed the NSE needs at all the stages of education: K-12, community college/technical college, four year university/college programs, PhD granting programs, continuing education, and informal education. This integrated approach is necessary because the stages of education are all interrelated. The workshop consisted of a plenary session where the current state-of-the-art in nanoscale education was presented. It was followed by breakout sessions, one each on the six stages. The workshop closed with a plenary session where the main suggestions from the breakout sessions were presented. The full agenda is given in Appendix A.

Participants in the workshop, identified in Appendix B, were selected to include representation from the various stakeholder communities, including various Federal agencies with STEM activities, state/local government, teachers and researchers from various levels of education, professional science and engineering organizations, industry, and international perspectives. There was a balance between those with primary knowledge of NSE and others with primary interest in STEM education.

The workshop focused on NSE needs at all the stages of education as identified in Table 1.

Table 1: Stages of Education

1. Primary	Grades K-5
Basic literacy and numeracy, as well as establishing foundations in science, mathematics, geography, history and other social sciences	
2. Secondary	Grades 6-12
Skills required in an increasingly complex society, including the dependence on science and technology	
3. Community College (CC)/Technical College (TC)	Grades 13-14
Transfer education – Transfer to a four-year institution to pursue a BS/BA degree Career education – Associate Degree and directly enter the workforce Developmental – Remedial education for high school graduates Industry training – Company pays to provide specific training/courses for their employees.	
4. Undergraduate (BS/BA)	Grades 13-16
Career education – decision makers in business, government, finance, etc.	
5. Graduate (MS/MA/PhD)	
Research toward the discovery of new knowledge/understanding	
6. Continuing Education	
Rounding out the knowledge needed for career goals	

Changing career paths

7. Informal Science Education (ISE)

Complement to formal education venues

The National Science Foundation (NSF) primarily, but with contributions from other agencies, has had efforts to incorporate NSE in all these education stages and has successfully initiated the NSEE process. Through the plenary presentations, the discussions during the breakout sessions, and the exhibit, the workshop addressed the challenges and opportunities facing NSEE worldwide, with a special attention to:

- The knowledge base that will be needed in the workforce/population 5-10 years from now, and how to prepare students for that future;
- An identification of best practices for the global NSEE efforts;
- Methods to build awareness of and access to the best NSEE resources;
- Potential avenues to incorporate NSEE into curricula being developed for the newly released U.S. Next Generation K-12 Science Standards and similar standards;
- Opportunities to leverage the symbiosis among NSE, information technology, biology/medicine, and cognitive processes (perhaps with the U.S. BRAIN and European Union Brain Project initiatives);
- Potential mechanism(s) to keep abreast of the changing workforce education needs as nanotechnology continues its rapid market penetration;
- The best approaches for ongoing public education and engagement with nanoscale science, engineering, and technology; and
- The role of NSEE in broadening participation in the STEM workforce.

The international participation in this workshop has precipitated interest in similar workshops abroad. For instance, Asia Nano Forum Summit Workshop on Nanotechnology and Sustainability where NSEE was a key focus was held on Aug. 4th 2015 in Singapore. There is also interest in a European-based workshop in the summer of 2016, hosted by the International Iberian Nanotechnology Laboratory (INL).

Thanks to the efforts of Drs. Roco and Tuominen, and of Bob Stevens, Web Database Developer, University of Massachusetts, Amherst Libraries, the workshop materials have been incorporated into a NSEE website (http://nseeducation.org/2014/). It contains all of the presentations, descriptions of the exhibits, and short descriptions of the various workshop participant programs.

An article addressing the workshop results will be published in the *Journal of Nano Education*, and a book, *Global Perspectives of Nanoscience and Engineering Education*, based in part on the workshop contributions, is under development by Drs. Winkelmann and Bhushan of Florida Institute of Technology and Ohio State University, respectively.

Exhibit to showcase NSEE Assets

Over the past two decades there have been many NSE teaching aides such as lessons, textbooks, demonstrations, videos, games, massive open online courses (MOOCs), etc. that have been developed.[8] Most have been tested/used in relatively small student populations. Some better known examples include the NanoSchoolBox (Advanced Materials Science, Germany), NanoDays kits (NISE Net), K-16 nanotechnology lessons for teachers and Nanooze Magazine for children and K-16 resources (National Nanotechnology Infrastructure Network), NanoLeap (McREL), NanoSense (SRI International), TechNYou (CSIRO, Australia), Nano Lessons and Courses (NCLT, Northwestern Univ.), Nano-Infusion (Nano-Link, Dakota County Technical

College), NanoEd Resources (NACK, Penn State Univ.), The Big Ideas of Nanoscale Science and Engineering (NSTA), Nanosphere (Dragonfly TV), nanoScience Instruments (Nanoscience.com), An Introduction to Nanoscience and Nanotechnology (Nouailhat, Wiley), and Introduction to Nanoscience and Nanotechnology (Hornyak and Tibbals, CRC Press). As noted in the prior workshops and the Manhattan Strategy study "Considerations for Effective Interdisciplinary Collaboration to Facilitate Learning in Emerging Sciences: Lessons Learned from NSE Education Collaborations," one task in need of attention is to improve, vet, and scale up the already developed assets beyond local demonstrations.[20]

This workshop included an exhibit for the developers of assets to showcase their product(s); a listing of exhibitors is included in Appendix C. A flyer was prepared and distributed to publicize the event (included in Appendix C) to representatives of: foundations interested in STEM education, professional science and engineering societies' education efforts, the NSE business community, the various Federal agencies associated with the National Nanotechnology Initiative, NSF leadership, local school districts, Congressional offices (alerted through the USC Federal Relations Office), and the news media (alerted through the NSF publicity office). A primary goal for the exhibition was to facilitate a more rapid large-scale utilization of NSEE teaching aides. The exhibit was highly successful in informing and coordinating the workshop participants, and approximately 20 non-workshop individuals were also in attendance. Those individuals included a group of teachers and students from the South River High School STEM Magnet Program in Edgewater, Maryland.

Plenary Session

The plenary session provided the foundation for the workshop. There were presentations regarding Federal programs from the National Science Foundation and the Department of Education; presentations representing a variety of perspectives including international, industry, and educators' points of view; and presentations regarding the state-of-the-art in NSEE in K-12, community college/technical college, university, and informal education. The presentation materials are available on the workshop website (http://nseeducation.org/2014/).

A snapshot of the international nanoeducation landscape was provided as a summary of the 'Skills and Education for Nanotechnology in an Increasingly Multidisciplinary Environment' project conducted by the Organization for Economic Co-operation and Development (OECD). For all ten countries responding to the OECD survey, nanotechnology-relevant education and training, within the broader science curriculum, takes place across the educational spectrum including primary, lower secondary, upper secondary, university, and advanced university. Nanotechnology focused education was available in all ten countries at the university and advanced university levels, and even in the advanced secondary level for one country. There is a mix of approaches for nanotechnology specific education with four of ten offering it at the undergraduate level and all countries offering programs at the postgraduate level. Skills for innovation were also discussed highlighting the need for certain behavioral and social skills as well as critical thinking and creativity in addition to technical know-how.

Additionally, the Asia presentation summarized Asia's efforts in NSEE initiatives. In particular, efforts from Taiwan, Korea, Japan, Iran, China, Thailand and Singapore were highlighted. Taiwan includes nanotechnology education in its national nanotechnology initiative and allocates about 2.5% of its total nanotechnology funding (about 2-3 million USD/year dedicated to NSEE) in developing education infrastructure, curriculum, and public outreach. Korea has started the process of developing standardized NSEE curriculum and has created the e-learning platform called e-NanoSchool. Japan stands out for its effort in developing a multidisciplinary and industry focused NSEE program at the graduate school level which is offered at Osaka University. Tsukuba University includes international collaboration in its PhD Honors Program with focus on nanoelectronics. The Iran Nanotechnology Initiative Council places strong emphasis on NSE education and has extensive undergraduate and postgraduate programs in universities. The participation in its Nano Olympiad initiative grew 20 times during a 4 year period to over 20,000 participants in 2013. The Thailand National Nanotechnology Center (NANOTEC) operates the Nanotechnology Learning Center (NanoPlus Learning Center) which has reached 250,000 trainees since 2008 with 190 trainers trained. Soochow University in China offers a unique bachelor's degree in NanoMaterials and Technology in collaboration with the University of Waterloo with joint curriculum in English. This collaboration extends to MSc and PhD through the exchange research program between the two universities. The National University of Singapore (NUS) is a pioneer in NSEE programs and offers NSE modules to science and engineering faculty. In addition, NUS offers general education modules (GEM) in nanotechnology to all undergraduate students with a focus on nanotechnology impact on sustainability and entrepreneurship.

The Commonwealth of Virginia incorporated nanotechnology into its Science Standards of Learning in 2010 (implemented in the 2012-2013 school year).[21] To illustrate the practical problems in implementing NSEE, the Virginia experience was presented, including the process for making changes to the standards and plans for implementation. The Virginia Science Standards of Learning and Curriculum Framework are reviewed every seven years in a public process that includes teachers, district science leaders, scientists, and industry leaders; approved by the Board of Education; and serve as the foundation science curriculum for each of the 132 Virginia school divisions. Nanoscience appears in 'current applications of science' throughout K-12 and explicitly in grade 5, physical science, chemistry, and physics with topics such as size and scale, structure of matter, forces and interactions, quantum effects, size dependent properties, and models and simulations. A *Big Ideas of Nanoscience* curriculum (with more than 50 lessons and activities), Nano Fellows Institutes for teachers, and the Imagine Nano website have been developed by the MathScience Innovation Center (MSiC) to support the implementation of the new standards.[22] Three key needs and actions were identified to take the implementation of nanotechnology in education to scale: leadership and awareness (bringing industry and education together to build basic and advanced understanding of nanoscale science and engineering); building a community of practice (professional development for teachers); and appropriate curriculum resources (teaching materials correlated to the Virginia Science Standards of Learning).

Breakout Session Discussion

During the breakout sessions, participants were divided into six groups to focus on specific stages of education: K-12; community college/technical college; college/university; graduate degree; continuing education; and informal education. This method of organization was selected because each stage has its own culture and unique challenges. Each of the breakout sessions discussed the following topics in the context of that session's stage in education.

- The state-of-the-art in NSE education
- High-priority NSE education challenges and opportunities
- NSE resources available to assist in the education process
- The best way to facilitate NSE education resource scale-up
- Stakeholder involvement needed for that scale-up

- The quick incorporation of the convergence of nano-, bio-, info-, cogno-technologies in education curricula
- The best use of NSE to attract underrepresented populations to STEM
- Top actions that could be taken to address the items above

Participants shared a multitude of opinions while discussing NSEE with regard to the above topics. The following write-ups attempt to capture all the points made during those discussions.

K-12
Discussion Leader: John Ristvey

Summary

Discussion among stakeholders from the K-12 community concentrated on providing teachers with NSEE materials and training, and the integration of nanotechnology concepts into standards and curricula. There is a need for a central, updated, searchable portal for NSEE resources. In addition to providing teachers with resources, regional nanotechnology education hubs similar to the MathScience Innovation Center model would support professional development, student programs, and the opportunity for schools to partner with universities and businesses.

K-12 stakeholders also identified Virginia's integration of nanotechnology concepts into its Standards of Learning as the state-of-the-art in NSE education. As a way to begin institutionalizing the integration of NSEE for all K-12 learners in the United States, the group sees a need to identify and leverage insertion points for nanotechnology concepts in existing standards and curricula. NanoTeach has begun the work of integrating NSE into high school curriculum. This effort is described in the project's final report.[23] Recognizing that this effort will require changes in policy, they pointed out the advantage of national forums such as National Science Teachers Association, National Governors Association, the Council of State Science Supervisors, International Test and Evaluation Association, and National Council of Teachers of Mathematics, working in partnership with relevant people from education, industry, academia, and government to propose policy. The final points of the discussion related to finding ways to assess student learning improvement and NSEE programs.

The state-of-the-art in NSE education

Since NSE has yet to be incorporated into the vast majority of U.S. K-12 curricula, the discussion focused on the goals that need to be accomplished:

- Institutionalize the implementation and integration of NSE education for all K-12 learners in the United States.
- Apply a systematic approach to scaling NSE principles and applications across the education venues.
- Expand student and teachers understanding of science/engineering concepts through the use of nanoscience and technology examples.

While the U.S. effort is nascent, Taiwan has had a national undertaking in NSE education since 2004. Taiwan has been working to include NSE in K-12 curricula and there are over 500 K-12 teachers trained in summer workshops and many textbooks have been developed.[24] Taiwanese teachers build a lot of the teaching material, but it is necessary to find subject matter experts to make sure all the content is correct. It is not easy to add content into the curricula, so there needs to be individuals who can judge what content is important, what is good to add to curriculum, and how to standardize the content across the nation. High school teachers, usually volunteers, help with standardized testing, training students, and adding new NSE materials. There is a website with the NSE materials, but it is presently only in Chinese. It contains a list of the subject matter suitable for the various levels and, if a teacher wants to teach a concept for a given level, there are materials and videos he/she can review.

High-priority NSE education challenges and opportunities

One major challenge discussed was how K-12 curricula can be updated to incorporate new information more quickly. For instance, one of the participants related the experience of teaching biology that was badly outdated because biology has undergone a renaissance over the past 50 years. So K-12 proponents need to be forward thinking, especially in the implementation of the Next Generation Science Standards based on the National Research Council (NRC) framework.[9, 25] Coherence of NSE across grade levels and subject matter is a challenge. Further, many states are going to be implementing new science and engineering practices as described in the NGSS or NRC Framework. It will be necessary to provide mechanisms to engage teachers, peer groups, districts, community colleges, and businesses because they must work together to approach the incorporation of NSE.

MathScience Innovation Center
Richmond VA

VIRGINIA IS FOR SCIENCE LOVERS

The MSiC provides teacher training, develops and implements lesson plans in advanced topics, and runs summer camps and teacher forums. It services 8 school districts in Central Virginia. Since 2010, more than 250 middle school students have participated in the MSiC Summer Regional Governor's School course "I am Nano" and the Camp Innovation summer course "Nanotechnology: Science of the Small." In 2014, in order to provide increased access to teachers and students in the region, the MSiC Nano team developed and implemented a hybrid nanoscience program for teachers. The MSiC Nanoscience curriculum with over 50 lessons, includes ideas and concepts focused on size and scale, the structure of matter, size-dependent properties, tools and instrumentation, forces and interactions, models and simulations, quantum effects, self-assembly, and nano & society.

Many NSE modules have been developed and are listed in Appendix D. However, for the materials to gain widespread use, alignment to NGSS and/or NRC Framework would need to be improved. One participant offered three possible examples of NGSS for high school (HS) physical science (PS) in which NSE subject matter experts might be able to fit proposed nanomodules:

1. HS-PS1-3 Matter and its Interactions
Students who demonstrate understanding can:
Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.

Clarification Statement: Emphasis is on understanding the strengths of forces between particles, not on naming specific intermolecular forces (such as dipole-dipole). Examples of particles could include ions, atoms, molecules, and networked materials (such as graphite). Examples of bulk properties of substances could include the melting point and boiling point, vapor pressure, and surface tension.

Assessment Boundary: Assessment does not include Raoult's law calculations of vapor pressure.

2. HS-PS1-6 Matter and its Interactions
Students who demonstrate understanding can:
Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.

Clarification Statement: Emphasis is on the application of Le Chatelier's Principle and on refining designs of chemical reaction systems, including descriptions of the connection between changes made at the macroscopic level and what happens at the molecular level. Examples of designs could include different ways to increase product formation including adding reactants or removing products.

Assessment Boundary: Assessment is limited to specifying the change in only one variable at a time. Assessment does not include calculating equilibrium constants and concentrations

3. HS-PS2-6 Motion and Stability: Forces and Interactions
Students who demonstrate understanding can:
Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.

Clarification Statement: Emphasis is on the attractive and repulsive forces that determine the functioning of the material. Examples could include why electrically conductive materials are often made of metal, flexible but durable materials are made up of long chained molecules, and pharmaceuticals are designed to interact with specific receptors.

Assessment Boundary: Assessment is limited to provided molecular structures of specific designed materials.

Other possible fits for NSE in the NGSS standards were identified in the International Benchmark Workshop on K-12 Nanoscale Science and Engineering Education.[8]

Within the K-12 context the realities for NSEE include: a need for coherence with the National Research Council Framework for K-12 Science Education,[25] the NGSS, and the current individual state standards; understanding and navigating the many K-12 systems; awareness of the policy considerations associated with the introduction of any new material into a crowded curricula; communicating NSE to stakeholders; the need for NSE content appropriately developed for each level of learner and linked to prior/next grade levels; bridging to post-secondary learning; and a lack of teacher NSE content knowledge.

The session participants developed a list of the main challenges and opportunities in K-12 NSE:

- There are scale-up and sustainability issues. There are many local NSEE efforts, primarily associated with NSF funded centers, but there are curricular and financial impediments to larger scale implementation.
- There is a need for assessment of the changing technologies to assist the learning process. This is not unique to NSE.
- The challenge of aligning NSE with current curriculum since it is unlikely to be explicitly added to the NGSS.
- The interdisciplinary nature of NSEE and the relevance of NSE, especially to future career paths, is a strength that may help with its integration into curricula.
- Additionally, NSE fosters creativity, innovation, and 21st century skills.

NSE resources available to assist in the education process

There are many examples of NSE education modules that have been developed (see Appendix D), but none have achieved wide scale use. Their relevance to the NGSS or to State Standards must be clear. The resources need to have (1) a coherent "vertical" path across the various grades, (2) be affordable, and (3) be readily available to teacher communities across the nation. Otherwise it will be difficult to convince teachers to utilize them.

The best way to facilitate NSE education resource scale-up

Communication and awareness of NSEE is key to scaling up resources. For instance, it is important for teachers to learn about the most current science (including NSE) so that they are aware of and comfortable with the topics. Teachers also need ways to integrate new materials into their existing courses/curriculum in a manner that promotes deep student understanding. There was also discussion of convening a group of K-12 educators, or organizing events at one of their national meetings, in order to impress upon them the importance of nano-enabled ("nano inside") technology.

It will be necessary to institutionalize NSEE in order to effectively scale it up. The NGSS provides an opportunity in that there could be one set of standards that is adopted by most of the states, rather than a multitude of local standards. While NSE is not formally incorporated into the NGSS, there are opportunities (such as those suggested in the prior section) to insert NSE. NSE does provide a timely, interdisciplinary aspect of science and engineering that incorporates biology, chemistry, physics, materials sciences and engineering/technology. Lesson plans and syllabi, along with classroom materials, must be utilized and/or created and NSE must be integrated into any assessment tests because teachers will focus on preparing for those tests. It will be important to have a systematic, vertical approach that leads to growing sophistication as the grade level advances. Something taught for a couple days and never reinforced again throughout the years will slip out of memory. The approach must be consistent across all education stages. Organizing all of the available NSEE information on one site, so they are easy to find and utilize, will help with scale-up. The site should include a teacher-based portal with all searchable information aligned with local needs.

Vertical articulation is one strategy that reinforces a systematic approach. For instance, a student group at the University of Virginia, the Nano and Emerging Technologies (NExT) Club, was formed with part of its mission to work with area high schools through helping with science clubs. The high school groups were then to reach out to middle schools. The idea is to create a network of student groups to help students in lower grades.

The participants acknowledge that teachers are already under considerable pressure and it will be a challenge to develop NSEE contributions in a way that is not seen as a burden. So NSE has to be incorporated in the form of examples that enable more effective instruction for the NGSS science and engineering topics. Those examples should be framed to excite the students, as well as educate them. For example, NSE is a driver for technologies that will address societal problems in energy, environment, health, and security. Using examples would show that NSE relates directly to the world in which the students live.

Stakeholder involvement needed for that scale-up

Participants felt that a council, including K-12 and community college communities, should be convened to look globally at policies and initiatives to address the current situation. School counselors, teachers, and parent/caregiver involvement can help facilitate the scale-up of opportunities and information available. Community colleges, technical schools, and school counselors in high schools do not often know the career paths open to someone studying nanotechnology. Parents/caregivers are also not aware. As a result, when a student goes to college they may not choose NSE fields because they have not been made aware of the opportunities and importance of the fields. Without community involvement, there will be insufficient motivation for scale-up. Teacher training programs are another area where involvement will be useful because most do not include nanoscience in their curricula. Professional societies are another group whose involvement will be helpful. It will be useful to start at the regional level; that way efforts reflect local interests and needs.

Top actions that could be taken to address the items above

- Create a central, searchable NSEE portal repository for teachers; possible partners mentioned included nanoHUB.
- Identify and leverage insertion points for NSE concepts in existing standards and curricula.
- Develop a national network of regional NSE education hubs for professional development, student programs, and university and business partnerships.
- Leverage national forums (examples of possible partners included the National Science Teachers Association, Council of State Science Supervisors, National Council of Teachers of Mathematics, National Governors Association, International Test and Evaluation Association) with stakeholders from education, industry, academia, and government to propose policy recommendations.
- Explore ways to assess student learning improvements and evaluate NSE educational programming impacts over time.

Community College/Technical College
Discussion Leader: Deb Newberry

Summary

The community college/technical college stakeholders discussed the importance of standardizing programs for nanoscience and nanotechnology workforce education so employers while still allowing for region specific adaptations. In order for standardization to work there must be the development of, or improvement in, the nanoscience pipeline; students (pre-K through gray) must be prepared in basic core knowledge, best practices created when addressing local industry needs in technician training, and the needs of non-traditional (career transitioning, retraining, socioeconomic standing) students addressed.

A major theme during the discussion was the need to raise awareness that 2-yr and 4-yr training, with access to continuing and technical education, is sufficient for the needs of many students and their future employers. Many CC/TC's partner with universities and/or businesses in order for their students to have access to equipment and materials necessary for training. One method highlighted to reach both industry and students is the development of informational packets that can complement, and be tailored to, existing efforts in local regions which can aid in the building of partnerships. The Micro Nano Technology (MNT) conference was mentioned as a setting to share activities and available resources in order to build a community for technician education and training. As a part of this, and with regard to partnering with local industries and universities, the development of a generic workshop was also discussed to train educators and administrators on how to work with those groups. The workshop would be offered at appropriate annual conferences.

The state-of-the-art in NSE education

Presently, the requisites for NSE at CC/TCs are ill defined. Where must incoming students start, in terms of knowledge/education, in NSE? Where should the CC/TC NSE program endpoint be? Industrial needs and skills can vary widely; those skills need to be better defined for CC/TCs to best address the needed education/training programs and appropriate infrastructure for their particular region. At the CC/TC level, one might define three different tracks in NSE:

- Nanotechnology-relevant: could be applied to the nanotechnology sectors with further academic training and/or vocational training; e.g. a general science curriculum;
- Nanotechnology-focused: within a broader 'nanotechnology relevant' curriculum, some focus starts to be given, e.g. specific focus for a two year A.A.S. degree or nanoscale engineering modules within an engineering degree; and
- Nanotechnology-specific: direct application e.g. targeting transfer to four-year degree programs that have a NSE focus.

Nano-Link

Center for Nanotechnology Education

The Nano-Link program is led by Dakota County Technical College, and consists of 15 educational institutions throughout the US. The program is designed to provide NSE savvy technicians to industry through 2 year A.A.S. degree programs, provide modularized educational content for grades K-14, and to provide hands-on educator workshops. There is an emphasis on multidisciplinary perspectives with foci in nanoelectronics, nanobiotechnology, and nanomaterial science. The DCTC Nano-Link works with its affiliates to determine what their local industry needs and education infrastructure resources are, and how they match up in that region.

With a few exceptions, community colleges may not initially be sufficiently equipped for training and education in NSE. For example, SEM use and cleanroom (for semiconductor industry) training is not broadly available, or of sufficient sophistication for industry needs hence the need for partnerships beyond the single community college.

There are three NSF funded Advanced Technological Education (ATE) Centers with efforts specifically focused on NSE. There are an additional three focused on micro/nano science and engineering. Representatives from the Nanotechnology Applications and Career Knowledge (NACK) Network (University Park, PA) and the Nano-Link Program (Rosemount, MN) were present at the workshop.

High-priority NSE education challenges and opportunities

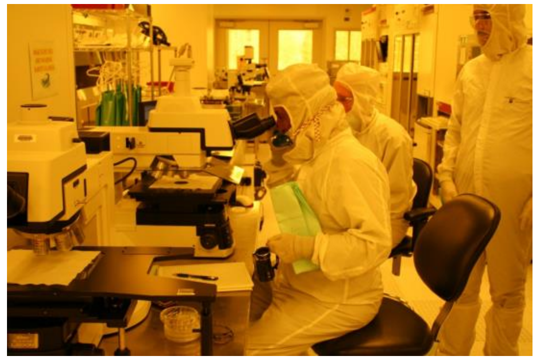
How does the NSE curriculum attract students into programs and keep them there? States are spending a great deal on education and there is a push for 60 & 120 mandated credit hours for an A.A.S degree. However, it is difficult to bring a student through A.A.S. programs if they are not already at some level of competency in basic core knowledge. This can be a greater problem for some underrepresented populations. How might one address remedial needs? They will vary with socioeconomic diversity, low-income constraints, fitting in the 60-hour credit limits, and inability to afford any remedial coursework on top of the NSE-specific curriculum. The issue is bigger than just money; there is need to articulate multiple models/methods to support success at all socioeconomic levels.

A major hurdle to recruiting CC/TC students to NSE is the lack of familiarity. One opportunity is to build a broader community (industry, education, government) to articulate what is needed in K-12 curricula. Informal education can provide another approach to better familiarity. Celebrity advocates can also be beneficial; one relatively recent example was the Thailand royal family talking about nanoscience.

Similar to the problem of attracting students to NSE, companies may not always be aware of what skills and knowledge are available from CC/TC programs. There is a growing need for technician/manufacturing level work for which 2-yr and 4-yr CC/TC training can suffice. However, industrial perceptions may be changing. For example, Nano-Link is getting inquiries for NSE program graduates from companies beyond their region and outside the United States. Nonetheless, CC/TCs need to do a better job of branding and marketing their 'product' at the local, state and national levels. The need is not just for new employees, as products evolve, it also becomes increasingly important to retrain existing workers.

NACK Network

Nanotechnology Applications and Career Knowledge Network



The NACK Network is led by Pennsylvania State University and builds partnerships in nanotechnology education among research universities, 2-year CC/TCs, and 4-year colleges through resource sharing (course, programs, laboratory, facilities, staff) and through 2 + 2 programs for students. NACK also provides an opportunity with *Remotely Accessible Instruments for Nanotechnology* (RAIN) that allows students (K-16) to access and control microscopes to examine nanoscale materials from the ease of classrooms, or even home computers.

As already noted, there are some efforts toward engaging companies in the definition of NSE programs. But certification remains a problem; how is a NSE program to compare with existing formal education and training certifications, including those used in the continuing education venue? ASTM has been working with NACK in order to determining testing for certification[26]; the American Society for Engineering Education (ASEE) and Accreditation Board for Engineering and Technology (ABET) (an organization that accredits college and university programs) may be other possible resources for building certification.

NSE resources available to assist in the education process

The six Micro & Nano Technologies themed ATE Centers have web accessible NSEE resources and a mandate to make them available nationwide. These include the Maricopa Advanced Technology Education Center (MATEC) NetWorks (Phoenix, AZ), Northeast Advanced Technological Education Center (NEA TEC) (Troy, NY), Southwest Center for Microsystems Education (SCME) (Albuquerque, NM), Seattle's Hub for Industry-driven Nanotechnology Education (SHINE) (Seattle, WA), in addition to NACK and Nano-Link.

Top actions that could be taken to address the items above

Variants of the NACK and Nano-Link CC/TC programs need to be replicated across the nation. In order to do this, it will be necessary to improve awareness of these models within the CC/TC realm. Suggested mechanisms to develop "community of practice" awareness include:

- Develop and improve the NSE pipeline for the associate level workforce:

    - By creating best practices to address local industry needs where technician training is specific to geographic locale and industry therein (and there is high employment potential);
    - Through education from pre-K through gray (and for broadening participation) for input into the CC/TC programs, and for outputs to industry and advanced degree programs;
    - By addressing specific needs for socioeconomic and non-traditional (career transitional, retraining, adult education) student populations.
- Create a best practices manual which builds on the efforts of Nano-Link, NACK, and other efforts to help with nationwide translation, replication, and tailoring of programs to specific local/regional needs. This manual should acknowledge the multitude and diversity of approaches.
- Create 'global' marketing plans that can complement existing efforts in local regions and be tailored for specific needs (e.g. a generic packet of information provided to partner schools in order to 'franchise' for their regional/local needs and setting).
- Use the Micro Nano Technology Conference as a setting to share activities and available resources, and to give participants an opportunity to build a community for technician education/training. This conference moves around the country on an annual basis, with each meeting reflecting the local 'flavors' of nanotech education/training.
- Develop a workshop to train educators and administrators on how to work with industry.
- Continue to develop and propagate NSE education workforce standards.

College/University
Discussion Leader: Kurt Winkelmann

Summary

Stakeholders from the college and university breakout group discussed the need to convince both administrators and students of the benefits of NSEE programs at their institutions. Within that discussion, it was stressed that industry represents an important NSEE stakeholder in colleges and universities. From teaching students about entrepreneurship to the introduction of an industrial REU, integrating a business point of view into education was seen as crucial to promoting NSEE. Possible methods for adding NSEE ranged from incorporating nanoscale science in existing courses to degree programs. Participants shared that, typically, there are two or three core NSE courses with other courses borrowed from different departments.

This speaks to another key point in the discussion: NSE is a truly interdisciplinary field. As a result, NSEE requires cooperation and coordination from multiple departments. It also means that a central repository for resources would be a very useful tool for integrating NSEE into colleges and universities. This group felt that stressing the interdisciplinary nature of NSE and its potential for impacting society would be a strong method for increasing diversity in STEM.

The state-of-the-art in NSE education

There are a variety of approaches to incorporate NSE at the participants' institutions, ranging from individual courses, minors, certificate programs, as well as bachelor's and graduate degree programs. Overall, there are typically two to three courses used as the NSE core, with other courses borrowed from different departments. But there is no readily available curriculum, a problem exacerbated by the rapid subject matter change in NSE. Further, at this time, many universities and colleges do not offer any NSE course work.

High-priority NSE education challenges and opportunities

A challenge for NSEE at the undergraduate level is convincing college and university administrators that there is a need for NSE departments and/or programs. For example, at Lund University, Sweden, when a nanotechnology degree program was started 10 years ago, there was an initial concern by the administration that adding the program would take students away from other departments and not attract new students to the institution. However, the reality has been that the program has brought more students to the university. Another challenge is that students with the nanotechnology label sometimes encounter problems finding employment because human resources departments in the business sector are unfamiliar with this terminology. Therefore, the students have to be adaptive and self-promote by explaining how their degree is relevant to particular companies. At other European institutions, NSE is offered as a course, or the content is added to other existing courses in the curriculum as modules or as an infusion with the existing course material.

nanoHUB

Network for Computational Nanotechnology

nanoHUB's mission is to support the NNI by creating and operating an ever-evolving cyber-platform for sharing simulation and education resources. The site hosts a rapidly growing collection of simulation programs for nanoscale phenomena. Additionally, nanoHUB provides online presentations, courses, learning modules, podcasts, animations, teaching materials, and more. The educational page directs users to several sections, starting with overview videos that provide an idea of what the nanoscale is, and challenges that nanotechnology can address.

As to which method of implementing NSE at institutions is more effective, the general thought is that all modes (courses, certificates, minor, or degree) have some value and the choice would depend on the institution. For example, an introductory course in nanotechnology that targets students very early in the curriculum can give them a broad understanding of how nanoscience is interconnected with other disciplinary areas and is involved with how things are made. This course would give students perspective and confidence about the field, so they then go on to other courses and understand how nanoscience is related.

Nanoscale science and engineering is a truly interdisciplinary field and has to be a collaborative effort between several departments (e.g. chemistry, physics, biology, material science). A challenge, in this respect, is to help departments and faculty recognize this interdisciplinarity thereby overcoming any resistance to collaboration. Highlighting that nanotechnology is making something useful for society and is not just a "service" science may help in this endeavor. As more faculty members with interdisciplinary training or exposure enter the field and become more involved in efforts, the departmental resistance to collaboration will likely resolve itself. Two participants whose institutions (Lund University, Sweden and University of Jyväskylä, Finland) have nanotechnology degree programs, noted that the programs exist as consortia and not as individual departments at their institutions. This parallels the Nanoscale Science and Engineering Centers (NSECs) funded by the NSF in the U.S. If nanotechnology employment is readily available, such as in nanoelectronics, this will influence the mode of implementation. However, it is also worth pointing out that it may not be about having a specific nanotechnology industry, but developing awareness that nanotechnology is integral to all companies.

Determining the benefits to universities and students of different types of nanotechnology programs at universities is also a challenge for NSEE. However, participants mentioned that studies have shown that women are more attracted to interdisciplinary fields.[27] Also, students who become involved in undergraduate research in these fields are more likely to continue on to doctoral studies.[28]

Several opportunities for NSEE that were raised, including its potential to attract more underrepresented minorities because the nanoscience field has done a reasonable job of showing that it is societally relevant. Innovative pedagogy (active learning, problem-based learning, etc.) can be widely used in NSEE to help students to make and integrate connections among the various areas. The potential exists to break down disciplinary barriers and bring NSE into other areas such as into the electrical engineering curriculum. NSE offers a way for students to engage among themselves (peer groups working together, creating interconnections between various students) because they have a chance to develop and convey scientific knowledge with students in other classes and with other majors. Another challenge to NSEE is to communicate with potential employers to determine the necessary skill sets to be imparted by NSE curricula.

The best way to facilitate NSE education resource scale-up

Participants felt that improving access to materials, for instance with the continued and expanded use of nanoHUB, is one way of facilitating scale-up. Creating a central repository for nanotechnology resources is also needed. For example, the NSF has funded many Nanotechnology Undergraduate Education (NUE) in Engineering programs and having a central, searchable location for all the resources that have been developed would be very useful. The National Nanotechnology Infrastructure Network, which recently transitioned into the National Nanotechnology Coordinated Infrastructure (NNCI), disseminates their resources through their own educational portal and is talking with nanoHUB about a long-term location for their assets. Most participants agree that they would use resources (websites, journals, etc.) that are already available which they would customize for their own particular usage. The material would be adapted to highlight specific areas or interconnections. Effective modification would also include how the material is presented or explained to different students or for different application fields. It was pointed out that because NSE is much closer to research than other established fields, participants feel it is more amenable to adapting and incorporating research outcomes into classes. Further recommendations include incorporating business interests into the effort, and providing interdisciplinary professional development. One way of addressing the latter may be to develop NSE workshops similar to the NSF-funded Chemistry Collaborations, Workshops & Community of Scholars efforts which sponsor faculty workshops and learning communities to support chemists in STEM education dissemination projects.[29] The NSE workshops should be organized by at least two different departments, so that the truly interdisciplinary nature of the field is incorporated. This type of requirement would help to develop cross-disciplinary understanding of the types of terminology used in each area. Scaling up NSEE efforts would also benefit from the creation of student activities and organizations outside of class. Building connections with high school teachers and other forms of outreach may also help facilitate this scale-up.

NSE resources available to assist in the education process

Participants pointed out that the instrumentation available has an influence on the types of laboratory involvement that are implemented. It is possible to develop one's own equipment and educational materials or to use internet-based resources including open source course material. A point was made about intellectual property issues and the concerns that it might deter some faculty from making their curriculum or course material open source. There are a few good textbook choices, but more are needed that are geared for undergraduates.

Stakeholder involvement needed for that scale-up
Industry is a definite stakeholder. There is a need to incorporate the added value of entrepreneurship into the classroom, thereby giving students the opportunity to think about making their own jobs and about commercialization. The incorporation of training that addresses government and policy jobs will give students a more expansive view of what to do with their education. Looking into creating a Nano Congressional Fellowship was also mentioned. One approach would have graduate students reach out to their high school teacher and get the graduate student involved as an advisor for high school NSEE projects. The high school teacher would then be involved with and exposed to university research and can take back this knowledge to their classrooms. It might be good press for the college or university and the teacher could become a spokesperson to promote the institution to prospective students at their school. Conducting periodic town-hall style talks (or using other informal settings such as museums) to engage the public with nanotechnology is another way of increasing stakeholder participation. This strategy also has potential to expose and engage parents with the field. The value of nanotechnology themed interdisciplinary workshops with people from more than two disciplines was reiterated. These types of workshops could help foster interconnections between people in different departments at the same institution and also help in overcoming departmental barriers.

Also mentioned was the involvement of students in outreach. Students at the Norwegian University of Science and Technology (Trondheim, Norway), who built their own AFMs, are a good example; their completed devices provided them with the opportunity to show it off to other students and explain what it does. The formation of an association (perhaps internationally) of students in nanotechnology was mentioned as well as ways of fostering the integration of undergraduate students into research as a means to have them incorporated in the research community.

Involving the business sector in various stages of student education and career planning (from the high school through graduate levels of education) is needed for inclusion of more undergraduates in the industrial research experience. This could be accomplished by getting more support from industry for Research Experiences for Undergraduates (e.g. an industrial REU). A key target for outreach could be small firms whose smaller monetary resources might inhibit opportunities to take short courses on nanotechnology to learn about the field and how it could benefit them. The involvement of Non-Governmental Organizations (NGOs), consumer rights groups, food safety groups, etc. could help students and the NSE-field envision the broader connections to society.

By establishing partnerships with education departments, NSE proponents could expose those who will be teachers, or go into teaching, to nanoscience. Perhaps schools could have an option for NSE students in science and engineering majors to get teaching certification. Accessibility to NSE facilities is seen as an issue, with a need for a wide availability of resources. There should be a mechanism to centralize the information, though this activity would likely need funding to get accomplished. NanoHUB seems like a good model since it incorporates user feedback and is set up as more of a community. It might not be necessary to have the materials in one location, but at least provide links at the centralized location for the various materials (for those who are willing to share their materials). Most people are likely to adopt a course if it has been tested and proven by three or more users, so the centralized portal would need a system for vetting and organizing resources.

Quick incorporation of new information, such as the convergence of nano-, bio-, info-, cogno-technologies, in education curricula

Quick incorporation of new materials into science curricula is a continuous challenge because science is constantly evolving. Explicitly teaching this aspect of scientific research by using NSE as a prime example is one way of quickly incorporating it into curricula. Providing interdisciplinary professional development and minimizing barriers between academic departments would also help. Engaging industries involved in nano/bio/info/cogno areas, perhaps through company-sponsored interdisciplinary student club activities or projects, is another possibility. Student teams would take ownership of the activity and be exposed to real-world problems. Anecdotally, one participant mentioned that when university students engaged with company projects (as individuals or as teams), they saw an exponential increase in the number of students that got involved. This effect was noticed for all topics not just nanotechnology.

Best use of NSE to attract underrepresented populations to STEM

Participants feel that promoting the interdisciplinary nature and societal impacts of NSE is one way of attracting underrepresented populations. For example, these aspects have been shown to attract more females.[27] Identifying role models is also a useful method, however, it was noted that engagement around NSE itself was likely more important initially than finding role models. There might not be many role models from underrepresented populations at the outset, but making NSE appealing to gain more underrepresented students and researchers would lead to having more of these role models in the future.

Top actions that could be taken to address the items above

- Determine the benefits of different types of NSE programs to universities and students. Existing research centers such as Science and Technology Centers (STC), Engineering Research Centers (ERC), Nanosystems Engineering Research Centers (NERC), Materials Research Science and Engineering Centers (MRSEC), and Louis Stokes Alliances for Minority Participation Program (LSAMP) could be used as case studies. These interdisciplinary research centers and training grants have impacted traditional programs and often have detailed reports to submit to funding agencies that have valuable information such as creation of interdisciplinary community, student training and education, longitudinal tracking, diversity, and outreach to K-12.
- Create and promote interdisciplinary cooperation and professional development opportunities among educators.
- Promote the interdisciplinary nature and societal impacts of NSE in order to increase diversity.
- Involve the business sector at all the stages of student education and career planning.

Graduate Degree
Discussion Leader: Mark Tuominen

Summary

The graduate degree stakeholders' group identified two current modes for integrating NSEE; a nanotechnology-specific degree program or having a NSE research emphasis while being based in a traditional discipline. Due to NSE's interdisciplinary nature, they also stressed a need to allow for both generalist and specialist thinking. Broadening graduate coursework to include entrepreneurship and management training was also seen as important. They pointed to a need for standardized, high quality textbooks for graduate level nanoscale science. Issues with MOOCs (accreditation and IP concerns) also must be addressed. Building and maintaining relationships with institutions which traditionally serve underrepresented groups and encouraging dialogue about the values and challenges (anti-elitism, family cohesion, work/life balance, connection to original community) of underrepresented populations in STEM were two suggestions for broadening participation in NSE within graduate programs.

Communicating NSE was discussed within a number of contexts. Graduate degree stakeholders recognized the need to nurture trans-disciplinary opportunities that facilitate the development of common languages between disciplinary fields. They also felt that there must be more communication of the state-of-the-art of nanotechnology progress, education, and career opportunities to the general public in order to aid in their perception of nanotechnology. The group also identified an opportunity to improve the pipeline for graduate programs and help train graduate students in communication (with an eye towards Broader Impacts) by having them engage with K-12 students. Within graduate programs, students need to be informed that there are multiple pinnacles of achievement (policy maker, entrepreneur, teacher, science communicator, etc.) for those with advanced degrees.

Colleges of Nanoscale Science + Engineering

State University of New York Polytechnic Institute

COLLEGES OF NANOSCALE SCIENCE + ENGINEERING
SUNY POLYTECHNIC INSTITUTE

SUNY Poly CNSE is a global education, research, development, and technology deployment resource dedicated to preparing the next generation of scientists and researchers in nanotechnology. It is the world's first college to offer comprehensive baccalaureate programs in Nanoscale Engineering and Nanoscale Science. SUNY Poly CNSE's cross-disciplinary Ph.D. and M.S. curricula integrate the fundamental principles of physics, chemistry, computer science, biology, mathematics, and engineering with the cross cutting fields of nanosciences, nanoengineering, nanotechnology, and nano-economics.

High-priority NSE education challenges and opportunities

The most effective use of graduate education happens when highly motivated students are available. There is opportunity to further strengthen the vertical integration of K-12, college/university and graduate education. Further, we need to transition from 'data acquisition' to idea synthesis. Examples of programs that can be utilized to accomplish this include NSF's Robert Noyce Scholarship Program, the NSF Research Experiences for Teachers (RET), and the Triangle Coalition's Einstein Distinguished Educator Fellowship Program.

Each graduate education program is different, depending on factors such as the local environment, thesis advisor, lab facilities, and degree of collaboration. Nonetheless, there is a need for attention to the skill sets required by eventual employers. There is also the need to better bridge between industry's mission-driven thinking, and the academic discipline-driven thinking. Furthermore, entrepreneurship and management training in the graduate coursework (start-ups, lab management, etc.) could lead to more rapid insertion of laboratory discovery into marketable innovations. Today, major technological breakthroughs occur continually, with significant changes during the typical time scale for completing a PhD thesis. Graduate students face a situation where the technical skills that they learned at the beginning of graduate school are dated when they graduate. Graduate education must prepare the student for a lifetime of continuing education. The availability of faculty who are sufficiently well versed in and can effectively communicate the state-of-the-art across a broad set of disciplines would help to address many of the challenges listed above.

NSE resources available to assist in the education process

At the graduate level, advanced facilities become far more important. Member agencies of the NNI have created nanoscale characterization and fabrication facilities open to external users (e.g. the NNIN/NNCI, the DOE Nanoscale Science Research Centers at five national laboratories, the NIH Nanotechnology Characterization Laboratory, and the NIST NanoFab Facility). However, there is a lack of NSE resources addressing advanced manufacturing, informal networking, and nanotechnology-specific textbooks. Given the breadth of NSE impact, it is impractical for each university to sustain expertise in all the NSE facets; to ameliorate this problem there are a growing number of online courses.

Joint School of Nanoscience and Nanoengineering

North Carolina A&T State University and the University of North Carolina at Greensboro

The JSNN was formed as a collaborative project of North Carolina A&T State University and The University of North Carolina at Greensboro. The mission of the JSNN is to prepare students from a variety of disciplinary backgrounds to conduct basic and advanced research in Nanoscience and Nanoengineering in industrial, governmental or academic settings. It offers a Master of Science in Nanoengineering and a Professional Master of Science in Nano-science. It also has PhD programs in Nanoengineering and Nanoscience.

The best way to facilitate NSE education resource scale-up

The most precious resource for the graduate programs is prepared students. This can be addressed by efforts such as: (1) the EU's TEMPUS program, (2) K-12 outreach and K-12 educator engagement/professional development, and (3) helping K-12 educators by making university resources available. Supplementary funding should be available to enable graduate students to communicate to K-12 audiences, and to support the development of high quality NSE related textbooks; this could be done as part of Broader Impacts.

At the graduate level, the challenge to deliver adequate breadth could be addressed by (1) center-based summer schools and short courses, (2) funding a professional group to standardize high quality textbooks for graduate level nanoscale science, and (3) creating incentives for university departments to recognize the importance of cross-disciplinary degrees.

Stakeholder involvement needed for that scale-up

As noted above, there are multiple challenges to bridging the academic-industry-government-public motivations associated with NSE. Additionally, these stakeholders are encouraged to develop a common understanding of public-private partnerships that can leverage expertise across disciplines and stakeholder sectors, e.g. academic, government, and industry, that also address potential conflict of interest concerns. Professional societies, accreditation organizations, and university departments must evolve beyond their traditional foci and endorse a greater emphasis on interdisciplinary coursework and materials.[30]

Science and engineering schools can directly impact the technical aspects of innovation, but it will also be necessary to establish associations with law and public policy schools to ensure well integrated ethical legal societal implications (ELSI) that enable the acceptance of rapid innovation. This effort must also include better quantification of risk managements.

Quick incorporation of the convergence of nano-, bio-, info-, cogno-technologies in education curricula

NSF centers (e.g. STC, ERC, NERC, MRSEC) have been an effective mechanism to establish new interdisciplinary degree pathways. Since converging technologies compel the integration of the traditional academic disciplines, it is time to rethink the basis for graduate degrees and allow for generalists and well as specialists - for both 'T' (generalist) and 'I' (specialist) thinking. To best enable the broader perspectives, one might consider: (1) multiple 'teachers' for courses (guest lectures, team teaching), (2) interdepartmental seminars (formal and informal), (3) collaborative coursework planning between departments, and (4) explicitly focusing on 'big ideas' or the 'big picture' (e.g. Grand Challenges such as the ones created by the National Academic of Engineering).

Best use of NSE to attract underrepresented populations to STEM

The pipeline for students entering graduate education must be addressed, with special attention to a) fostering community driven recruitment (a sense of inclusion), b) building and maintaining explicit pipelines with institutions, which traditionally serve underrepresented populations (maintain trusted relationships), and c) having a dialogue about values and challenges for each underrepresented population (anti-elitism, family cohesion, work/life balance, connection to original community).

Top actions that could be taken to address the items above

- Promote the state-of-the-art of nanotechnology progress, education, and career opportunities to the general public
- Provide opportunities to exercise and refine science communication skills, which are critical at all levels of graduate education
- Allow for both 'T' and 'I' (generalists and specialists) thinking in degree programs
- Require entrepreneurship and management training in graduate coursework
- Develop policies for public-private partnerships that bring all key stakeholders to the table as true partners and effectively enable convergent opportunities
- Provide teaching assistantships for graduate students to communicate to K-12, this could fit under Broader Impacts
- Provide hands-on platform or project based opportunities that catalyze convergent innovations and critical thinking skills
- Fund a committee for standardizing high quality textbooks for graduate level nanoscale science
- Address accreditation and IP issues for MOOCs
- The pipeline for students entering graduate education must be addressed, with special attention to building and maintaining trusted relationships with institutions and communities which traditionally serve underrepresented groups in order to encourage underrepresented populations in STEM and NSE. There needs to be a dialogue about values and challenges for each underrepresented population (e.g. anti-elitism, family cohesion, work/life balance, connection to original community)

Continuing Education
Discussion Leader: Russ Maguire

Summary

An education scheme that could be "complete" for more than one or two decades past the end of "formal" education is not realistic in an era of rapid progress in science and engineering. Thus, it is necessary to examine approaches to informal and continuing education.

Members of the continuing education breakout group saw access to educational resources, tailoring materials to the needs of continuing education students, and integrating the needs of industry into content as major components to NSEE. Individuals interested in NSE continuing education need resources that are inexpensive, easy to digest, and accessible. As part of accessibility, a central repository of resources that allows one to assemble the pieces necessary to create a personalized integrated program on a portal such as nanoHUB was discussed. The stakeholders also pointed out that organizing NSE continuing education around problems, rather than the more traditional lecture based model, is more effective for their learners.

MOOCs were recognized as critical for upgrades of an organization's technical staff. NSE education should address the needs of industry in order to encourage its involvement in continuing education; this will require supporting both public and proprietary information. To be compelling, there must be a mechanism in place that allows for the separation of public domain knowledge from the knowledge that is infused with proprietary and competitive knowledge, and transitioning between the two must be smooth and secure.

The state-of-the-art in NSE education

NSEE continuing education is presently accomplished:

- Through community colleges and universities
- Through internships, for example one-on-one mentorships which do not lend themselves to scale-up
- By in-house classes at companies (for proprietary information)
- Through resources available at Nano-Link, the NACK Network, and other Micro & Nano Technologies ATE Centers
- With online learning and MOOCs that provide world wide open access and low barriers to access, nanoHUB is an example of an NSE content delivery platform
- Using full-semester courses, for example:
  - Short courses on cutting-edge topics from nanoHUB education group
  - Fundamentals of Nanotechnology, an introductory course out of Purdue University that presents concepts relating to nanoelectronics and mesoscopic physics
  - Thermal Energy at the Nanoscale, a course on thermal energy at the nanoscale from Purdue University
  - Certificate in Aircraft Composite Materials & Manufacturing from the University of Washington and Boeing Company Learning

The needs in continuing NSEE

Since NSEE will be pertinent to all levels of educational accomplishment, a better determination of individuals' needs at multiple levels is needed: high school graduates, CC/TC graduates, bachelor's degree holders, advanced degree holders, professors, business people, venture capitalists, and executives. In particular, up-to-date guidance on occupational safety and health issues is important to inform benefit/risk decisions at all levels.

In order to meet the NSEE needs there must be engagement by (1) professional societies through tutorials and webinars, (2) standard-setting bodies through certification programs, and (3) university-industry partnerships to ensure college graduates have the skill sets needed by continuously evolving industry needs. Since continuing education generally needs to accommodate the working person, the content should be kept succinct, easily accessible, and be low cost. Both broad overview and specific courses will be necessary. As noted in the prior breakout group discussion, hands-on training can be more effective and might be provided through: (1) public-private development platforms (such as the Colleges of Nanoscale Science + Engineering SUNY Polytechnic Institute); (2) user facilities, especially with remote access capability; (3) community college facilities, and (4) museum of science interactive exhibits.

The best way to facilitate NSE education resource scale-up

The key in successful professional programs is to provide robust and rigorous programs that are at the same time flexible, thus providing alternatives to non-traditional students. Online learning can provide fast, flexible publication in new content, especially important to fields like NSE that are evolving rapidly. Current providers include:

- nanoHUB
- Micro & Nano Technologies ATE Centers
- Texas State University NanoTRA

What stakeholder involvement is needed for that scale-up?

Public–Private Partnerships will be necessary, the former for curriculum development and the latter to identify the important topics to be included in the curriculum. This effort will need a funding source.

Top actions that could be taken to address the items above

- Creation of easily accessible, low cost, and readily digested materials
- Identify the resources already available, for example from the ATE Centers or courses on nanoHUB, and make it easy for anyone to assemble these into learning packages tailored to specific curricula need
- Identify and collect existing resources appropriate for continuing NSEE in one location, and post them on an online portal such as nanoHUB
- Encourage NSEE and continuing education sites to cross-post: NSEE sites should specify what is for continuing education, continuing education sites should specify nanotechnology content
- Proactively engage industry through (1) a broad survey to a significant portion of industry members, (2) roadmapping workshops with key companies to identify priorities through long term strategies.

Informal
Discussion Leader: Larry Bell

Summary

The discussion among Informal Science Education (ISE) stakeholders concentrated on the work and future applications of the NISE Network. The national infrastructure that NISE has developed over the past ten years is an asset which may be useful for aggregating broader impacts. Identifying methods of expanding the reach of the NISE Network was touched upon, including two explicit examples of supporting teacher professional development and creating testing materials for classroom use.

Refocusing the discussion around NSE from a general purpose technology to specific applications and Grand Challenges was seen as a way of increasing its relevance, and of promoting interest in the field by the public. The group saw an opportunity to bring informal NSEE to underserved and underrepresented audiences by expanding the reach of NISE. They specifically highlighted working with youth-serving groups such as the Girl Scouts, Boy Scouts, and 4-H.

The state-of-the-art in NSE education

There are hundreds of NSE educational materials that have been developed and are web accessible. Examples are the physical assets which have been distributed annually through NanoDays kits to 250 sites and the 93 copies of the *Nano* small-footprint exhibition. In addition, the NISE Network has established a national infrastructure with regional hubs and approximately 600 institutional partners that provide in-person informal educational experiences for members of the public nationwide.[31] Participants see the value in the science of science communication and how this effort is beginning to (1) incorporate science and society concepts and (2) to establish better mechanisms to address emerging and developing research areas like NSE. There are also NSE professional development programs for informal educators implemented through in-person workshops, online brownbag conversations, conference sessions, and training materials distributed in the kits. The ability for children to visit state-of-the-art NSE research sites is also a resource, but one that is underutilized because access is constrained to those locales where such facilities exist and the appropriateness of public visitors during research operations. Beyond NISE, community and youth-serving groups like 4-H, and Girl Scouts, educational television programs like NOVA, and professional societies present additional informal education opportunities to disseminate NSE. The NSF Advancing Informal STEM Learning program-funded Center for Advancement of Informal Science Education (CAISE) is a resource center with project descriptions, evaluation reports and tools, and learning research resources for the entire field of informal STEM education.

NISE Network

Nanoscale Informal Science Education

NISE Network is a national community of researchers and informal science educators dedicated to fostering public awareness, engagement, and understanding of nanoscale science, engineering, and technology. Their website is an online digital library of public nano educational products and tools designed for educators and scientists to increase their capacity to engage their audiences in nanoscale science, technology, and engineering. NISE is responsible for distributing NanoDays kits to 250 sites annually and by the end of 2105 eight million people will have participated in NanoDays program.

High-priority NSE education challenges and opportunities

Participants feel the biggest challenge to informal NSEE is finding funding mechanisms to sustain and evolve the existing NSE informal education infrastructure, which was developed with ten years of NSF funding. Curation takes money and online resources established by NISE will be actively maintained for only a short time after NISE funding ends. There is the possibility of looking to industry (potential funders discussed included Intel, Exxon Mobil, Chevron) or the U.S. Department of Education to fund informal NSEE. Other challenges and opportunities that were discussed focused on the need for continued networking of informal education practitioners in order to better disseminate what is being done at individual sites across the U.S. This network should respond to changes in the research infrastructure for NSE by involving universities and other types of facilities, and reaching out to professional organizations beyond the Materials Research Society, which has had a strong partnership with the NISE Network over the past decade. Another challenge that this expanded network may address is keeping current with NSE research; some of the NISE materials now available will eventually be out-of-date, especially as new applications of nanotechnology become more prevalent. People are more easily engaged if they see a connection to the science in their daily lives. As the science of science communication expands and matures, there is the opportunity for informal education venues to be great places to work with, and prepare, scientists for connecting more effectively with the public. New nanotechnology and society approaches were only recently introduced to NISE Network materials and they suggest further development of a changing dynamic between visitors and museums in which museums recognize and validate the role of values, ethics, personal experiences, and stakeholder perspectives along with scientific data in personal and societal decision-making. Participants also saw opportunities for the resources developed by the NISE Network to be valuable in K-12 education, for undergraduate education, and for adult education beyond museum walls, if the appropriate partnerships and funding mechanisms could be found to do so.

The best way to facilitate NSE education resource scale-up

The group acknowledged that the NISE Networks partnerships between universities and science and children museums reach primarily the groups that visit those venues and that expanding NSE informal education to community and youth-serving organizations (4-H, Girl and Boy Scouts, and other out-of-school programs) that could use NISE resources and expertise, is one method of scaling up their informal NSEE efforts. Expanding the role of informal education by equipping museum staff with the skills to run professional development for K-12 teachers beyond what is already being done (primarily enrichment and hands-on classroom demonstrations); maintaining and enhancing on-line resources and bringing in new partners for content; and fostering relationships between museums, researchers, and teachers were also discussed as ways to scale-up informal NSE education resources. NISE Network has applied for, and received, a supplement to its NSF award to allow a pilot project designed to partner community and youth-serving organizations with NISE Network's current partners to bring NSE content and educational activities to a broader demographic of participants.

Stakeholder involvement needed for that scale-up

Participants strongly believe that stakeholder involvement is necessary for scale-up because nanotechnology-themed exhibits and programs cannot be funded by people buying tickets to see them. They listed a number of groups and events that informal NSEE could look to as models for raising support such as FIRST Robotics, Science Olympiad, and the maker community dues model. Repackaging the NISE Network around new topics of interest to the NSF, looking to the U.S. Department of Education for funds because of their interest in public engagement (Expedition Learning Outward Bound was the example given), building a "Friends of Nano" community, and involvement with the Association of Science – Technology Centers were also discussed.

Quick incorporation of the convergence of nano-, bio-, info-, cogno-technologies in education curricula

Participants believe that repurposing the NISE Network to address nanotechnology, biotechnology, information technology, and cognitive science (NBIC) convergence is one method of quickly incorporating those technologies into informal education exhibits and programs nationwide. Those efforts would then benefit from the existing connections and infrastructure leading to a long term vision and holistic approach instead of smaller, piecemeal efforts.

Best use of NSE to attract underrepresented populations to STEM

The group feels that there is nothing inherent to nanoscale science and engineering content *per se* that could help encourage underrepresented groups to get involved in STEM. However, a shift in outreach focus to the expected outcomes of NSE-enabled applications may attract those communities. They suggest that aligning NSE with possible solutions to societal problems and identifying and focusing on NSE Grand Challenges would help with reaching underrepresented groups. To this end, the informal science education community needs more information on the types of problems and Grand Challenges that NSE can help solve. They also discussed the need to go beyond museums, connecting to after-school and community based organizations.

Top actions that could be taken to address the items above
Participants identified four priorities for informal NSE education:

- A good way of increasing relevance and interest in NSE by the public may be refocusing outreach efforts for presenting NSE around specific applications that address societal Grand Challenges rather than presenting it as a general-purpose approach to technology.
- Expand the reach of the NISE Network beyond museums and research centers to youth-serving, community based organizations nationally that reach a broad demographic including under-served and under-represented audiences.
- The use of the NISE Network would be a good test model for aggregating broader impacts not just within an organization but across organizations because it can leverage the national infrastructure developed over the last 10 years.
- The NISE Network can also serve as a pilot project for knowledge transfer from NSF to the Office of STEM Education in the Department of Education. Potentially expanding the reach of NSF's investment in the NISE Network to explicitly support teacher professional development and testing materials for classroom use.

Key Findings

The top actionable items from the six breakout sessions reflect the viewpoint of the people in each session. Those items were presented to all the participants of the workshop in order to gain perspective on the broader audience's priorities. Based on feedback received from almost half of the participants, the top actionable items for each stage are:

K-12

- Identify and leverage insertion points that can be linked across grade levels for NSE concepts in existing standards and curricula.
- Create a central, searchable NSEE portal repository for teachers, possible models and/or partners included nanoHUB.

CC/TC

- Create a best practices manual which builds on the efforts of the Nanotechnology Applications and Career Knowledge (NACK) Network, Nano-Link, and others to help with nationwide translation, replication, and tailoring of programs to specific local and regional needs. This manual should reflect the multitude and diversity of approaches.

Undergraduate

- Create and promote interdisciplinary cooperation and professional development opportunities among educators.
- Promote the interdisciplinary nature and societal impacts of NSE in order to increase diversity in the student population.

Graduate

- Address the pipeline for students entering graduate education with special attention to building and maintaining trusted relationships with institutions which traditionally serve underrepresented groups in order to encourage underrepresented populations in STEM and NSE.

Continuing

- Identify the resources already available, for example from the ATE Centers or courses on nanoHUB, and make it easy for anyone to assemble these into learning packages tailored to specific curricula needs

Informal

- Refocus NSE outreach efforts around specific applications that address societal Grand Challenges in order to increase relevance and interest for the public.
- Expand the reach of the Nanoscale Informal Science Education (NISE) Network beyond museums and research centers to youth-serving, community based organizations nationally that reach a broad demographic including underserved and underrepresented audiences.

The consideration of all the recommendations leads to a number of key findings which cut across the stages of education. There is compelling need to:

Identify, develop, and evolve the NSE workforce skillset requirements (and the education venues necessary to acquire them).

As nanoscale discoveries continue to move into the marketplace, the required skillset for the workforce will evolve. It is critical to continually engage industry to keep informed of their workforce needs and work across the educational spectrum to incorporate the necessary skills and knowledge at the appropriate intersections.

Possible Next Steps:

A group of stakeholders in NSE can come together to identify target skills at different educational levels. Industry and academia representatives can identify competencies needed to be successful in the field and these can be aligned with skills identified by the committee. This group could engage companies (e.g. Right Management) that match employers in the areas of nanotechnology with the scientists and engineers seeking this type of employment. These companies have large databases of information from companies about the types of skills employers are looking for in future employees. These companies also have a vested interest in insuring that students receive the desired training so they may be willing to help fund these efforts. These skills need to be carried over from post-secondary to graduate levels, but often are not intentionally embedded in the curriculum. There are efforts in the ATE Micro-Nano Technological programs (Nano-Link and NACK for examples) that can serve as starting points. Those programs have used local industry information to design their curriculum and foster effective collaborations. NACK is working with ASTM to establish standards for a NSE curricula at the CC/TC level.[26]

The Department of Labor has an Occupational Outlook Handbook with career information about hundreds of occupations. The NNCO/NSET might develop the information necessary for NSE occupations to be present in that handbook. There could also be a feature article on the DOL Career Outlook site.

The NSF has several programs to better link college-level education with industry such as GOALI, I-Corps, IUCRC and ERC. These have been used by NSE in the past and should be further exploited into the future.

In order for identified workforce skills to be effectively incorporated there needs to be both vertical integration (from K-12 through college) and horizontal integration (nanoscale examples integrated into the traditional courses in mathematics, biology, chemistry, earth science, physics and the new focus on engineering/technology). The goal of the NSF Research Coordination Networks (RCN) program is to advance a field or create new directions in research or education by supporting groups of investigators to communicate and coordinate their research, training and educational activities across disciplinary, organizational, geographic and international boundaries. Prior to its sunsetting, the Nanotechnology Center for Learning and Teaching would have acted as a central point to coordinate NSEE efforts across regional workforce skillset requirements. Perhaps the RCN program could be utilized to fulfill this need, at least in part.

Review existing NSEE efforts to identify and disseminate best practices.

It is clear that excellent NSEE efforts exist across the educational spectrum, but these efforts are not yet commonplace nor fully integrated into the educational system. Workshop participants stressed the need to leverage existing efforts by identifying and propagating best practices. For K-12, this includes properly vetted materials aligned with relevant standards and teacher professional development programs. Community and technical college programs can leverage national experience, but also need to emphasize local industry requirements. Colleges and universities, at both the undergraduate and graduate level, need to assess the benefits of departments, degree programs, and minors or specialty programs in the context of broader institutional goals and educational needs of their students. The roles of evolving educational platforms, such as massive open online courses, need to be evaluated, especially in the context of continuing education.

Possible Next Steps:

At the K-12 level, NSE is mentioned only in passing in the Next Generation Science Standards, but NSE does provide excellent examples of the interdisciplinarity touted in the NGSS. Further, the Commonwealth of Virginia and the state of Colorado have formally incorporated NSE in their standards. The NNCO could lead a collaboration with the Virginia MathScience Innovation Center to facilitate the insertion of the developed NSEE resources into Virginia's curriculum. Success in Virginia could serve as a role model for other states to follow, while working with their own K-16 curricula. The involvement of the Council of State Science Supervisors may be important in translating this success to other states. Leveraging the work that is being done at the national level by groups such as nanoHUB, McREL, and NNIN/NNCI to incorporate NSE lessons and best practices would accelerate the process.

In accordance with the algorithm for providing financial support to the NNCO, the Department of Education (ED) does not presently contribute any monies to the NNI. As part of its STEM education focus, perhaps ED could contribute a fellowship position or part of a government employee's time to assist in the NNCO education effort.

As mentioned earlier, NACK is currently working with ASTM International in order to create a set of uniform standards for workforce education in nanotechnology.[26] In the future, students who have acquired nanotechnology workforce education knowledge will be able to take ASTM International tests and attain a set of industry recognized stackable certificates. This is an excellent method for identifying and disseminating best practices and should be encouraged as a best practice for NSEE development.

Identify, evolve, and/or develop NSEE materials with well-defined links to appropriate standards and curricula. Additionally, promote their scale-up and widespread use.

These materials could include high quality demonstrations, lesson plans, lectures, and e-books that can be readily updated. The workshop exhibit provided an opportunity to showcase some of the vast array of resources that have been developed for NSEE (see Appendix C). To maximize the impact and implementation of these resources, however, they need to be clearly linked to the relevant standards and curricula. To promote scale-up and wide spread use, activities of standards organizations and professional societies, depending on educational level, should be strongly leveraged. For example, in K-12 the National Research Council's Framework, Next Generation Science Standards has the Educators Evaluating the Quality of Instructional Products (EQuIP) rubric developed by NSTA and Achieve that could be employed.[32] Other organizations with potentially relevant activities include the American Society for Testing and Materials (ASTM), the Accreditation Board for Engineering and Technology (ABET), the American Chemical Society (ACS), the American Physical Society (APS) and the American Society for Engineering Education (ASEE).

Possible Next Steps:

Existing materials must be reviewed and aligned with the EQuIP rubric and the NGSS. Most existing NSEE materials have not been fully vetted in this manner because of the timing of the development efforts and the recent release of NGSS. A major hurdle for this requirement is the lack of support for the work of alignment, which is separate from funding for research. Since these materials are potentially saleable (K-12 education in the US is nearly a trillion dollar annual endeavor[33]), the possible use of SBIR/STTR funds should be explored as the source of that support.

Provide a mechanism for teacher evaluation of the materials; widespread adoption of new teaching aides is facilitated through "informal accreditation" by fellow teachers. However, evaluation is difficult because of the lack of funding and the lack of people whose job description it befits. A concrete way of doing the evaluation, so that it also benefits the spreading of materials, is connecting it to teacher workshops about NSEE. Such workshops require teachers to try out the materials and to use the EQuIP rubric or design an evaluation rubric such as McREL's Lesson Quality Assessment Tool (LQAT) for the NanoTeach project, whichever way is desired. Perhaps this requirement could be added to NSF funded "NSE center-like" efforts, or to the regional education hubs mentioned below.

In order to ensure successful implementation of NSEE materials in the classroom, educators' workshops are necessary to prepare the teachers. In developing a training program, open discussion with participants on how and where in the curriculum to incorporate existing materials should be center stage. Given their responsibilities for STEM education, NSF and Department of Education would be logical sources of support for this activity, but other agencies, the professional teachers' societies, and industry could also play a role.

Representatives from the NNIN/NNCI and Nano-Link have been attending the NSTA National Conference. Following their example, the NNCO could send staff in order to raise awareness of NSE teaching aides and showcase their utility. Any remaining funds from NSEE workshops could be devoted to this effort by providing the NNCO with existing teacher aides; newly funded projects could have this as an option.

Establish a central, searchable, e-portal that identifies and provides links to vetted NSEE materials, is readily accessible, designed for intuitive use, and sustainable.

There is a vast array of resources that have been developed across the educational spectrum, but they are often difficult for teachers, faculty, or students to find. Workshop participants strongly suggested the establishment of a portal to enable easy access to vetted NSEE materials. The portal would link to other central repositories relevant to specific educational levels (such as the ATE Centers for community college level resources, NISE Network for outreach materials, NNIN/NNCI, etc.). The difficulty in maintaining and sustaining such a resource was noted, and the leveraging of existing resources or professional societies was encouraged.

Possible Next Steps:

In response to the high priority all the workshop participants placed on the need for an NSEE portal, the NNCO is working with nanoHUB to develop a central resource. Materials to be included in the portal will originally be coming from those listed in Appendix D of this report. NISE Net and the NNIN are already working with nanoHUB in order to add their materials to the site. Teachers will have a central, searchable location to find NSEE materials and then be provided links to the home of the resources. As a part of this effort, the NNCO is looking for champions for the resources to be included in the portal; champions would assist with adding and curating information about their materials.

There needs to be efforts to widely publicize the central e-portal in professional science/engineering teacher communities/professional societies and engage them in a discourse to explore possible implementations that would survive a sunset of the NNI. As already mentioned earlier, NNCO staff at education conferences like the NSTA National Conference can help raise awareness of the portal.

Develop a national network of regional education hubs that effectively utilize the diverse stakeholder communities, leverage national forums, and address the challenges identified in the other recommendations.

There is a strong need for a network of regional support sites that would bring together educational resources, offer teacher training, and provide expertise while leveraging and supporting the local community. The hubs would promote vertical integration (from K-12 through college) and horizontal integration (nanoscale examples integrated into the traditional courses in mathematics, biology, chemistry, earth science, physics and the new focus on engineering/technology).

Existing assets include NSE centers at research universities, ATE regional centers such as Nano-Link and NACK, NISE Network, and state-based centers such as the MathScience Innovation Center in Richmond, Virginia. The expertise and resources from the NSF supported groups operating at the national level such as nanoHUB, McREL, NSF funded NSE Centers, and NNCI/NNIN must be leveraged with this regional approach.

Possible Next Steps:

NNCO should bring together the key federal agencies under the NNI that are involved with NSE education to pool efforts and resources. These efforts should become part of the regional support sites. Funding should come from federal, state, and, industry resources. Nanotechnology industries should be brought in to help support this because they will need skilled workers in the future. These various groups are presently disconnected and need to come together.

The NSF ATE program has six centers with a micro-nano technology focus. They are reasonably distributed across the nation; located in New York, Pennsylvania, Minnesota, Arizona, New Mexico and Washington. These Centers have an education focus and might provide assets for regional support sites, supplemented by other NSF funded NSE focused centers.

The Nanotechnology Center for Learning and Teaching would have acted as a central point to coordinate NSEE efforts across regional hubs but reached an early sunset. The goal of the NSF Research Coordination Networks (RCN) program is to advance a field or create new directions in research or education by supporting groups of investigators to communicate and coordinate their research, training and educational activities across disciplinary, organizational, geographic and international boundaries. Perhaps the RCN program could be utilized to fulfill this need, at least in part.

Establish clearly defined, nanotechnology-enabled approaches toward the solution of societal Grand Challenges in order to engage students, underrepresented populations, and general public interest.

In addition to the many current commercial applications that incorporate nanomaterials to enable lighter, stronger, antimicrobial, or water repellent products, the unique properties at the nanoscale can spark wonder at applications such as invisibility cloaks and the ability to detect cancer at the cellular level. Workshop participants suggested identifying and publicizing nanotechnology-enabled approaches to the solution of Grand Challenges to promote interest and engage students and the general public. Examples could include water purification, alternative energy, and treatment of disease.

Possible Next Steps:

The National Nanotechnology Initiative is presently engaged in an effort to add Grand Challenges into the National Nanotechnology Initiative. Since the pending NNI Grand Challenges will likely address solutions toward society needs, any programs created to address those Grand Challenges could explicitly include the development of teaching aides which highlight the role of NSE in successfully addressing the challenge.

Educational materials for both formal and informal audiences need to be developed, leveraging those resources already developed (see Appendix D). The materials do not have to establish a new curricula per se, but can be enrichment activities. One example was developed in South Africa to interest middle school students in their nanotechnology Grand Challenges; these eye-catching posters come with lessons and activities. Social media could be another way to engage people with nanotechnology Grand Challenges.

Appendix A: Workshop Agenda

<u>Day one</u>

0700 – 0800	Registration, Continental Breakfast, and NSEE Asset Exhibit set up	
0800 – 1200	Morning Plenary session	Co-Chairs, Jim Murday, USC and Donna Riley, NSF
0800 – 0810	Welcome	Dr. Pramod Khangonekar, NSF ENG
0810 – 0820	Welcome	Dr. Susan Singer, NSF EHR/DUE
0820 – 0830	Charge to the Workshop	Dr. Jim Murday, USC
0830 – 0855	Overview NSEE	Dr. Mike Roco, NSF
0855 – 0925	OECD Perspective	Mr. Richard Scott, OECD
0925 – 0955	Educator perspective	Dr. Patricia Simmons, NCSU and NSTA
0955 – 1020	Morning Break / Networking	
1020 – 1050	Industry perspective	Dr. Celia Merzbacher, NRC
1050 – 1120	ED Education program	Dr. Russell Shilling, Dept. Educ.
1120 – 1150	Infrastructure/Global Access to NSEE	Dr. Krishna Madhavan, nanoHUB
1150 – 1300	Working Lunch, complete exhibit set up	
1300 – 1500	Public session: exhibition showcasing NSEE assets	
1500 – 1630	Afternoon Plenary session	Chair, Chris Cannizaro, DOS
1500 – 1530	Australia perspective	Mr. Rob Thomas, Australia
1530 – 1600	European perspective	Dr. Lars Montelius, INL
1600 – 1630	Asia perspective	Dr. Lerwen Liu, NanoGlobe, Singapore
1630 – 1700	Break	
1700 – 1800	Dinner	
1800 – 2000	Evening Plenary Session	Chair, Deb Newberry, DCTC
1800 – 1830	K-12	Dr. John Ristvey, UCAR (formerly McREL)
1830 – 1900	CC/TC	Dr. Steven Fonash, NACK, PSU
1900 – 1930	University	Dr. Murday for Dr. Robert Geer, CUNY
1930 – 2000	ISE	Mr. Larry Bell, NISE Network

<u>Day 2</u>

0700 – 0800	Continental Breakfast	
0800 – 0845	Morning Plenary	
0800 – 0830	Adding NSE to VA SOLs	Mr. Eric Rhoades, VA Depart. Educ.
0830 – 0845	Charge to the Working Groups	
0845 – 1200	Six working groups organized by stages of education: K-12, Community College/Technical College, College/University, Graduate Degree, Continuing Education, Informal Education	
1015 – 1200	Continuation of working groups	
1200 – 1300	Working Lunch	
1300 – 1500	Afternoon Plenary session	Chair, Lisa Friedersdorf, NNCO
1300 – 1445	Reports from each of the six working groups – including each group's top 2-3 recommendations	
1445 – 1500	Wrap-up	
1500	Adjourn	

Appendix B: Attendees

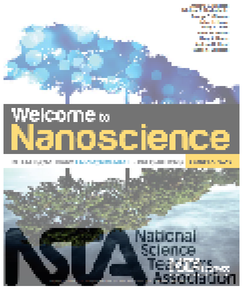
Name		Email	Institution	Session
Allen	Joyce	joyce.allen@ien.gatech.edu	NNIN, Georgia Inst of Technology	K-12
Awadelkarim	Osama	ooaesm@engr.psu.edu	NACK Network, Penn State Univ.	College/Univ
Batterson	James	jimbatterson@live.com	NASA (ret)	K-12
Bell	Larry	lbell@mos.org	Boston Museum of Science	ISE
Bell	Jamie	jbell@astc.org	Center for Advancement of Informal Science Education (CAISE)	ISE
Bennett	Ira	ira.bennett@asu.edu	Center for Nanotechnology in Society, Arizona State Univ.	ISE
Bhushan	Bharat	bhushan.2@osu.edu	Ohio State	Continuing
Blonder	Ron	ron.blonder@weizmann.ac.il	Weizmann Institute, Israel	K-12
Bobalek	John	John.Bobalek@bep.gov	Nanoscale Science Engineering and Technology Subcommittee	
Burnham	Nancy	nab@wpi.edu	Worcester Polytechnic Institute	College/Univ
Cannizzaro	Chris	CannizzaroCM@state.gov	Department of State	
Chang	Bob	r-chang@northwestern.edu	Northwestern Univ.	K-12
Chen	Jia Ming	jmchen@cnsi.ucla.edu	California Nanosystems Inst., UC Los Angeles	K-12
Cohen	Sidney	sidney.cohen@weizmann.ac.il	Weizmann Institute, Israel	Graduate
Curreli	Marco	marcocurreli@omninano.org	Omni Nano	K-12
Ehrmann	Robert	REhrmann@engr.psu.edu	NACK Network, Penn State Univ	CC/TC
Faltens	Tanya	tfaltens@purdue.edu	nanoHUB, Purdue University	Continuing
Flowers	Mark	mflowers@nanoscience.com	nanoScience Instruments	CC/TC
Fonash	Steve	sfonash@psu.edu	NACK Network, Penn State Univ	Graduate
Friedersdorf	Lisa	lisaf@virginia.edu	UVA and National Nanotechnology Coordinating Office (NNCO)	K-12
Geer	Robert	rgeer@albany.edu	SUNY, College of Nanoscale Science and Engineering (CNSE)	Graduate
Gillian-Daniel	Anne	agillian@wisc.edu	MRSEC on Structured Interfaces, Univ of Wisconsin	K-12
Goodwin	Jay	JTGOODWI@nsf.gov	AAAS Science & Technology Policy Fellow	CC/TC
Gray	Amber	amber@usc.edu	University of Southern California	K-12
Hall	Michelle	hall@scieds.com	Teen Science Café Network	ISE
Healy	Nancy	nancy.healy@mirc.gatech.edu	NNIN, Georgia Inst of Technology	College/Univ
Herr	Daniel	djherr@uncg.edu	Univ. North Carolina, Greensboro	Graduate
Kähkönen	Anna-Leena	anna-leena.m.kahkonen@jyu.fi	University of Jyväskylä, Finland	College/Univ
Lee	Jo-Won	jowon@hanyang.ac.kr	Hanyang University, Korea	Graduate
Lightfeather	Judith	judith.lightfeather@tntg.org	The Nanotechnology Group, Inc.	K-12

Lippel	Philip	phlippel@mit.edu	Massachusetts Institute of Technology	Continuing
Lisensky	George	lisensky@beloit.edu	Beloit College	College/Univ
Liu	Lerwen	lerwen@nano-globe.biz	NanoGlobe, Singapore	Continuing
Madhavan	Krishna	cm@purdue.edu	nanoHUB, Purdue University	
Maguire	Russ	russ.maguire@yahoo.com	Boeing (retired)	Continuing
Martin	Paul	pmartin@smm.org	Science Museum of Minnesota	ISE
Mayol	Ana-Rita	anaritamayol@gmail.com	University of Pennsylvania	CC/TC
Merzbacher	Celia	celia.merzbacher@src.org	Semiconductor Research Corporation (SRC)	Graduate
Moeck	Peter	pmoeck@pdx.edu	Portland State University	College/Univ
Montelius	Lars	lars.montelius@ftf.lth.se	Lund Univ, Sweden and International Nanotechnology Lab, Portugal	Graduate
Morita	Shelah	smorita@nnco.nano.gov	AAAS Science and Technology Policy Fellow	Graduate
Murday	James	murday@usc.edu	University of California	
Murdock	Maajida	MMurdock@bccc.edu	Consultant	CC/TC
Newberry	Deb	deb.newberry@dctc.edu	Dakota County Technical College, Minnesota	CC/TC
Nonninger	Ralph	r.nonninger@nanoschoolbox.com	Advanced Materials Science	K-12
Porcello	Darrell	porcello@berkeley.edu	Lawrence Hall of Science, Berkeley California	ISE
Regalla	Lisa	lisa@makered.org	MakerEd	K-12
Rhoades	Eric	Eric.Rhoades@doe.virginia.gov	Office of Science and Health Education, VA Dept. of Education	K-12
Riley	Donna	driley@nsf.gov	National Science Foundation	College/Univ
Ristvey	John	jristvey@ucar.edu	McREL and University Corporation for Atmospheric Research	K-12
Roco	Mihail	mroco@nsf.gov	National Science Foundation	
Schmidt	Daphne	dschmidt@mymsic.org	VA MathScience Innovation Center	K-12
Scott	Richard	richard.scott@oecd.org	OECD, Directorate for Education and Skills	College/Univ
Shilling	Russell	Russell.Shilling@ed.gov	US Department of Education	
Simmons	Patricia	patricia_simmons@ncsu.edu	North Carolina State Univ and National Science Teachers Assoc.	CC/TC
Spadola	Quinn	qspadola@nnco.nano.gov	AAAS Science & Technology Policy Fellow	ISE
Taylor	Terri	t_taylor@acs.org	American Chemical Society	K-12
Thomas	Rob	Robert.Thomas@industry.gov.au	Australia	K-12
Trybula	Walt	w.trybula@tryb.org	Texas State University – San Marcos	CC/TC
Tuominen	Mark	tuominen@physics.umass.edu	National Nanomanufacturing Network, Univ Mass, Lowell	Graduate
Ucko	David	ucko@MuseumsPlusMore.com	Consultant	ISE
Vázquez	Liz Díaz	lizvazquez8@gmail.com	University of Puerto Rico	College/Univ
Walker	Natasha	nlwalker@usc.edu	University of Southern California	

Walsh	Kevin	kevin.walsh@louisville.edu	University of Louisville	ISE
Watford	Bevlee	bwatford@nsf.gov	National Science Foundation	
Watson	Heather	hwatson@nsf.gov	AAAS Science & Technology Policy Fellow	College/Univ
Winkelmann	Kurt	kwinkel@fit.edu	Florida Institute of Technology	College/Univ
Yao	Da-Jeng	djyao@mx.nthu.edu.tw	Institute of NanoEngineering and MicroSystems, Taiwan	K-12

Appendix C: NSE Education Assets Presented in the Showcase

1. California NanoSystems Institute (CNSI)
   Jia Ming Chen, CNSI, University of California, LA
2. Omni Nano
   Marco Curreli, Omni Nano
3. Center for Hierarchical Manufacturing Education
   Mark Tuominen, University of Mass., Amherst
4. Materials World Education Modules
   Robert Chang, Northwestern University
5. McREL: NanoLeap, NanoTeach, NanoExperiences
   John Ristvey, Univ. Corp. for Atmospheric Research
6. National Science Teachers Association
   Patricia Simmons, North Carolina State University
7. Nano-Science & Engineering: A STE Minor
   Peter Moeck, Portland State University
8. nanoHUB
   Tanya Faltens, Network for Computational Nanotechnology, Purdue University
9. Nano-Link
   Deb Newberry, Dakota County Technical College
10. MRSEC Education Group
    Anne Lynn Gillian-Daniel, Univ. Wisc. – Madison
11. Nanoscale Instructional Materials
    George Lisensky, Beloit College
12. Nanoscale Instructional Materials
    Nancy Burnham, Worcester Polytechnic Institute
13. Nanotechnology Applications and Career Knowledge
    Stephen Fonash, Penn State University
14. NanoScience Instruments
    Mark Flowers, NanoScience Instruments
15. Nanoscale Informal Science Education
    Larry Bell & Carol Lynn Alpert, Boston Museum of Science
16. NanoSchoolBox/NanoSchool Kits
    Ralph Nonninger, Advanced Materials Science, Nano GmbH
17. Nanoscale Instructional Materials
    Liz M. Diaz Vazquez, Puerto Rico
18. Springer Nanotechnology Books and Encyclopedia
    Bharat Bhushan, Ohio State University
19. National Nanotechnology Infrastructure Network
    Nancy Healy, Joyce Allen, Georgia Tech
20. Nanoscale Instructional Materials
    Walt Trybula, Texas State University
21. Nanoscale Instructional Materials
    Anna-Rita Mayol, Port Educational Consulting
22. Nanotechnology Quantum Simulation Graphics
    José A. Torres, Lerwen Liu, Atelgraphics
23. Korean NSEE Instructional Materials
    Jo-Won Lee, Hanyang University, Korea



Nanoscale Science and Engineering Education (NSEE) Materials Exhibition

Part of an NSF funded NSEE Workshop

Free Event at the Westin Arlington Gateway
Arlington, VA
Fitzgerald Ballroom A
December 11, 2014   1:00 to 3:00 pm

- See proven nanoscale education resources from around the world
- Talk with over 25 different developers (including NanoSchoolBox-Europe, NanoDays-NISENet, nanoHUB-Purdue)
- Learn where to find these incredible resources
- Explore ways you can use them

NSE Provides Important New Perspectives to Education

It is important to introduce nanoscale science and engineering (NSE) into current teaching practice at all levels. For the past two decades people have been working on ways to do just that. After years of shaping nanoscale education resources into useful materials, they are ready for larger audiences.

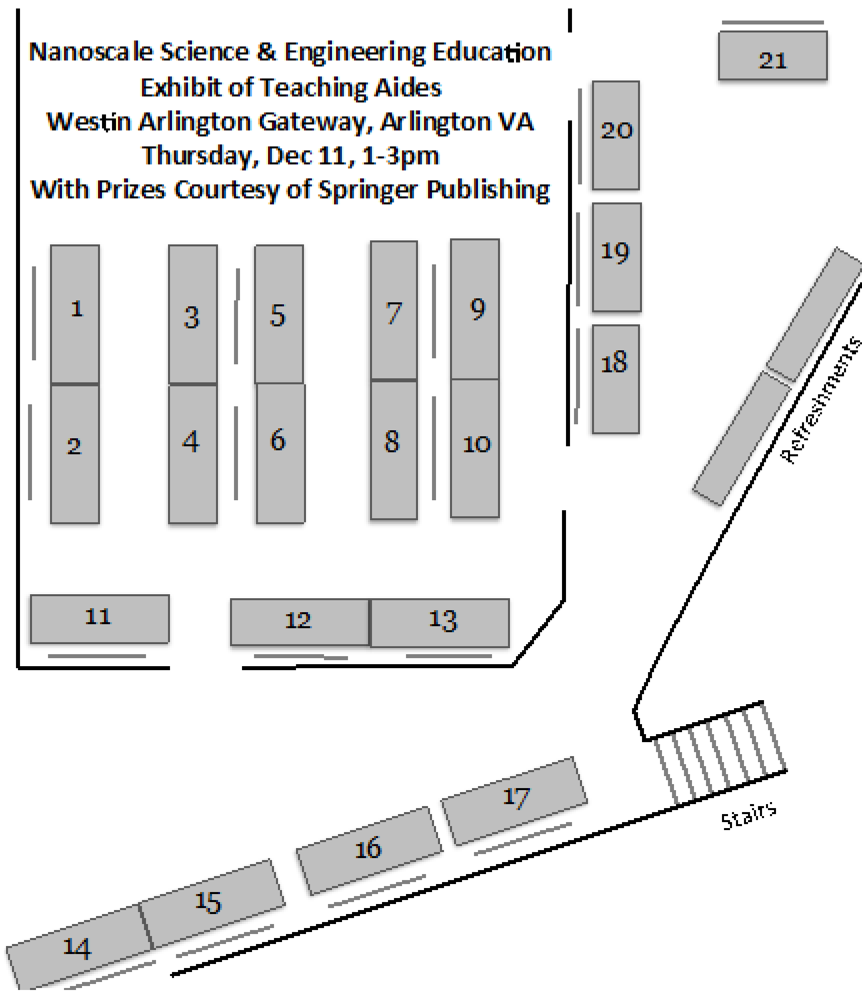
At the nanoscale materials behave differently. This is why water rolls off of lotus leaves and geckos can walk on the ceiling. Looking at these differences brings fresh insights that fit nicely into standards-based teaching. Studying the nanoscale brings together biology, chemistry, physics and engineering into a truly multidisciplinary adventure.

Nanotech Is Enabling Solutions to Societal Challenges

Understanding the different ways materials behave at the nanoscale will lead to new solutions to societal problems. NSE is being used to upgrade information technologies; create new medical diagnostics and therapeutics; and build affordable, renewable energy sources. Further, we need an informed public in order to address concerns about nanostructures' environmental, safety and health impacts.

For more information on what you will experience visit www.usc.edu/esvp and enter password NSEE

REFRESHMENTS AVAILABLE



1. **California NanoSystems Institute (CNSI)**
   Jia Ming Chen, CNSI, University of California, LA
2. **Omni Nano**
   Marco Curreli, Omni Nano
3. **Center for Hierarchical Manufacturing Education**
   Mark Tuominen, University of Mass., Amherst
4. **Materials World Education Modules**
   Robert Chang, Northwestern University

5a. **Mid-continent Research for Education and Learning**
   John Ristvey, Univ. Corp. for Atmospheric Research

5b. **National Science Teachers Association**
   Patricia Simmons, North Carolina State University

6. **Nano-Science & Engineering: ASTE Minor**
   Peter Moeck, Portland State University
7. **nanoHUB**
   Tanya Faltens, Network for Computational Nanotechnology, Purdue University
8. **NanoLink**
   Deb Newberry, Dakota County Technical College
9. ***MRSEC Education Group***
   Anne Lynn Gillian-Daniel, Univ. Wisc. - Madison
10. ***Nanoscale Instructional Materials***
    George Lisensky, Beloit College
11. **Nanoscale Instructional Materials**
    Nancy Burnham, Worcester Polytechnic Institute
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    Mark Flowers, NanoScience Instruments
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    Larry Bell & Carol Lynn Alpert, Boston Museum of Sci.
15. **NanoSchoolBox/NanoSchool Kits**
    Ralph Nonninger, Advanced Materials Science, nano GmbH
16. **Nanoscale Instructional Materials**
    Robert Geer, CNSE, SUNY Polytechnic Institute
17. **Springer Nanotechnology Books and Encyclopedia**
    Bharat Bhushan, Ohio State University
18. **National Nanotechnology Infrastructure Network**
    Nancy Healy, Joyce Allen, Georgia Tech
19. ***Nanoscale Instructional Materials***
    Walt Trybula, Texas State University
20. ***Nanoscale Instructional Materials***
    Anna-Rita Mayol, Port Educational Consulting

21a. **Nanotechnology Quantum Simulation Graphics**
   Atelgraphics, *(Lerwen Liu)*

21b. **Korean NSEE Instructional Materials**
   Jo-Won Lee, National Program of Tera-Level Devices

Appendix D: Table of NSE K-12 Assets

Source	Module	Grade level	Video	Labs	Teaching Aids	Map to Standards	Core Discipline	S	T	E	M	Inquiry Learning	Interactive Media/Game	Cross-cutting Topic	Nanoscience "Big Idea"
California NanoSystems Institute		http://cnsi.ctrl.ucla.edu/nanoscience/pages/homepage													
	Biotoxicity	9-12		X	X	X	Bio/Chem/ Physics	X		X		X			NS12/NS3/NS4/ NS9
	Photolithography	9-12		X	X	X	Math/Physics	X		X	X	X			NS3/NS11/NS4/ NS8/NS9
	Self Assembly	9-12		X	X	X	Chemistry/ Physics	X		X		X			NS6/NS9/NS3
	Solar Cells	9-12		X	X	X	Physics	X		X		X			NS3/NS4/NS11/ NS9
	Super Hydrophobic Surfaces	9-12		X	X	X	Bio/Chem/ Physics	X		X		X			NS12/NS3/NS5/ NS9
	Water Purification	9-12		X	X	X	Bio/Chem/Ph ysics	X		X		X			NS11/NS3/NS4/ NS9
	Supercapacitors	9-12		X	X	X	Physics	X		X		X			NS12/NS9
CK-12 Foundation - Flexbooks		http://www.ck12.org/fleXbook/													
	Nanoleap Student Journal (see McRel)														
	How Can a Gecko Walk on a Ceiling		X		X	X		X				X			
	What Do We Mean When We Speak About Surfaces in Contact			X	X	X		X			X	X			NS4
	What are Your Ideas About Small Sizes			X	X	X		X			X	X	X		NS8/NS7/NS12
	What Do We Learn When We Look More Closely			X	X	X		X			X	X			NS4
	What Types of Forces Can Hold Objects Together				X	X		X				X			NS4
	How Much Force is Needed to Make an Object Stick			X	X	X		X				X			NS4
	How Do We Measure Forces at the Nanoscale Level?		X	X	X	X		X	X			X			NS8/NS4
	NanoSense Student Materials (see NanoSense)														
	Size Matters			X	X	X		X	X	X	X	X			NS1/NS3/NS8/N S7/NS12
	Clear Sunscreens			X	X	X		X				X	X		NS12
	Fine Filters			X	X	X		X				X			NS7/NS12/NS4
DragonflyTV		http://pbskids.org/dragonflytv/nano/indeX.html													
	Matter and Motion														

Source	Module	Grade level	Video	Labs	Teaching Aids	Map to Standards	Core Discipline	S	T	E	M	Inquiry Learning	Interactive Media/Game	Cross-cutting Topic	Nanoscience "Big Idea"
	Size and Scale	all	X		X		Math/Physics	X			X				NS1
	Structure of Matter	5-12	X		X		Bio/Chem/Physics	X							NS3/NS9/NS10
	Small is Different	5-12	X		X		Chemistry/Physics	X							NS2/NS11/NS12
	Stained Glass	5-12	X		X		Chemistry/Physics	X							NS5/NS12
	Self Assembly	5-12	X		X		Physics	X							NS6/NS9
	What's Nano	5-12	X		X		Math				X				NS1
	Hockey Sticks	5-12	X		X		Chemistry/Physics	X		X					NS12
	Surface Area	5-12	X		X		Chemistry/Math	X			X				NS2
	Earth and Space														
	Water Clean Up	5-12	X		X		Bio/Chem	X							NS12
	Nanotechnology and Society	9-12	X		X		Bio/Chem/Physics	X							NS7
	Skateboard Scientist	5-12	X		X		Bio/Chem	X							NS12/NS7
	Technology and Invention														
	Applications of Nanotechnology	5-12	X		X		Bio/Chem/Physics	X							NS12/NS7
	Nanosilver	5-12	X		X		Bio	X		X					NS7/NS11/NS12
	Where's Nano	5-12	X		X		Bio/Physics	X							NS1
	Nanocar Engineer	5-12	X		X		Physics			X					NS12
	Living Things														
	Forces at the Nanoscale	5-12	X		X		Biology/Physics	X							NS4
	Gecko Feet	5-12	X		X		Biology/Physics	X							NS2/NS4/NS12
	Butterfly Wings	5-12	X		X		Biology/Physics	X							NS11/NS3
	Nasturtium Leaves	5-12	X		X		Biology/Physics	X							NS4/NS11
	Body and Brain														

Source	Module	Grade level	Video	Labs	Teaching Aids	Map to Standards	Core Discipline	S	T	E	M	Inquiry Learning	Interactive Media/Game	Cross-cutting Topic	Nanoscience "Big Idea"
	Bone Regrowth	5-12	X		X		Biology/Physics	X	X	X					NS3/NS12
Inst for Chemical Education		http://ice.chem.wisc.edu/Nanoscience.html													
	Exploring the Nanoworld Kit	5-12		X	X		Physics	X				X			NS8/NS5/NS3
	LED Color Strip Kit	5-12		X	X		Physics	X				X			NS12/NS11/NS3
	Solid-State Model Kit	7-12		X	X		Math/Physics	X			X	X			NS9/NS3/NS11
	Polyhedral Model Kit	7-12		X	X		ChemistryPhysics	X				X			NS9/NS11
	DNA Optical Transform Kit	5-12		X	X		Physics	X				X			NS8/NS9
	Optical Transform Kit	7-12		X	X		Physics	X				X			NS8/NS11
	Nanocrystalline Solar Cell Kit	9-12		X	X		Bio/Chem/Physics	X				X			NS11/NS9
	Nanoworld Presenter's Guide with "Try This" Packet	all		X	X		Physics	X				X			NS8/NS9
	Nanoworld "Try This" Packets with Handout	all	X		X	X	Physics	X				X			NS8/NS9
	NanoVenture: the Nanotechnology Board Game	9-12			X		Bio/Chem/Physics	X	X				X		NS7/NS12
	Memory Metal	all		X	X		Chem/Physics	X				X			NS3
McREL Nanoleap		http://www.mcrel.org/nanoleap/													
	Physical Science: Investigating Static Forces in Nature														
	How Can a Gecko Walk on a Ceiling		X		X	X		X				X			NS4
	What Do We Mean When We Speak About Surfaces in Contact			X	X	X		X			X	X			NS4
	What are Your Ideas About Small Sizes			X	X	X		X			X	X	X		NS8/NS7/NS12
	What Do We Learn When We Look More Closely			X	X	X		X			X	X			NS4
	What Types of Forces Can Hold Objects Together				X	X		X				X			NS4
	How Much Force is Needed to Make an Object Stick			X	X	X		X				X			NS4
	How Do We Measure Forces at the Nanoscale Level?		X	X	X	X		X	X			X			NS8/NS4
	How Can a Gecko Walk on a Ceiling (advanced)		X	X	X	X		X				X			NS3/NS4/NS11/NS8/NS7

Source	Module	Grade level	Video	Labs	Teaching Aids	Map to Standards	Core Discipline	S	T	E	M	Inquiry Learning	Interactive Media/Game	Cross-cutting Topic	Nanoscience "Big Idea"
	Chemistry: Nanoscale Materials and Their Properties														
	What is it?		X	X	X	X		X	X			X			NS1/NS7/NS11/NS12
	Metallic and Ionic Nanoparticles: EXtendable Structures				X	X		X							NS5/NS11/NS7/NS3
	Neat and Discrete Nanoparticles				X	X		X							NS3/NS7
	Videos														
	NanoSize Me		X		X			X	X						NS1/NS3/NS12
	Tricky Feet		X		X			X							NS3/NS11
	How Do You Build Something So Small?: Nanofabrication		X		X			X		X					NS8
	A NanoLeap Into the Atomic Force Microscope		X		X			X		X					NS8
	Demonstration of How an Atomic Force Microscope Works		X		X					X					NS8
	Magnetic Probe Model		X		X			X		X					NS8
	Melting of Ice		X		X			X							NS3
	Interactives														
	NanoScale Me				X			X				X	X		NS1
	Nanoparticle Builder				X			X				X	X		NS3
Molecularium (RPI)		http://www.molecularium.com/about.html													
	Molecules to the MaX	1-4	X		X	X	Chemistry/Physics	X							NS1/NS3/NS11/NS4
	Riding Snowflakes	1-4		X	X	X	Physics	X				X			
	Nanospace	all	X				Chemistry	X				X	X		NS3
	Molecularium Project: Teacher's Resource Guide	K-4		X	X		Chemistry	X				X			NS3
	Molecules to the MaX: Educator's Resource Guide	5-8		X	X	X	Chemistry	X				X			NS1/NS3
MWM Materials World Modules (Northwestern)		http://www.materialsworldmodules.org													
	Biodegradable Materials	9-12		X	X	X	Bio/Chemistry	X	X	X	X	X		X	NS3/NS12/NS9/NS4/NS11

Source	Module	Grade level	Video	Labs	Teaching Aids	Map to Standards	Core Discipline	S	T	E	M	Inquiry Learning	Interactive Media/Game	Cross-cutting Topic	Nanoscience "Big Idea"
	Biosensors	9-12		X	X	X	Bio/Chemistry	X	X	X	X	X		X	NS11/NS3/NS9/ NS12/NS4
	Ceramics	9-12		X	X	X	Chem/Physics	X	X	X	X	X		X	NS3/NS4/NS11
	Composites	6-12			X	X	Chem/Physics	X	X	X	X	X		X	NS3/NS4/NS11/ NS9
	Concrete: An Infrastructure Material	6-12		X	X	X	Chem/Physics	X	X	X	X	X		X	NS3
	Environmental Catalysis	9-12		X	X	X	Chemistry	X	X	X	X	X	X	X	NS12/NS3/NS4/ NS11
	Food Packaging	6-12		X	X	X	Chem/Phys	X	X	X	X	X		X	NS12/NS9
	Intro to the Nanoscale	6-12		X	X	X	Chem/Phys/M ath	X	X	X	X	X	X	X	NS1/NS8/NS2
	Manipulation of Light in the Nanoworld	9-12		X	X	X	Physics	X	X	X	X	X	X	X	NS3/NS4
	Nanotechnology	9-12		X	X	X	Bio/Chem/Ph ysics	X	X	X	X	X		X	NS5/NS1/NS9
	Polymers	9-12		X	X	X	Chemistry	X	X	X	X	X	X	X	NS3/NS4/NS11
	Smart Sensors	9-12		X	X	X	Chem/Physics	X	X	X	X	X		X	NS12/NS3/NS4
	Sports Materials	6-12		X	X	X	Physics	X	X	X	X	X		X	NS3/NS12
	Drug Delivery at the Nanoscale	9-12		X	X	X	Bio/Chem/Ph ysics	X	X	X	X	X	X	X	NS12/NS3/NS4
	Dye Sensitized Solar Cells	9-12		X	X		Chem/Physics	X	X	X	X	X	X	X	NS12/NS9
	Nanopatterning	9-12		X	X	X	Chem/Physics	X	X	X	X	X		X	NS3
	Nanosurfaces (under development)														NS3/NS4
NCLT (Northwestern)		http://community.nsee.us													
	Nano Lessons and Courses:	http://community.nsee.us/indeX.php?option=com_content&view=category&id=71:nano-lessons-and-courses-&Itemid=74&layout=default													
	Apples to Atoms	6-9		X	X		Chem/Physics	X	X	X	X	X		X	NS1/NS8/NS2
	Introduction to the Nanoscale	6-9		X			Chemistry/Ph ysics	X				X			NS1/NS2/NS3
	DNA and Models	6-9			X		Chem	X				X			NS9/NS11/NS3/ NS4/NS6
	DNA Fingerprinting Activity	8-12		X	X		Biology/Chemi stry	X						X	NS3/NS11/NS7
	High School Teaching Module using "Macro-AFM"	9-12			X			X			X	X			NS1/NS8

Source	Module	Grade level	Video	Labs	Teaching Aids	Map to Standards	Core Discipline	S	T	E	M	Inquiry Learning	Interactive Media/Game	Cross-cutting Topic	Nanoscience "Big Idea"
	Instructional Resources on 3D Body Force	9-12			X		Physics	X		X		X	X		NS4
	LEGO Atomic Force Microscope and Magnetic Force Microscope	9-12		X	X		Physics	X			X	X			NS8/NS9
	Nanotechnology Module	9-12		X	X		Chemistry/Physics	X				X			NS1/NS3/NS5
	What Can Electrons Do? - Electron Microscopy	9-12			X		Chemistry/Physics	X		X					NS8
	NanoSchoolBoX	12+		X	X		Chemistry/Physics	X		X		X			NS2/NS3/NS5/NS12
	Online Lessons, Simulations, and Games:	http://community.nsee.us/indeX.php?option=com_content&view=category&id=74:online-lessons-and-simulations&Itemid=74													
	Nanopatterning: The Science of Making Small Things from the Top Down	6-12		X	X		Chemistry/Physics	X		X		X			NS8
	How a Dye-Sensitized Solar Cell Works	7-12					Chemistry/Physics	X	X	X		X	X		NS12/NS2
	Size and Scale Computer Games	7-12					Math				X	X	X		NS1
	Nanocos: The Card Game of Nanotechnology Concepts	7-12					Chemistry/Physics	X				X	X		NS1/NS2/NS3
	Insights in Nanomedicine: Fighting Cancer with Gold Nanoshells	9-12	X		X		Biology/Chemistry	X	X						NS12/NS3
	Investigating Static Forces in Nature: The Mystery of the Gecko	9-12		X	X	X	Physics	X			X	X			NS3/NS4/NS8/NS1
	Optical Tweezers	9-12		X			Physics			X	X				NS8
	Nanomagnetism	9-12					Physics	X			X				NS4
	Diffraction, Intrerference, and Young's Double Slit Experiment (Simulation)	9-12			X		Physics	X			X		X		NS4
	Diffraction by a Metal Nanoparticle (Simulation)	10-12			X		Physics	X					X		NS4
	Photonic Band Gap (Simulation)	11-12			X		Physics	X			X	X	X		NS4
	Nanopattern Formation of 2D Weakly Charged Telechelic Gels by Self Assembly	>12						X	X						NS4/NS6
	Copper Nanowire Formation Through Electron Deposition	12+			X		Chemistry	X				X			NS12/NS10
Nano-Link (NDSCS)		http://www.nano-link.org/nano-infusion/nip-modules													
	Nano Infusion:														
	Unit Cells and Crystal Structures			X	X		Chemistry	X				X			NS3
	Thin Films			X	X		Chemistry/Physics	X				X			NS4/NS3

Source	Module	Grade level	Video	Labs	Teaching Aids	Map to Standards	Core Discipline	S	T	E	M	Inquiry Learning	Interactive Media/Game	Cross-cutting Topic	Nanoscience "Big Idea"
	Nanoparticles and Sunscreen			X	X		Chemistry/Physics	X		X		X			NS2/NS5/NS12
	Scientific Method			X	X			X				X			
	Superhydrophobicity			X	X		Physics	X				X			NS4
	Surface Area to Volume Ratio			X	X		Math	X			X	X			NS2
	Cross Linked Polymers			X	X		Chemistry	X				X			NS4
	Ring Polymers			X	X		Chemistry	X			X	X			NS2
	NanoTreatment			X	X		Chemistry/Physics	X			X	X			NS4/NS5/NS12
	Memory Metals (Coming Soon)														
Nano4me (PSU)		http://www.nano4me.org/													
	Introductory Level Modules:	http://nano4me.live.subhub.com/categories/Modules_new													
	Nanotechnology: What Is It, and Why Is It So "BIG" Now?		X		X			X							NS1/NS8
	A Brief History of Nanotechnology				X			X							NS1/NS8/NS12/NS3
	A Snapshot of Nanotechnology Today				X			X							NS7/NS12/NS3/NS4
	The Uniqueness of the Nano-scale				X			X		X					NS2/NS3/NS4/NS8/NS5
	How Do We "See" Things at the Nano-scale: An Introduction to Characterization Techniques		X		X			X	X						NS8
	How Do You Make Things So Small: An Introduction to Nanofabrication				X			X							NS3/NS4
	How Do You Build Things So Small: Top-Down Nanofabrication				X			X	X	X					NS10/NS8
	How Do You Build Things So Small: Bottom-Up Nanofabrication				X			X							NS3/NS4
	Nanotechnology, Biology, and Medicine		X		X			X		X					NS3/NS4/NS7/NS12
	Nanotechnology: Impact on Microelectronics				X			X	X	X					NS12
	High School Level Experiments	http://nano4me.live.subhub.com/categories/experiments													
	Microencapsulation			X	X	X		X				X			NS6/NS3
	Silver Nanoparticles (Part 1)			X	X	X		X				X			NS3/NS4

Source	Module	Grade level	Video	Labs	Teaching Aids	Map to Standards	Core Discipline	S	T	E	M	Inquiry Learning	Interactive Media/Game	Cross-cutting Topic	Nanoscience "Big Idea"
	Silver Nanoparticles (Part 2)			X	X	X		X				X			NS3/NS4/NS11
NanoSchoolBox (Europe)		http://www.nanoschoolbox.de/en/nutzungsbedingungen/nanoschoolbox.html													
	From the Lotus effect to the technical application of monolayers	9-12	X	X	X		Physics	X				X			NS3/NS12
	Functionality through nanotechnology	9-12	X	X	X		Physics	X				X			NS3
	Use of TiO2 in nanotechnology	9-12	X	X	X		Physics	X				X			NS3
	Ferrofluids	9-12	X	X	X		Physics	X				X			NS12/NS3/NS4
	Nanoscale gold Colloids	9-12	X	X	X		Physics	X				X			NS3/NS4
	Memory effect	9-12	X	X	X		Physics	X				X			NS3/NS12
	From sand to chip	9-12	X	X	X		Physics	X				X			NS3/NS4/NS12
	The smaller the particle, the greater the effect	9-12	X	X	X		Physics	X				X			NS5
NanoSense		**http://nanosense.sri.com/activities.html**													
	Size Matters: Intro to Nanoscience			X	X	X		X	X	X	X	X			NS1/NS3/NS8/NS7/NS12
	Clear Sunscreen: How Light Interacts with Matter			X	X	X		X				X	X		NS12
	Clean Energy: Converting Light into Electricity		X	X	X	X		X				X	X		NS7/NS12
	Fine Filters: Filtering Solutions for Clean Water			X	X	X		X				X			NS7/NS12/NS4
NanoYou (Europe)		http://nanoyou.eun.org/web/nanoyou/home													
	Teacher Training Kits:														
	Part 1: Fundamental Concepts in Nanoscience and Nanotechnologies														
	Ch 1: Intro to Nanoscience and Nanotechnology				X		Chemistry/Physics	X							NS1/NS5/NS7
	Ch 2: Nanoscience in Nature				X		Chemistry/Physics/Biology	X							NS4/NS3
	Ch 3: History of Nanotechnologies				X		Chemistry	X							NS8/NS12
	Ch 4: Fundamental "Nano-Effects"				X		Chemistry/Physics	X	X						NS2/NS3/NS4/NS6/NS10/NS12
	Ch 5: Overview of Nanomaterials				X		Chemistry/Biology	X	X						NS4/NS6/NS12

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	Ch 6: Characterization Methods				X		Physics		X	X					NS8
	Ch 7: Fabrication Methods				X		Chemistry/Physics	X		X					NS6/NS8/NS10
	Part 2: Applications of Nanotechnologies														
	Ch 1: Medicine and Healthcare				X		Chemistry/Physics/Biology	X	X						NS11/NS12
	Ch 2: Environment				X		Chemistry/Biology	X	X						NS4/NS11/NS12/NS7
	Ch 3: Energy				X		Chemistry/Physics	X	X	X					NS4/NS5/NS12
	Ch 4: Information and Communication Technologies				X		Physics	X	X	X					NS4/NS12
	Lesson Plans:														
	What are NTs - Module 1		X		X		Chemistry/Physics	X				X			NS1/NS5
	What are NTs - Module 2		X		X		Chemistry/Physics	X				X			NS5/NS12
	What are NTs - Module 3		X		X		Chemistry/Physics	X				X			NS5/NS12
	ELSA Aspects on NTs - Module 4				X		Chem/Physics/Bio	X				X			NS7
	ELSA Aspects on NTs - Module 5				X		Chem/Physics/Bio	X				X	X		NS7
	Nanoyou: Virtual Nano Lab	7-12			X		Physics	X					X		NS12/NS11
	Experiment with Superhydrophobic Materials	7-12			X		Physics	X				X			NS12/NS3
	Experiment with Colorimetric Gold Nanosensor	7-12	X	X	X		Physics	X				X			NS3/NS5
	Experiment with Natural Nanomaterials	7-12	X	X	X		Biology/Physics	X				X			NS3/NS4/NS12
	Experiment with Liquid Crystals	9-12	X	X	X		Physics	X				X			NS6/NS3/NS8/NS9
	Nano to Touch	all	X	X	X		Physics	X					X		
Nanozone		http://nanozone.org/													
	What is Nano?	2-7	X			X		X							
	Measure Yourself	2-7			X	X					X	X			NS1
	Scientiest Stat Cards	2-7			X	X		X					X		NS3

Source	Module	Grade level	Video	Labs	Teaching Aids	Map to Standards	Core Discipline	S	T	E	M	Inquiry Learning	Interactive Media/Game	Cross-cutting Topic	Nanoscience "Big Idea"
	Life Stories	2-7			X	X									
	Green Milk Games	2-7			X	X							X		
	Save Ratty	2-7			X	X		X					X		NS11/NS12
	Virus Worker	2-7			X	X		X	X				X		NS11/NS12
	NanoVideo	2-7	X		X	X		X							NS1
	AskNanoBrain	2-7			X	X		X				X	X		NS3
	Fishing for Fun	2-7				X						X	X		
	Talk to the Scientist	2-7			X	X		X				X			
	Scanning Electron Microscope Images	2-7				X		X	X						NS8
	How Small is Small?	2-7			X	X		X					X		NS1
nanoHUB		https://nanohub.org/resources/teachingmaterials													
	K-12: Introduction to Quantum Wells	4-5						X							NS5, NS9
	Quick and Easy Guide to Carbon Structure Simulations using Crystal Viewer Tool	9-12						X							NS3, NS9
	Scale Cards Activity	2-7				X		X							NS1
	Using nanoHUB to Introduce Elementary and Middle School Students to Models and Simulations	6-9						X		X					NS3, NS9
NISE Network		http://www.nisenet.org/catalog													
	Biomimicry: Synthetic Gecko Tape through Nanomolding	9-12		X	X		Biology/Physics	X	X	X	X	X			NS7/NS12
	DNA Nanotechnology	2-12		X	X		Biology/Chemistry	X					X		NS11
	Experiment on Natural Nanomaterials	6-12		X	X		Biology/Physics	X				X			NS5
	Experiment with Superhydrophobic Materials	6-12	X	X	X		Biology/Physics	X	X			X			NS8/NS7/NS12
	Exploring Fabrication - Electroplating	all		X	X	X	Chemistry	X		X					NS8
	Exploring Fabrication - Gummy Capsules	all		X	X	X	Biology/Chemistry	X					X		NS6/NS11/NS12
	Exploring Fabrication - Self-Assembly	all		X	X	X	Physics	X				X	X		NS6

Source	Module	Grade level	Video	Labs	Teaching Aids	Map to Standards	Core Discipline	S	T	E	M	Inquiry Learning	Interactive Media/Game	Cross-cutting Topic	Nanoscience "Big Idea"
	Exploring Forces - Gravity	all		X	X	X	Physics	X				X			NS5
	Exploring Forces - Static Electricity	all		X	X	X	Math/Physics	X			X	X			NS5
	Exploring Materials - Ferrofluid	all		X	X	X	Physics	X				X			NS5
	Exploring Materials - Graphene	all		X	X	X	Physics/Chemistry	X					X		NS3/NS5/NS10
	Exploring Materials - Hydrogel	all		X	X	X	Physics	X							NS3/NS8/NS4
	Exploring Materials - Liquid Crystals	all		X	X	X	Chemistry	X				X			NS5
	Exploring Materials - Memory Metals	all		X	X	X	Physics	X				X			NS5
	Exploring Materials - Nano Gold	all		X	X	X	Physics	X				X	X		NS5
	Exploring Materials - Ooblek	all		X	X	X	Chemistry/Physics	X	X			X	X		NS5
	Exploring Materials - Polarizers	all		X	X	X	Physics	X				X			NS4/NS3
	Exploring Materials - Stained-Glass Windows	all		X	X	X	Chemistry	X	X						NS5
	Exploring Materials - Thin Films	all		X	X	X	Biology/Physics	X				X			NS3
	Exploring Nano and Society - Flying Cars	all		X	X	X	Social Science								NS7
	Exploring Nano and Society - Invisibility Cloak	all		X	X	X	Social Science/Physics	X				X	X		NS4/NS7
	Exploring Nano and Society - Space Elevator	all		X	X	X	Social Science					X	X		NS7
	Exploring Nano and Society - Tell a Nano Story	all			X		Social Science	X	X			X	X		NS7
	Exploring Nano and Society - Tippy Table	all		X	X		Social Science					X	X		NS7
	Exploring Nano and Society - You Decide!	all		X	X	X	Social Science					X	X		NS7
	Exploring Products - Computer Hard Drives	all		X	X	X	Physics	X		X		X	X		NS12
	Exploring Products - Kinetic Sand	all		X	X	X	Physics	X				X			NS5
	Exploring Products - Liquid Crystal Displays	all		X	X	X	Physics/Chemistry	X	X	X			X		NS5
	Exploring Products - Nano Food	all		X	X	X	Biology	X				X	X		NS5/NS12
	Exploring Products - Nano Sand	all		X	X	X	Physics	X				X			NS3/NS5

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	Exploring Products - NanoFabrics	all		X	X	X	Physics	X				X			NS3/NS5
	Exploring Products - Sunblock	all		X	X	X	Physics	X				X			NS12
	Exploring Properties - Capillary Action	all		X	X	X	Physics	X					X		NS5
	Exploring Properties - Electric Squeeze	all		X	X	X	Physics	X							NS3
	Exploring Properties - Heat Transfer	all		X	X	X	Physics/Chemistry	X				X			NS3/NS4/NS10
	Exploring Properties - Invisibility	all		X	X	X	Chemistry/Physics	X	X						NS5
	Exploring Properties - Surface Area	all		X	X	X	Physics	X				X			NS2/NS5
	Exploring Properties - UV Bracelets	all		X	X	X	Physics	X							NS5
	Exploring Size - Ball Sorter	all		X	X	X	Math/Physics	X			X	X	X		NS1
	Exploring Size - Measure Yourself	all		X	X	X	Math/Physics	X			X	X			NS1
	Exploring Size - Memory Game	all		X	X	X	Math/Physics	X			X		X		NS1
	Exploring Size - Moving Molecules	all		X	X	X	Math/Physics	X			X	X	X		NS1
	Exploring Size - Powers of Ten Game	all		X	X	X	Math/Earth Science	X			X		X		NS1
	Exploring Size- Scented Balloons	all		X	X	X	Biology	X				X			NS1
	Exploring Size- Scented Solutions	all		X	X	X	Biology	X				X			NS1
	Exploring Size - Stretchability	all		X	X	X	Math/Biology	X			X		X		NS1
	Exploring Size - Tiny Ruler	all		X	X	X	Math	X			X	X			NS1
	Exploring Structures - Buckyballs	all		X	X	X	Math/Chemistry	X			X	X			NS3
	Exploring Structures - Butterfly	all		X	X	X	Physics/Chemistry	X							NS3/NS4
	Exploring Structures - DNA	all		X	X	X	Biology	X					X		NS6
	Exploring Tools - 3D Imaging	all		X	X	X	Physics	X		X			X		NS8
	Exploring Tools - Dress Up Like a Nanoscientist	all			X	X	Biology	X				X	X		NS8
	Exploring Tools- Mitten Challenge	all		X	X	X	Biology/Physics	X		X		X			NS8/NS1

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	Exploring Tools - Mystery Shapes	all		X	X	X	Physics			X		X	X		NS8
	Exploring Tools - Special Microscopes	all		X	X	X	Physics	X				X			NS8
	Exploring Tools - Transmission Electron Microscopes	all		X	X	X	Physics			X			X		NS8
	High School Nanoscience Program - Self Assembly	5-12		X	X		Physics	X					X		NS6
	Interference Acrylics: Painting with Structual Color	all		X	X		Chemistry	X					X		NS4/NS3
	Introduction to Nanomedicine Video	2-12	X				Physics	X							NS1/NS7
	Invisibility Cloak Video	all	X		X		Social Science								NS7
	Invisible Sunblock	2-12	X	X	X		Biology/Chemistry	X		X					NS11/NS5/NS12
	It's a Nano World	all			X		Physics	X					X		
	Kitchen Chemistry	2-12	X		X		Chemistry	X							NS4
	Liquid Crystals	all		X	X	X	Physics	X	X	X		X			NS5
	MiXing Molecules	5-12	X				Physics	X					X		NS3/NS11
	Multimedia Zoom into a Human Hand	5-12			X		Biology/Physics	X					X		NS1/NS3
	Multimedia Zoom into a Nasturtium Leaf	5-12			X		Biology/Physics	X					X		NS3
	Nano Dreams and Nano Nightmares	all			X	X	Math/Physics	X			X				NS1/NS5/NS11
	Nanosilver: Breakthrough or BioHazard video	5-12	X		X		Biology/Physics	X							NS7/NS12
	Nanotechnology Class Materials	5-12	X		X		Physics	X							
	Oleophobic Surfaces: Anti-Graffiti Demo	2-12		X	X		Chemistry	X					X		NS3
	Sand, Pants, and Plants	all		X	X		Chemistry	X							NS5
	Sights Unseen: Images of the Nanoworld	all			X		Physics	X							
	Talking Nano	1-12	X		X		Physics	X							NS1/NS7/NS12/NS3/NS5
	The Amazing Nano Brothers Juggling Show	all	X		X	X	Physics	X							NS1/NS5/NS3/NS11/NS8/NS7
	Three Drops	all	X		X		Math/Physics	X					X		NS1/NS5

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	Tiny Solutions to Our Big Energy Problem	6-12			X		Physics	X							NS7/NS12
	TryNano	all	X		X	X	Physics	X							
	What Happens in a Nano Lab Video	all	X		X		Physics	X							NS8
	Zoom into a Butterfly Wing	5-12			X		Biology/Chemistry	X							NS1/NS11
Nanooze		http://www.nanooze.org/main/Nanooze/													
	Nanotechology Primer	4-8			X		Math/Physics	X			X				NS7/NS3/NS6/NS8/NS1
	Zoom Into Nanotechnology	9-12			X		Physics	X							NS11/NS8/NS7/NS12/NS10
	Five Senses	4-12			X		Biology/Chemistry	X							NS12/NS11/NS7
	Magazine Issues:														
	Issue 1: What is Nanotechnology?	4-12			X		Chemistry/Math	X			X				NS1/NS12
	Issue 2: Get Nano with Nanooze	4-12			X		Chemistry/Biology/Physics	X	X						NS1/NS2/NS10/NS12
	Issue 3: Sight	4-12			X		Chemistry/Biology	X							NS8/NS11
	Issue 4: Smell and Taste	4-12			X		Chemistry/Biology	X							NS11/NS12
	Issue 5: Touch and Hearing	4-12			X		Biology/Physics	X							NS3/NS4
	Issue 6: Self Assembly	4-12			X		Physics	X							NS6/NS12/NS8/NS9/NS3
	Issue 7: Food	4-12			X		Biology/Physics	X							NS7/NS12
	Issue 8: Nanomedicine	4-12			X		Biology/Physics	X					X		NS8/NS12/NS10/NS11NS7
	Issue 9: Space	4-12			X		Physics/Chemistry	X	X						NS12
	Issue 10: Atoms	4-12			X		Chemistry	X							NS1/NS3/NS4
	Issue 11: Molecules	4-12			X		Chemistry/Biology	X							NS2/NS3/NS4
	Issue 12: Molecules in Motion	4-12			X		Chemistry/Biology	X							NS3/NS4
	Issue 13: Unexpected Properties	4-12			X		Chemistry/Physics	X	X	X					NS2/NS5/NS12
NNIN Nanotechnology Education		http://www.nnin.org/nnin_k12teachers.html													

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	Big vs Little - Micro to Nano	K-6		X	X						X	X			NS1
	Bigger is Not Always Better	9-12			X			X							NS5
	Blood Glucose Monitor	9-12		X	X		Biology/Chemistry	X	X		X				NS9/NS11
	Case of Patent Pending	7-8		X	X		Biology/Chemistry	X				X	X		NS3/NS12
	Catalytic Converters and Nanocatalysts	9-12		X	X	X		X		X					NS9
	CDs and DVDs as Diffraction Gratings	9-12		X	X			X				X			NS12
	Changing Conductive Properties By Diffusion	8-12		X	X	X		X				X			NS3/NS4/NS11/NS12
	Coffee Break with Nanoscience: Film Formation and "Coffee Rings"	9-12		X	X		Chemistry	X							NS8/NS10/NS12
	Design Challenge	8-12		X	X	X		X		X		X			NS9/NS7
	Effects of Gold and Silver Nanoparticles on Brine Shrimp: Toxicology Study	9-12		X	X		Biology/Chemistry	X							NS7/NS11
	Electrodeposition	9-12		X	X		Chemistry	X			X	X			NS3/NS12
	Electroplating	7-8		X	X		Chemistry	X			X				NS3/NS12
	Exploring Nanotechnology Through Consumer Products	7-12			X	X		X				X			NS7/NS12
	Exploring the Properties of Magic Sand	9-12		X	X			X				X			NS5/NS3/NS4
	Gelatin Microfluidics	9-12		X	X		Biology/Chemistry	X							NS3/NS11/NS12
	Help or Hype?: The Ethics of Bio-nanotechnology	7-12			X			X				X			NS7
	Hiding Behind the Mask	9-12		X	X	X		X		X		X			NS3/NS4
	How Big is a Nanometer?	9-12			X	X		X			X	X			NS1/NS8
	How Catalysts Work	9-12			X		Chemistry	X							NS4
	How Dry am I?: Exploring Biomimcry and Nanotechnology	7-8			X		Biology/Physics	X							NS3/NS4/NS11
	How Small is That?	7-12		X	X		Biology	X				X			NS1
	Introduction to Creative Problem Solving in Nanotechnology	9-12			X			X	X			X	X		NS7/NS12
	Is Measuring an Art or a Science?	9-12			X			X				X			NS1/NS7

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	Lab On a Slab	9-12		X	X		Biology/Chemistry	X							NS3/NS11/NS12
	Learning About Surface Area and Volume	K-6			X						X				NS2
	Lines on Paper	9-12		X	X		Physics	X							NS3/NS4
	Magnetism and Nanotechnology	8-12		X	X	X		X				X			NS3/NS4
	Making a Liquid Crystal Thermometer	9-12		X	X		Chemistry	X							NS3
	Metric System From Big to Small	6-12		X	X	X					X	X			NS1/NS8
	Micro and Macro Worlds	K-12			X						X				NS1
	MiXtures and Nanotechnology	7-12		X	X			X							NS1/NS5
	Modeling Self-Assembly	6-12		X	X	X		X				X			NS9/NS6
	Nanobacteria	6-8		X	X	X		X			X	X			NS5/NS11
	Nanomotors	9-12		X	X	X		X		X		X			NS3//NS4/NS9
	Nanoparticle Pollutants	9-12			X		Biology	X				X	X		NS7
	Nanoparticles: Land to Ocean	9-12		X	X		Biology	X							NS7/NS11
	Nanotechnology and Cosmetics	9-12					Chem/Bio								NS9/NS12/NS11
	Nanotechnology Invention and Design: Phase Changes, Energy, and Crystals	9-12			X		Physics	X	X			X			NS3/NS4/NS12
	Noodling Around	K-12		X	X						X	X	X		NS1
	Paper Diagnostics	7-12			X		Biology	X				X			NS7/NS11
	Powers of Ten with the Blue Morpho Butterfly	7-12		X	X			X			X				NS1
	Properties of Fluids	6-12		X	X	X		X				X			NS3/NS4
	Quantum Dots	9-12		X	X		Chemistry/Physics	X							NS3/NS5
	Reading and Analyzing Nanotechnology	8-12		X	X	X		X				X			NS7/NS12
	Right Tool for the Job	K-6		X	X			X				X			NS8
	Scale Models	K-12			X						X				NS1

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	Scanning Probe Microscopy: Feeling What You Can't See At the Nanoscale	7-12		X	X			X				X			NS8
	Seeing Nano: Using SEM to View Nano-Sized Objects	7-12		X	X		Biology/Physics	X							NS1/NS8
	Shrink Me	K-12			X						X				NS1
	SI System and Nanoscale Science	6-8			X	X		X			X	X			NS8
	Silicon Solar Cell Efficiency	9-12		X	X		Physics	X			X				NS4
	Silver and Bandages	9-12		X	X		Biology	X				X			NS3/NS5/NS12
	Silver Nanoparticle Socks	9-12		X	X		Chemistry/Biology	X	X						NS5/NS12
	Silver Nanoparticle Synthesis, Spectroscopy, and Material Growth	9-12		X	X		Chemistry/Biology	X			X				NS3/NS5/NS11
	Size and Scale: Learning About Measurement	5-12		X	X	X		X			X	X			NS1/NS8
	Small Scale Stenciling	7-8		X	X		Chemistry	X	X	X					NS8
	Smart Materials: Shape Memory Alloys	6-12		X	X	X		X				X			NS3/NS12
	Snake Oil	9-12		X	X		Biology	X				X			NS5/NS12/NS11
	Solar Ovens: Understanding Energy Transfer	7-8			X		Physics	X							NS4
	Surface Area to Volume Ratio	6-12		X	X	X		X				X			NS3/NS4/NS11
	Sometime We Need Big Numbers	K-6			X						X				NS1
	Synthesis and Characterization of CdSe Quantum Dots	9-12		X	X		Chemistry	X	X						NS3/NS5
	Taking a Closer Look at Objects	4-8		X	X			X				X			NS1/NS8
	Uncertainty Measurements and the Wavelength of Light	9-12		X	X		Physics	X			X	X			NS4
	Understanding Waveguides	6-12		X	X	X		X			X	X			NS9/NS8/NS4
	Understanding Wave Motion and Power Loss	6-12		X	X	X		X		X		X			NS3/NS4
	Using Gold Nanoparticles for Bacteria Detection	9-12		X	X		Biology/Chemistry/Physics	X							NS3/NS5/NS9/NS12
	Using Media to Explore Social and Ethical Issues in Nanoscience and Nan	9-12			X	X		X							NS7/NS12
	Using Modeling to Demonstrate Self-Assembly	9-12		X	X		Chemistry	X				X			NS3/NS6/NS12

Source	Module	Grade level	Video	Labs	Teaching Aids	Map to Standards	Core Discipline	S	T	E	M	Inquiry Learning	Interactive Media/Game	Cross-cutting Topic	Nanoscience "Big Idea"
	Water Filtration and Purity of Water	6-12		X	X	X		X				X			NS4/NS9/NS12
	Water Race: Hydrophilic/Hydrophobic Surfaces	9-12		X	X			X				X			NS3/NS4/NS11
	Wet Etching in Nanofabrication	7-8		X	X		Chemistry	X							NS3/NS4/NS12
	What's In Your Neighborhood?	K-12		X	X						X	X			NS1
North Carolina State University Nanoscale Education Group							http://www.ncsu.edu/project/scienceEd/								
	Scale and Scaling	2-12				X		X			X				NS1
	Nanotechnology Education	6-12						X							
	Haptics: Learning through Touch							X							NS8/NS3
	Spintronics	6-12													
NSTA Learning Center							http://learningcenter.nsta.org/products/								
	Big Ideas of NSE: A Guidebook for Secondary Teachers	9-12			X	X	Bio/Chem/Physics	X							NS1/NS2/NS3/NS4/NS5/NS6/NS7/NS8/NS9
	EXtreme Science: from Nano to Galactic	6-12		X	X	X	Bio/Chem/Physics	X				X			NS1/NS2/NS3/NS4/NS5/NS6/NS8/NS9
	Science Sampler: Nanoscale in Perspective	6-8		X	X	X	Bio/Chem/Physics	X				X			NS1/NS8
	Nanoscale Science: Activities for Grades 6-12	6-12		X	X	X	Bio/Chem/Physics	X				X			NS1/NS8/NS5/NS3/NS4/NS12/NS7
	Fact or Fiction: Exploring the Myths and Realities of Nanotechnology	6-12			X	X	Chemistry/Physics	X				X			NS7/NS12
	Size and Scale														
	That's Huge	6-12			X	X		X				X			NS1
	One in a Billion	6-12		X	X	X		X				X			NS1
	Nano Shapes: Tiny Geometry	6-12			X	X	Math/Bio/Physics	X			X	X			NS3
	Biological Nanomachines: Viruses	6-12		X	X		Bio/Chem/Physics	X				X			NS9/NS11/NS3/NS4/NS6
	Tools and Techniques														
	What's in Your Bag? Investigating the Unknown	6-12		X	X	X		X				X			NS9

Source	Module	Grade level	Video	Labs	Teaching Aids	Map to Standards	Core Discipline	S	T	E	M	Inquiry Learning	Interactive Media/Game	Cross-cutting Topic	Nanoscience "Big Idea"
	Nanomagnets: Fun with Ferrofluid	6-12		X	X	X		X				X			NS3/NS12
	Scanning Probe Microscopy	6-12			X	X		X				X			NS8
	Unique Properties and Behaviors														
	It's a Small World After All: Nanofabric	1-8			X	X		X							NS3/NS7/NS12
	Biomimicry: The Mystery of the Lotus Effect	6-12			X	X		X				X			NS11/NS7/NS12
	How Nature Builds Itself: Self Assembly	6-12		X	X	X		X				X			NS6
	Physics Changes with Scale	6-12		X	X	X		X				X			NS4/NS5/NS2
	Shrinking Cups: Changes in the Behavior of Materials at the Nanoscale	1-8		X	X	X	Math/Physics	X			X	X			NS1/NS4
	Limits to Size: Could King Kong EXist?	6-12			X	X		X				X			NS2
	Nanotechnology Applications														
	Nanomaterials: Memory Wire	6-12			X	X		X				X			NS4/NS7/NS12
	Nanotech, Inc.	6-12			X	X	Bio/Chem/Physics	X				X			NS7NS12
	Nanomedicine	6-12		X	X	X	Bio/Chem/Physics	X				X			NS7/NS12
	Building Small: Nano Inventions	6-12			X	X	Bio/Chem/Physics	X				X			NS7/NS12
	Societal Implications														
	Too Little Privacy: Ethics of Nanotechnology	9-12			X	X	Chemistry/Physics	X							NS7/NS12
	Promise or Peril: Nanotechnology and the Environment	6-12			X	X	Bio/Chem/Physics	X							NS7/NS12
	Putting Nano-TeX to the Test	6-8			X	X	Chemistry/Physics	X							NS7/NS12
	Collaboration at the Nanoscale	9-12			X	X	Bio/Chem/Physics	X							NS8/NS3/NS4/NS11
	Conceptualizing Nanoscale	9-12		X	X	X	Bio/Chem/Physics	X				X			NS1
	Applications of Nanotechnology to Cosmetics and Foods	6-12	X		X	X	Bio/Chem/Physics	X	X						NS7/NS12
	Fats, Oils and Colors of Nanoscale Materials	9-12		X	X	X	Chemistry/Physics	X				X			NS3
	Idea Bank: Students as Nano-Detectives	9-12			X	X	Bio/Chem/Physics	X							NS7/NS12

Source	Module	Grade level	Video	Labs	Teaching Aids	Map to Standards	Core Discipline	S	T	E	M	Inquiry Learning	Interactive Media/Game	Cross-cutting Topic	Nanoscience "Big Idea"
	Linking Science, Technology, and Society by EXamining Impact of NT on a Community	6-12			X	X	Bio/Chem/Physics	X	X						NS7/NS12
	Nanomedicine: Problem Solving to Treat Cancer	6-8		X	X	X	Bio/Chem/Physics	X				X			NS7/NS12
	Podcast: Appl of NT to Cosmetics and Foods	all	X		X	X	Bio/Chem/Physics	X							NS7/NS12
	Podcast: Knowing Nano	9-12	X		X		Chem/Physics	X							NS2/NS5/NS4/NS6
	Podcast: Nanoscale Fact or Fiction	6-12	X		X		Bio/Chem/Physics	X							
	Podcast: Nanotechnology Benefits and Threats to the Environment	6-12	X		X		Bio/Chem/Physics	X							NS7/NS12
	Podcast: Properties of the Nanoscale NanoScience	6-12	X		X		Bio/Chem/Physics	X							NS1/NS8/NS3/NS4/NS7/NS12
	Welcome to Nanoscience: Interdisciplinary Environmental Explorations	9-12			X	X	Bio/Chem	X							NS1/NS2/NS5/NS7/NS12
	NDEP														
	Just Add Water	all	X		X		Chem	X	X						NS3/NS12
	Carbon Nanopearls	9-12	X		X		Chem	X	X						NS3/NS6/NS12
	Wafer Power: Building Circuits	7-12	X		X		Chem/Physics	X	X	X					NS8/NS12
	Spinning Nanofibers	9-12	X		X		Bio/Chem/Physics	X	X						NS3/NS12
	Light Antennas	7-12	X		X		Physics	X	X						NS5/NS12
	It's a Small World	all	X		X		Bio/Chem/Physics	X	X						NS1/NS5/NS8/NS12
	Science Teacher														
	The Science Behind Nanosunscreens	9-12			X	X	Bio/Chem/Physics	X	X						NS3/NS5/NS12
	Conceptualizing Nanoscale	9-12			X	X	Physics	X			X				NS1
	Putting Nanotechnology Under the Microscope	9-12						X				X			NS7/NS11
	Idea Bank: Students as Nano-Detectives	9-12			X	X		X	X			X			NS12
	Collaboration at the Nanoscale	9-12					Physics								NS8
	Fats, Oils, and Colors of a Nanoscale Material	9-12			X	X	Bio/Chem	X							NS3/NS5
	Seeing the Unseen	9-12		X	X	X	Physics	X	X			X			NS8/NS1

Source	Module	Grade level	Video	Labs	Teaching Aids	Map to Standards	Core Discipline	S	T	E	M	Inquiry Learning	Interactive Media/Game	Cross-cutting Topic	Nanoscience "Big Idea"
	Real Science or Marketing Hype?	9-12		X	X	X	Chem	X							NS3/NS5
	"New Science" and Societal Issues	9-12			X	X	Bio	X							NS7
	Editor's Corner: Small Science	9-12						X							NS7
	The Art of Electrospining	9-12		X	X	X	Physics	X	X						NS3/NS8
	Self Assembly: How Nature Builds	9-12		X	X	X	Chem	X							NS6
	The Structure and Properties of Carbon	9-12			X	X	Chem	X							NS3
	Science Scope														
	Science Sampler: Nanoscale in Perspective	7-8		X	X	X	Math	X				X			NS1
	Bumpy, Sticky, and Shaky: Nanoscale Science and the Curriculum	7-8			X	X	Physics	X							NS1/NS5
	Putting Nano-TeX to the Test	7-8		X	X	X	Physics	X	X						NS12
	Green Science: Tiny, but Powerful: The Nanoscale	7-8			X		Bio	X							NS7/NS11
	Nanomedicine: Problem Solving to Treat Cancer	7-8		X	X	X	Bio	X				X			NS11
	Science and Children														
	It's a Small World After All	K-8		X	X	X	Chem	X	X			X			NS3/NS5
	Recognizing EXcellence: From Macro to Micro to Nano	K-6			X	X	Physics	X							NS8
	Virtual Inquiry Experiences	K-6		X	X	X	Physics	X							
TryNano		http://www.trynano.org/lesson_plans.html													
	Be a Scanning Probe Microscope	3-8		X	X			X				X			NS8
	Duckboy in Nanoland				X								X		NS1
	Exploring at the Nanoscale	3-8		X	X	X		X		X		X			NS1/NS7/NS2
	Fizzy Nano Challenge	3-8		X	X			X				X			NS2/NS5
	Nano Waterproofing	3-12		X	X	X		X		X		X			NS12/NS5
	NanoMission Game Series				X								X		NS1

Source	Module	Grade level	Video	Labs	Teaching Aids	Map to Standards	Core Discipline	S	T	E	M	Inquiry Learning	Interactive Media/Game	Cross-cutting Topic	Nanoscience "Big Idea"
	Power of Graphene	3-12		X	X		Chem/Physics	X							NS3/NS9
	Sugar Crystal Challenge	3-8		X	X	X		X				X			NS2/NS3/NS10
	Try Your Hand at Nano	3-7		X	X		Chemistry	X			X	X			NS1/NS3
	Virtual Microscope				X			X	X			X	X		NS8
	Waterproof that Roof	3-12		X	X	X		X		X		X			NS12
	What is a Nanometer	3-6		X	X	X		X		X	X	X			NS1/NS8
Univ Wisc							http://education.mrsec.wisc.edu/curriculum/								
	Amorphous Metal	5-12		X	X		Physics	X				X			NS12
	Applications Activity: Liquid Crystal Sensors	7-9		X	X		Chemistry	X	X						NS3/NS12
	Applications Activity: Nano-TeX	7-9		X	X		Chemistry	X							NS12
	Applications Activity: Nanoarchitecture	7-9			X		Chemistry	X				X	X		NS3
	Applications Activity: Nanomedicine	7-9		X	X		Chemistry	X	X						NS3/NS5
	Applications Activity: "Smart" Paper	7-9		X	X		Chemistry/Physics	X	X						NS9
	Citrate Synthesis of Gold Nanoparticles	9-12		X	X		Chemistry	X							NS5
	Cutting it down to Nano	3-6			X		Math	X	X		X	X			NS1/NS7
	Electrochromic Prussian Blue Thin Films	12-15	X	X			Chemistry/Physics	X	X						NS5/NS9
	Ferrofluids	2-12		X	X		Chem/Physics	X				X			NS3
	Giant Magnetoresistance	7-9		X	X		Physics	X							NS3/NS5/NS12
	How Can We "See" What We Can Not See?	7-9		X	X	X	Math	X			X	X			NS8/NS3
	How Small Are Nanotubes?	7-9			X		Math				X	X			NS1
	How Small Is a Pygmy Shrew?	7-9		X	X		Math	X			X	X			NS1
	Light Emitting Diodes (LEDs)	10-12		X	X		Math/Chem/Physics	X			X	X			NS12/NS11/NS3
	Magnetism	3-12		X	X	X	Physics	X	X	X		X			NS4

Source	Module	Grade level	Video	Labs	Teaching Aids	Map to Standards	Core Discipline	S	T	E	M	Inquiry Learning	Interactive Media/Game	Cross-cutting Topic	Nanoscience "Big Idea"
	Memory Metal: Using Shape Memory Metals in Simple Machines	7-9		X	X	X	Chemistry/Physics	X				X			NS12/NS11/NS3/NS4
	Mitten Challenge	all		X	X		Physics	X				X			NS1/NS8
	Molecular Motor	7-12			X		Biology/Chemistry	X	X	X					NS3
	NanoCommunity	5-9		X	X		Social Science	X	X						NS10
	Nanoscale Tools -Scanning Proble Microscopy and X-ray Diffraction	5-12	X	X	X		Chemistry/Physics	X	X			X			NS1/NS2/NS7/NS8
	NanoSolutions	5-9		X	X		Chemistry	X	X			X			NS1
	Nanostained Glass Activity	7-12	X	X	X		Chemistry	X	X						NS12/NS5/NS3
	NanoSugar	9-12		X	X		Math	X			X				NS1
	Nanotechnology Applications	7-9					Chemistry/Physics	X	X	X					NS5/NS9
	Nanotechnology & Society: Ideas for Education and Public Engagement	12-15			X		Physics/Chemistry/Social Science	X	X	X		X			NS10
	NanoWeights	7-12		X	X		Chemistry	X							NS1
	Nature: The First Nanotechnologist	7-9	X		X		Biology/Chemistry	X	X						NS3
	Nickel-Titanium: A Shape Memory Alloy	10-12		X	X		Chemistry/Physics	X				X			NS3/NS11/NS12
	Octadecanethiol Monolayer on Silver	10-12		X	X		Chemistry	X							NS6
	Preparation of Surface Conductive Glass	10-15	X	X			Chemistry/Physics	X	X						NS5/NS9
	Quantum Dots & Nanoparticles	7-12			X		Chemistry/Physics	X	X						NS5/NS9
	Rocks and Nanobots	5-9		X	X		Social Science	X	X						NS10
	Scanning Probe Microscopy and Xray Diffraction	10-12		X	X		Chemistry/Physics	X				X			NS8
	Smell: Sensing on the Nanoscale	3-12			X		Biology/Chemistry	X	X						NS2/NS3
	Societal Implications Activity: Technology and Public Policy	7-12		X			Social Science	X	X						NS10
	Synthesis of Aqueous Ferrofluid Nanoparticles	10-12		X	X		Chemistry/Physics	X				X			NS3/NS11
	Synthesis of Silver Nanoparticles	9-12		X	X		Chemistry	X							NS5
	Titanium DioXide Raspberry Solar Cell	7-12	X	X			Chemistry/Physics	X	X	X		X			NS5/NS9

Source	Module	Grade level	Video	Labs	Teaching Aids	Map to Standards	Core Discipline	S	T	E	M	Inquiry Learning	Interactive Media/Game	Cross-cutting Topic	Nanoscience "Big Idea"
	Using Diffraction to Determine the Position of Atoms	7-12		X	X		Physics	X	X						NS8
	Using SPM to Determine the Position of Atoms	7-12		X	X		Physics	X	X						NS8
	Using Vectors to Construct Carbon Nanotubes	10-12		X	X		Math/Chem/Physics	X			X	X			NS12/NS3/NS8
	What is Nanotechnology?	7-9	X		X		Chemistry/Physics	X	X	X					NS2/NS5/NS9
	Wheel of Fortune Activity	5-9			X		Chemistry/Physics	X	X						NS1/NS2
Virtual Lab: Nanoscience Class Homepage (UVA)		http://virlab.virginia.edu/Nanoscience_class/Nanoscience_for_elementary_and_middle_schools.htm													
	Microscopy Lesson	5-8	X	X	X		Physics	X				X			NS1/NS8

Appendix E: Brief Descriptions of Selected Workshop Participant Programs

E.1. A Resource Center for Informal Learning

Jamie Bell, The Center for Advancement of Informal Science Education (CAISE)

The Center for Advancement of Informal Science Education (CAISE) is a National Science Foundation (NSF)-funded resource center for professionals who design, research, and evaluate learning experiences that take place outside of formal classroom settings. CAISE works in cooperation with the NSF Advancing Informal STEM Learning (AISL) program to strengthen and advance the field of professional informal science education (ISE)—including those working in media, science centers and museums, zoos and aquariums, cyber learning and gaming, youth and community programs, citizen science, and science outreach.

Established in 2007, CAISE is based at the Association of Science-Technology Centers (ASTC) in Washington D.C. and works with co-principal investigators at informal science and academic institutions across the country. By using the NSF AISL portfolio of projects as a lens to understand the field writ large, CAISE has three major strands of work:

- Broader Impacts & ISE**:** One of CAISE's goals is to enhance connectivity and capacity for scientists, STEM-based professionals and university/lab directors of education and outreach to leverage ISE institutions and programs for their broader impacts plans, proposals and activities. Through the Outreach for Scientists page (*InformalScience.org/about/informal-science-education/for-scientists*) and conference presentations and posters, CAISE provides information and resources to researchers and professionals who are currently involved in or considering ISE collaborations and/or strategies.

- Research, Evaluation, and Practice**:** Developing impactful learning experiences and settings grounded in research and assessed through thoughtful evaluation is key to building a knowledge base that the wider field can draw from. CAISE provides access to evaluation resources—such as the *PI's Guide to Managing Evaluation in Informal STEM Learning Projects*—and research, including peer-reviewed journal articles, field-wide research agendas, and the community-generated Knowledge Base (formerly known as the ISE Evidence Wiki).

- Infrastructure: All of CAISE's work is integrated within the online infrastructure that our website, *InformalScience.org*, provides for advancing the professional field. The site offers a central point of access for those working in or exploring informal science education. It includes a curated, growing, searchable repository of 10,000+ ISE project descriptions, evaluation reports and instruments, and research and reference materials. The website also has a blog, newsletter, calendar, and growing member directory.

For nanoscale engineering scientists and educators, the following resources provide examples of related work that has been done in informal learning settings.

Projects:

- DragonflyTV: Investigating the NanoWorld (*InformalScience.org/projects/ic-000-000-007-608/*)
- Quarked! Adventures in the Subatomic Universe (*InformalScience.org/projects/ic-000-000-007-570/)*
- Too Small To See (*http://InformalScience.org/projects/ic-000-000-001-409/*)

Research:

- Broadening and Deepening the Impact: A Theoretical Framework for Partnerships between Science Museums and STEM Research Centers (*InformalScience.org/research/ic-000-000-008-530/*)

- Encountering Nanotechnology in an Interactive Exhibition (*InformalScience.org/research/ic-000-000-009-894/*)
- Informal Science Education: Lifelong, Life-Wide, Life-Deep (*InformalScience.org/research/ic-000-000-010-191/*)

Evaluation:

- The Amazing Nano Brothers Juggling Show (*InformalScience.org/evaluation/ic-000-000-003-279/)*
- Impact of Sci-Tech Nanotechnology Cable News Segments (InformalScience.org/evaluation/ic-000-000-003-292/)
- Impact of Television Presentation Formats on Understanding DragonflyTV Nano Content (*InformalScience.org/evaluation/ic-000-000-003-437/*)

Many of the resources—including evaluation reports, research, and descriptions of project activities—from the Nanoscale Informal Science Education Network (NISE Net) are also searchable through the *InformalScience.org* repository.

E.2. MEMS/NEMS and BioMEMS/BioNEMS Materials and Devices and Biomimetics

Dr. Bharat Bhushan, Ohio State University

MEMS/NEMS and BioMEMS/BioNEMS include a variety of sensors, actuators, and complex micro/nanodevices for industrial, consumer, defense, and biomedical applications. MEMS/NEMS devices are made from single-crystal silicon, LPCVD polysilicon and other ceramic films, and polymers. BioMEMS/NEMS devices involve biomaterials; many use PDMS or PMMA polymers for their construction. Many devices involve relative motion, and in those cases nanotribology and nanomechanics are important.[1-3] The scale of operation and large surface-to-volume ratio of the devices result in very high retarding forces such as friction and adhesion that seriously undermine the performance and reliability of the devices.[4,6] For BioMEMS/BioNEMS, adhesion between biological molecular layers and the substrate, and friction/wear of biological layers may be important.[5] Materials used in various devices must exhibit desirable micro/nanoscale tribological and mechanical properties. There is a need to develop lubricants and identify lubrication methods that are suitable for these devices.[1-3] The measurement and evaluation of the mechanical properties of micro/nanoscale structures is also essential to help address reliability issues. Atomic-force-microscopy-based techniques have been used to perform nanotribiological and nanomechanics studies on materials and devices.

Carbon nanotubes are being used for various nanotechnology applications. The mechanical strength of many of these devices critically relies on the nanotribology and nanomechanics of the CNTs. Various investigations of adhesion, friction, wear, and mechanics of MWNTs, SWNTs and MWNT arrays have been carried out.[9]

For bio/nanotechnology applications, to improve adhesion between biomolecules and silicon based surfaces, chemical conjugation as well as surface patterning have been used.[5] Friction and wear studies of biomolecules show that these act as a lubricant but exhibit some wear resistance.[5]

Device level studies on various devices including digital micromirror devices for optical projection displays have been carried out.[5]

In the area of biomimetics,[6-8] Lotus and other leaves has been characterized to understand the mechanisms responsible for super hydrophobicity (high contact angle), self-cleaning/antifouling, and low adhesion. Based on models, optimum roughness distributions have been developed for super hydrophobic surfaces.[7-8] Hierarchical structures of interest for high mechanical durability have been fabricated in the lab[8] and have shown excellent performance.

[1] Bhushan, B., Israelachvili, J.N., and Landman, U., "Nanotribology: Friction, Wear and Lubrication at the Atomic Scale," *Nature* **374**, 607-616 (1995).

[2] Bhushan, B., *Handbook of Micro/Nanotribology*, second ed., CRC Press, 1999.

[3] Bhushan, B., *Nanotribology and Nanomechanics I & II*, 3rd ed., Springer, Heidelberg, Germany, 2011.

[4] Bhushan, B., *Tribology Issues and Opportunities in MEMS*, Kluwer Academic Publishers, Dordrecht, 1998.

[5] Bhushan, B., *Springer Handbook of Nanotechnology*, 3rd ed. Springer-Verlag, Heidelberg, Germany, 2010.

[6] Bhushan, B., "Biomimetics:Lessons from Nature - An Overview", *Phil. Trans. R. Soc. A* **367**, 1445-1486 (2009).

[7] Nosonovsky, M. and Bhushan, B., *Multiscale Dissipative Mechanisms and Hierarchical Surfaces: Friction, Superhydrophobicity, and Biomimetics*, Springer, Heidelberg, Germany, 2008.

[8] Bhushan, B., *Biomimetics-Inspired Hierarchical-Structured Surfaces for Green Science and Technology: Superomniphobicity/Self-Cleaning and Controlled Adhesion*, Springer-Verlag, Heidelberg, Germany, 2012.

[9] Bhushan, B. "Nanotribology of Carbon Nanotubes", *J. Phys.: Condens. Matter* **20**, 365214 (2008).

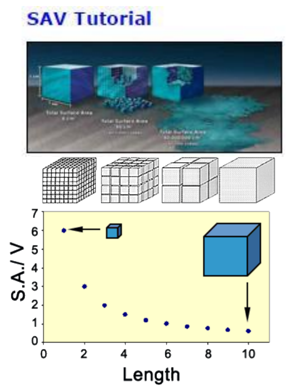
E.3. Materials World Modules Program
Dr. Robert Chang, Northwestern

INTERACTIVE i-MWM

What is the first and foremost property that increases in importance at the nanoscale?

As an object size gets smaller and smaller, the surface area-to-volume ratio becomes larger. The beginning of an understanding of the nanoscale is both getting a sense of how small it is and realizing that some intriguing properties arise when an object gets so small that surface behavior is dominant. i-MWM provides an interactive format to support mastery of non-intuitive, difficult core nano concepts.

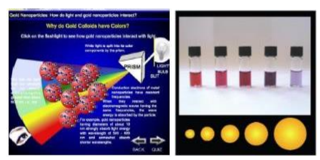
By adopting an interactive mobile platform, i-MWM combines hands-on scientific inquiry and engineering design projects with web-based multimedia tools (e.g. interactive animations, simulations, modeling and data analysis tools, games, and tutorials) to accelerate and deepen student understanding of complex spatial, time- and size-dependent phenomena that underlie emerging technologies.



Module At-a-Glance:

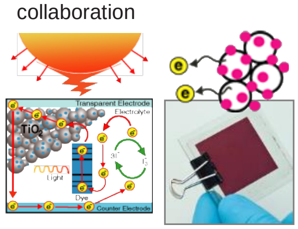
Activities (Gr 6-8/9-12)
- ■ Measurement & Tools
- ■ Size and Scale
- ■ Surface-to-Volume Ratio
- ■ Size-Dependent Properties

Design Projects
- ■ Geyser Design
- ■ Dye Solar Cell Design

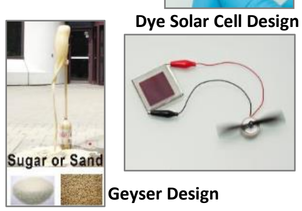


Interactive Gold Colloid Animation

- Linked core nano STEM concepts with traditional disciplinary subjects
- Aligned with NGSS and engaged in science and engineering design practices
- Connected to relevant nano crosscutting concepts to enhance learning across subjects
- Seamless integration with classroom activities
- Increased flexibility and broad access
- Rapid assessment feedback
- Cyber platform for community collaboration



Dye Solar Cell Design



Geyser Design

i-MWM is designed to improve STEM education

Science ▪ Technology ▪ Engineering ▪ Math

Interdisciplinary
Integrates science & non-science subjects

Flexible
Modify to your teaching style, students' ability and class time

Hands-on
Contains activities that lead up to inquiry-centered design projects

Cutting-edge
Introduces issues on the forefront of technological research

Chemistry
Chemical Reactions ■ Food Chemistry ■ Hydrogen Bonding ■ Polarity ■ Surface Chemistry/ Catalysis ■ Structure and Properties of Matter ■ Biochemical Reactions ■ Oxidation & Reduction ■ Natural & Synthetic Dye Molecules ■ Intermolecular Forces & Chemical Bonding ■ Energy Bonds/ Levels ■ Separation of Mixtures ■ Electrochemical Cells

Biology & Life Sciences
Size & Bones Strength ■ Size & Skin Coverage ■ Microscopy ■ Allometry ■ Size & Metabolic Rate ■ Size & Thermoregulation ■ Photosynthesis ■ Food Chain/ Web ■ Absorption & Diffusion ■ Cellular Structure ■ Energy Flow in the Ecosystem

Mathematics
■ Measuring ■ Graphing (Making & Interpreting) ■ Computing ■ Averages ■ Rates ■ Dimension ■ Scale ■ Estimation■ Power of Ten ■ Logarithm and Exponents ■ Ratios & Proportions ■ Length, Area & Volume Measurement ■ Surface Area to Volume Ratio ■ Graphical Analysis

Physics & Physical Sciences
Property of Matter ■ Potential Energy, Kinetic Energy & Work ■ Electromagnetic Spectrum & Absorption Spectra ■ Light Energy, Heat Energy & Energy Transformations ■ Charged Particles, Electricity ■ Circuits, Current, Voltage & Electric Power ■ Color ■ Capillary Forces ■ Energy Transfer■ Quantum Effects■ Size & Forces/ Strength ■ Size & Dominant Forces ■ Size & Surface Tension ■ Size & Terminal Speed ■ Size & Thermal Radiation ■ Types of Microscope ■ Astronomical Objects

Geology & Earth Science
Metals & Minerals ■ Use of Natural Resources ■ Renewable Energy ■ Environmental Pollution Issues

Environmental Science
Global Warming ■ Alternative Energy ■ Fossil Fuels ■ Cellular Structure ■ Energy Flow in the Ecosystem

Engineering Education
Designing ■ Building Prototypes ■ Communications ■ Optimization

Language Arts
■ Fantasy Stories ■ Sci-fi Stories ■ Literature

Materials World Modules
An Inquiry & Design Based STEM Education Program
Northwestern University ■ https://i-mwm.org
847-467-2489 ■ mwm@northwestern.edu

E.4. Complete and Customizable Nanotechnology Curriculum
Dr. Marco Curreli, Omni Nano

OMNI NANO
www.omninano.org
2999 Overland Ave.
Suite 103
Los Angeles, CA 90064
Phone: (424) 248-8707
Email: info@omninano.org

Omni Nano is a 501(c)(3) non-profit organization dedicated to providing an affordable, high-quality nanotechnology education to all high school and undergraduate college students.

Our mission is to inspire today's learners to become tomorrow's nanotechnology/STEM workforce by developing and producing grade-appropriate educational materials for nanotechnology courses. We envision future generations of American students who are educated in and passionate about nanotechnology – and who are inspired to pursue careers as scientists, engineers, and STEM entrepreneurs. Not only will this significantly impact their lives for the better, but it will also contribute to the continuing prosperity of our nation.

Omni Nano supports nanotechnology education through a variety of programs, as outlined below, including teaching nanotechnology first-hand, developing curricula and educational materials, and training teachers to implement nanotech lessons in their own classrooms.

- **Discover Nanotechnology Workshops:** Omni Nano provides nanotechnology workshops to high schools, after-school programs, and youth conferences in the greater Los Angeles area and across the US. These hands-on workshops are aimed at encouraging students to pursue a collegiate STEM education – and, ultimately, join the STEM workforce – by engaging them with the exciting, cutting-edge technologies of the 21st century. Workshops focus on explaining the practical applications of nanotechnology using simple STEM concepts with which students are already familiar from their high school science classes. Since the program's inception in late 2013, Omni Nano has already reached over 2,400 students by delivering over 75 of its innovative workshops – and we've been enthusiastically invited to return by every single school. For a full list of our workshops, visit ***blog.omninano.org***.

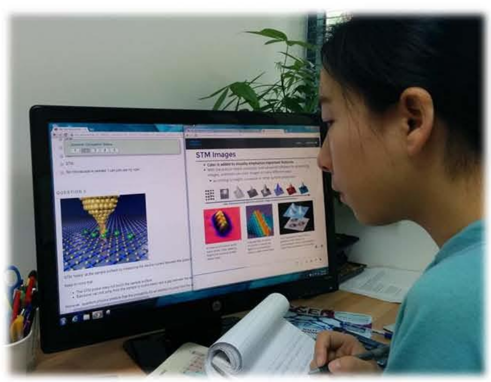
- **Educators! Our workshop materials are available for all educators interested in hosting local workshops.** The easy-to-use PowerPoint slides include a general introduction to nanotechnology followed by an overview of various applications including flexible electronics, nanomedicine, and super-hydrophobic surfaces. The length of the workshop, as well as the topics covered, are completely customizable.

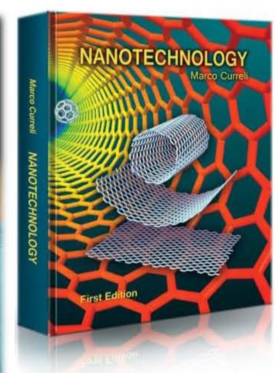
Omni Nano was founded in 2012 by Dr. Marco Curreli, whose graduate studies at USC focused entirely on nanotechnology. Dr. Curreli has extensive experience both in academia and industry and has an unsurpassed dedication to and passion for science education. For more information, visit **www.OmniNano.org** today!

- **Bridges to Nanotechnology Courses:** Omni Nano brings nanotechnology directly into classrooms, creating a precedent that schools and districts can emulate nationwide. Our engaging, highly-rated pilot course has been taught at 3 high schools in the greater Los Angeles area – and now, students and educators across the globe can preview our online course! Go to ***bitly.com/nsee-quest*** to learn more.

> **"Students' interest in a STEM career *skyrocketed* from 3% to 30% during the course!"**
>
> High School Principal

- **Nanotechnology Curricula:** Omni Nano's full-length electronic textbook covers all of the fundamentals of nanotechnology and then dives deeper into special topics including drug delivery, energy production and storage, fabrication techniques, and metamaterials, to name a few. Our student-centered, interactive course materials – including textbook, syllabi, lecture slides, instructional videos, and testing materials, integrated with existing laboratory resources – are designed to bridge the gap between today's standard science curricula and tomorrow's technologies, inspiring college and college-bound students to consider STEM majors and careers. Aligned with Common Core State Standards (CCSS) and Next Generation Science Standards (NGSS) frameworks, our curricula are suitable for both traditional classroom as well as online learning settings. Because our materials are in electronic format, they're quickly distributable and easily updatable, allowing us to continually improve based on feedback and success metrics. Best of all, all of our educational materials are available for educators who wish to include nanotechnology lessons in their science classes or to instruct their own nanotechnology course.





  - **Experts!** **We are proud to work with a strong community of STEM and nanotech gurus.** If you would like to join an outstanding team and contribute to this important cause, please consider donating your expertise by contributing to the development and continued improvement of the textbook and other course resources.

Awards and Recognitions: Omni Nano was finalist in the Los Angeles Business Journal's 2014 Patrick Soon-Shion Innovation Awards, and our Executive Director Dr. Marco Curreli was nominated for the 2015 Nonprofit Leadership Excellence Award.

E.5. EduNano – Improved Accessibility for Nanoscience Instruction

Drs. Sidney Cohen and Ron Blonder, Weizmann Institute of Science, IL

This section briefly summarizes a TEMPUS project for creating online courses in nanoscience, and its implementation at the Weizmann Institute of Science. TEMPUS is an EU project designed to reform and modernize education in member countries. Geographically, the TEMPUS framework includes 4 regions: Western Balkans, Southern neighboring area (including N. Africa and parts of middle east) Eastern neighboring area (includes Russian federation and adjacent countries that previously formed part of USSR), and Central Asia. The EduNano project focuses on education in the Nanosciences and Nanotechnologies for a wide spectrum of end-users including K-12, undergraduates, graduates, continuing education of professionals and teachers. The project leader is based at the University of Sofia in Bulgaria. In addition there is a team from the Grenoble Institute of Technology in France, and the Politecnico di Torino in Italy. However, the center of gravity of the program is in Israel, where 5 major university centers are involved. This project is directly linked to the second, educational phase of the Israel National Nanotechnology Initiative, which should promote nanoeducation with focus on the multiple skills required for developing nanotechnologies.

The goals of the project are to link both academic learning centers and industrial (small and medium enterprise) shareholders in order to fill needs of the industry. Thus, a needs analysis by a public policy center has provided needs from the industry which were used to help form the syllabi. The courses will be shared between the different learning centers, so that both instrumentation and expertise available at one site can be shared with all participants. The courses will provide university credit according to the European Credit Transfer and Accumulation System (ECTS). In addition to the online courses, student visits to specialized facilities will be offered. Examples of courses offered – Design of nanoscale ICs, Bio-Nanoelectric devices for Biosensing, nano medicine and pharmaceutical research, and optical and mechanical methods of material nano-characterization.

At the Weizmann institute, two courses are being developed: Graduate level and continuing education course in “Scanning Probe Microscopy and its Applications in Research and Nanotechnology Industry” and “Introduction to Materials and Nanotechnology for Science Teachers”. The SPM course will cover the fundamental physical principles behind the technique, considerations in the operation of the instrument, aspects of data acquisition and analysis, and applications. Subjects will largely be discussed through referral to current scientific literature. The course is presented in the Moodle learning environment in the form of online tutorials both html and video. On-line support by the tutor will be provided. Both lectures and lab demonstrations will be presented.

The course “Introduction to Materials and Nanotechnology for Science Teachers” was designed to expose high school teachers to modern research topics, introduce teachers to nanoscience, generate teacher interest, and increase chemistry teacher nanoliteracy by providing them with the essential concepts of nanoscale science and technology. The course is structured accordingly: the beginning of the course provides fundamental knowledge essential to understanding topics in nanoscience and advanced materials characterization. Then, the high school teacher students apply this knowledge while independently studying one self-selected topic. Thus, they integrate newly learned (nano) topics with their pedagogical knowledge by presenting their selected topic to the other teachers in the course. They then design a module for their students and teach it in class. The courses are built from video units, html, and assignments that are uploaded in the Moodle platform of the EduNano project: http://edunano-lms.tau.ac.il/login/index.php

For more information:
http://edunano.eu/ (site for the project)
http://stwww.weizmann.ac.il/g-chem/TEMPUS/ (site for Weizmann team)
Sidney Cohen: sidney.cohen@weizmann.ac.il
Ron Blonder: ron.blonder@weizmann.ac.il

E.6. GK-12 Program

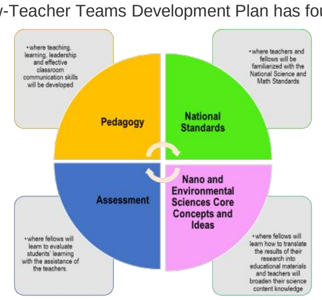
Dr. Liz Díaz Vázquez, University of Puerto Rico

GK-12 Program "From Hectares to Nanometers: GK-12 Multidisciplinary Explorations of Tropical Ecosystems and Functional Nanoscience"

K12 project is an interdisciplinary strategic partnership between the two largest and most developed research institutes of the University of Puerto Rico System: the Institute of Tropical Ecosystem Studies (ITES) and the Institute for Functional Nanomaterials (IFN). "One Universe, Many Worlds" is the unifying theme based by the comparison of the macro world with the nano world that will illustrate to our GK-12 Program fellow-teacher teams the recurring patterns in nature. The subject matter of these diverse fields spans 1011 orders of magnitude and to the untrained minds there seems to be no relation between them. This Program exploits this huge difference to introduce to the fellow-teacher teams "that the universe is a unified system" and that knowledge gained from studying one part can be applied to other scales and help understand what apparently seems to be very diverse worlds. It also increases the knowledge through multidisciplinary explorations of tropical ecosystems and functional nanoscience while improving fellows' abilities to communicate and teach science.

The Core: the **kernel of the project** is the **fellow-teacher teams** who will jointly participate in professional development activities to design, develop and implement the science instruction activities, creating inquiry-based educational materials in nano and environmental sciences and incorporating them into the middle and high school science curriculum. Fellows will spend 7-10 hours a week working in the classroom with the assigned teacher. Fellows will perfect their communication, teaching, team building, and collaboration skills, while presenting to the teachers core concepts related to their research. Public schools teachers will increase their knowledge of science concepts, while assisting fellows in developing the pedagogical skills required in the classroom. This initiative will improve students' knowledge of and excitement about the multidisciplinary fields of nano and environmental sciences, while fellow-teacher teams teach the same topics of the curriculum. The gk-12 will form a community of learners to exchange knowledge, ideas and strategies.

Principal Components : The Fellow-Teacher Teams Development Plan has four components:



GK-12 Activities Overarching Concepts

- System Dynamics
- Self-Assembly - Organization of Complex Systems
- Size and Scale
- Fractals
- Dominant Interactions-Forces
- Surface to Volume Ratio
- Complexity

Lending Library

Over 20 inquiry base activities with the teacher and students guides are available. The most popular are:

- **Let me Grow** : Explain at the nanoscale level the acidification of the ocean and its impact in the coral
- **Carbon Allotropes:** Students will explore the different forms of carbon. They will also learn about how carbon nanotubes are formed and its applications.
- **Can you be my Model?** Introduce the use of models and the scientific method
- **Solar Cells:** participants construct a dye base solar cell.
- **Fractals: Inside the Chaos there is some order** Explain fractal dimension and its relevance using a STEAM integration perspective.
- **What color I am?** Describe the function of pigments in photosynthesis from a nanoscale perspective.

Visit our page for more information, a list of all available modules and activities, and to request our materials **http://gk12.upr.edu/**

This material is based upon work supported by the National Science Foundation under Grant No. 0841338

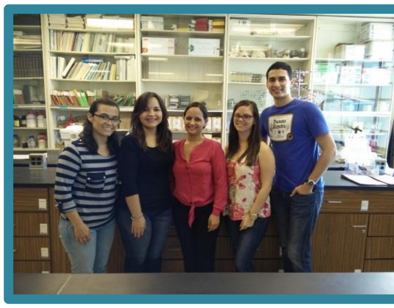
C0NTACT US

Mail:
Dr. Liz Diaz/ Dr. Gerardo Morell
Resource Center for Science and Engineering
PO Box 23334
San Juan, PR 00931-3334
Email: GK12PR@gmail.com
Phone: 787-248-9142

IFN Outreach and Education in Nanoscience and Nanotechnology

The Institute for Functional Nanomaterials (IFN) is a research center managed by the Resource Center for Science and Engineering and has active participants from several campuses of the University of Puerto Rico (UPR). The main goal of this institute is to increase the amount and quality of cutting-edge research and intellectual property on the island. The IFN has a unique opportunity to make a major contribution to increasing the diversity of the future nanoscience and technology workforce, since more than 95 percent of the undergraduate and K-16 population in Puerto Rico is of Hispanic origin.

Even though nanoscience and nanotechnology do not form integral part of the actual science education curriculum (chemistry, biology or physics), its relevance to society suggests that nano-related concepts should be taught in all academic levels. The focus of the IFN educational team is to create cross-disciplinary educational modules and activities that can be incorporated in the K-16 continuum in order to develop a nanoscience curriculum. These materials are used for teaching capstone concepts that can be explained using nanoscience.



Contact us
Mail: Resource Center for Science and Engineering
PO Box 23334
San Juan, PR 00931-3334
Facundo Bueso Building 340
Email: ifn.upr.edu@gmail.com

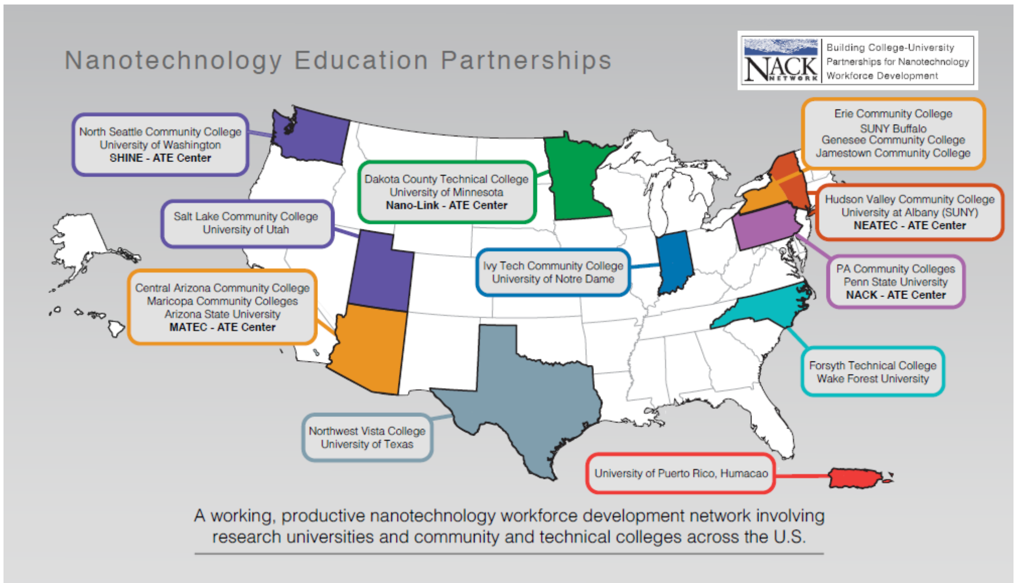
The IFN outreach and education division main objective is the diffusion of nanoscience and nanotechnology concepts. To accomplish this objective different strategies are used:

- ✓ Development of demonstrative and didactic materials that facilitate the teaching and learning of science, technology, and engineering concepts to students in the K-16 levels.
- ✓ Development of educational modules that emphasize the most commonly used concepts in nanoscience and nanotechnology. These modules are tested and validated in order to assess their educational efficacy.
- ✓ Module assessment, workshops, demonstrations, lab experiments and educational activities.
- ✓ Educational visits to schools and universities.
- ✓ Training of teachers, informal educators and students in nanotechnology and nanoscience education.
- ✓ Development of undergraduate lab experiences for physical science, chemistry and engineering classes.
- ✓ Diffusion of IFN faculty's research work to general public.
- ✓ Exposition of IFN research advances.

E.7. The NACK National Network for Nanotechnology Workforce Development

Drs. Stephen Fonash, Sam Agdasi, Osama Awadelkarim, Mike Opp, Trevor Thornton, Penn. State Univ.

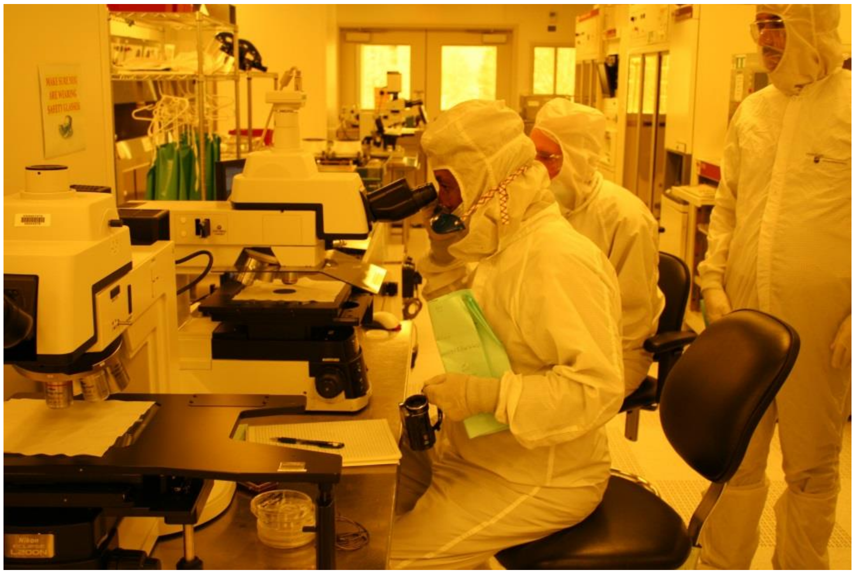
The Nanotechnology Applications and Career Knowledge (NACK, www.nano4me.org/) Network, a National Science Foundation funded Advanced Technological Education National Center of Excellence, is centered at Penn State and is dedicated to increasing the nanotechnology awareness of all Americans, including underrepresented groups, to broadening student preparation for careers in the wide spectrum industries utilizing micro- or nanotechnology, to furthering creative utilization of its bank of resources which it is continually evolving through this national partnerships/core-skills education effort, and to making nanotechnology education available in every part of the U.S. The NACK Network is committed to industry-ratified core-skills education, which it is propagating nationally through the current 11 partnerships of community colleges and research universities. These NACK Network partnerships are working to ensure the country has a workforce educated in this crucial advanced manufacturing area.



The NACK Network enables and fosters broad and economically viable nanotechnology workforce education across the U.S. through Community College-University Partnerships.

The NACK Network partners with education institutions across the U.S. to promote a model for broad nanotechnology education and preparation. The NACK Network is continuing to expand the role of existing partnerships and to form additional nanotechnology workforce education partnerships at areas across the U.S. where it is appropriate. The nanotechnology workforce skill set developed by the NACK Network and its industry partners enables students to enter this emerging field successfully. In partnership with ASTM International, the NACK Network is presently leading the effort to institutionalize nanotechnology education through the creation of a set of uniform standards for workforce education in nanotechnology. In the future, students who have acquired nanotechnology workforce education knowledge will be able to take ASTM International tests and attain a set of industry recognized stackable certificates.

The NACK Network makes nanotechnology education resources available to secondary and post-secondary faculty through professional development opportunities, as well as through its nano4me.org website. NACK Network online resources, developed with industry guidance, provide materials to update or develop individual courses or entire nanotechnology programs. To date, over 42,000 educational materials from nano4me.org have been downloaded. The NACK Network also provides Introductory Workshops, as well as Nanotechnology Course Resource Workshops at Penn State and monthly Webinars, for training and



educating teachers and incumbent workers. To date, NACK multi-day workshops have been attended by over 1,500 educators and industry personnel. NACK also cultivates a "nano-literate population" with webinars. More than 2,200 instructors, students, industry personnel, and interested adults are learning about nanoscience via NACK's webinars.

The NACK Network has also established and is growing the Remotely Accessible Instruments for Nanotechnology (RAIN) Network which presently includes instruments at Penn State University and six other colleges and universities across the U.S. RAIN lowers the barrier-to-entry into the world of “seeing” the nanoscale and enables instructors to deliver authentic and relevant educational activities for students. RAIN provides hands-on “remote” access and control of nano-scale characterization equipment to students from across the country who would otherwise have no exposure.

Through its numerous partnerships with K-12 schools, two-year colleges, and four-year universities, NACK has fostered a growing interest in nanotechnology education and workforce development. Although still an emerging technology, the demand for graduates with the knowledge, skills, and abilities to work in nano-related industries is projected to grow substantially over the next five years. To date, 23 programs in the U.S. and Puerto Rico include nanotechnology in their associate degrees or certificate programs thanks to NACK's assistance. This translates to more than 1,100 graduates, of which 69% are employed in a nanotechnology field. NACK promotes professional networking among these nanotechnology program graduates, and has created an alumni section on nano4me.org, as well as LinkedIn groups to facilitate this networking.

NACK’s six-course suite of sophomore-level courses provides post-secondary students with a unique skill set that includes fabrication, synthesis, and characterization. In a survey of 183 industry leaders, 100% endorsed the skills and education content taught in this suite as the right skills for the nanotechnology workforce. Students have also reported that the diversity of their skills and their proficiency with hands-on tasks allow them to jump into work immediately.

The NACK Network has a robust relationship with industry across the nation. Nanotechnology employers hire program graduates, serve as presenters in NACK's webinars, provide feedback on skill standards as they are developed, host internships for students, and guide NACK's nanotechnology workforce development initiatives.

E.8. Educational Materials
Dr. Anne Lynn Gillian-Daniels, Univ. of Wisc. Materials Research Science and Engineering Center

University of Wisconsin MRSEC | Materials Research Science and Engineering Center on Structured Interfaces Interdisciplinary Education Group (MRSEC IEG)

The University of Wisconsin Materials Research Science and Engineering Center (Wisconsin MRSEC) uses a multidisciplinary approach to solve complex materials challenges and to share cutting edge research with the public. Much of the Wisconsin MRSEC's research focuses on nanomaterials that can be used in broad range of applications such as solar cells, new semi-conductors, and sensors that detect toxins. The Wisconsin MRSEC also develops and disseminates research-inspired educational resources to K-12 and public audiences to excite people about nanotechnology. Outreach experts, K-12 teachers, research faculty, and graduate students from a broad range of disciplines collaborate to create educational resources that are hands-on, minds-on, engaging and accessible. We disseminate our resources in person through campus field trips, informal science events, school visits, workshops, and professional conferences (Figure 1). To broaden our dissemination to a global audience, we post our resources on our MRSEC education website (www.education.mrsec.wisc.edu) and publish in science education journals.

Figure 1: Wisconsin MRSEC disseminates through on-campus field trips (left), informal science events (middle), and hands-on workshops (right).

In order to reach the broadest possible audience, the Wisconsin MRSEC develops various types of resources including laboratory experiments, classroom and tabletop activities, videos and background materials, designed for a wide range of grade levels. Recently developed educational resources include a laboratory on synthesizing graphene by chemical vapor deposition, a video about liquid crystal sensors, and an interactive 3-D app about atom behavior in nanoscale materials.

We also collaborate with the Institute for Chemical Education (ICE) at UW to develop and distribute educational kits focusing on nanoscience. For example, the Nanoworld kit available in both English and Spanish teaches basic concepts about nanoscience including applications and the tools scientists use to investigate nanomaterials. Our iterative development approach that involves multiple rounds of synthesis, evaluation, and improvement results in high quality educational resources that can be used in a wide range of venues. Table 1 below includes some of the nanoscience based activities, laboratory experiments, kits, and background materials the Wisconsin MRSEC has developed.

Table 1: Examples of Wisconsin MRSEC Research-Inspired Education Resources

Module	**Grade Level**	**Module Type**	**Website URL**
AtomTouch	7-12.	Touch screen app	https://mobile.wisc.edu/mli-projects/project-atomtouch/
Citrate Synthesis of Gold Nanoparticles	7-12.	Laboratory experiment	http://education.mrsec.wisc.edu/277.htm
Cutting it down to Nano	3-6.	Activity	http://education.mrsec.wisc.edu/37.htm
Exploring the Nanoworld (English and Spanish)	3-10	Kit	http://ice.chem.wisc.edu/Catalog/SciKits.html
LED Color Strip Kit	7-12	Kit	http://ice.chem.wisc.edu/Catalog/SciKits.html
Liquid Crystal Sensors	5-12	Video	https://www.youtube.com/watch?v=5DgB14eN0QM
Nanotechnology Applications	7-9.	Background information	http://education.mrsec.wisc.edu/101.htm
NanoVenture: The Nanotechnology Board Game	9-15	Kit	http://ice.chem.wisc.edu/Catalog/SciKits.html
Nature: The First Nanotechnologist	7-9.	Background information	http://education.mrsec.wisc.edu/31.htm
Preparation of Surface Conductive Glass	12-15.	Laboratory experiment	http://education.mrsec.wisc.edu/304.htm
Quantum Dots & Nanoparticles	7-12.	Background information	http://education.mrsec.wisc.edu/150.htm
Synthesis of Silver Nanoparticles	7-12.	Laboratory experiment	http://education.mrsec.wisc.edu/278.htm
Titanium Dioxide Raspberry Solar Cell	7-12.	Laboratory experiment	http://education.mrsec.wisc.edu/289.htm
What is Nanotechnology?	3-12.	Background information	http://education.mrsec.wisc.edu/35.htm

E.9. Educational Materials

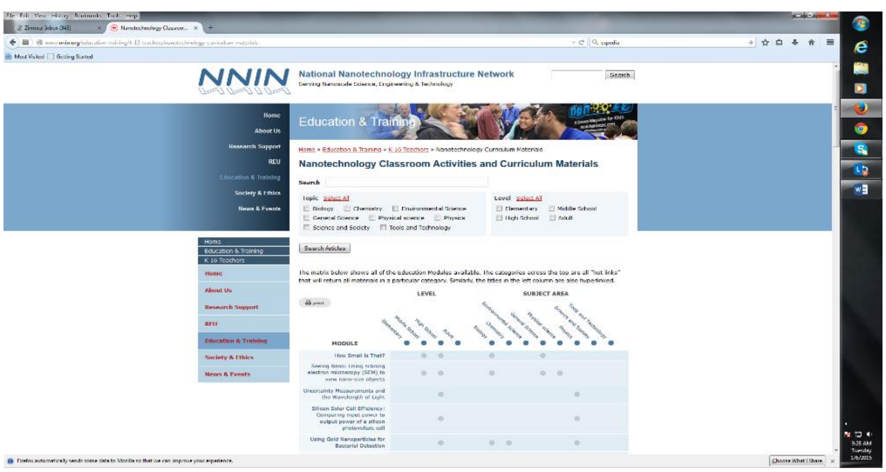
Dr. Nancy Healy and Joyce Allen, National Nanotechnology Infrastructure Network

The National Nanotechnology Infrastructure Network (NNIN) is a NSF-funded program which supports nanoscience researchers by providing state-of-the-art facilities, support, and resources. The NNIN is an integrated partnership of fourteen U.S. universities (http://www.nnin.org) which provide user support and resources for NSE researchers. We also have a networked education agenda which offers a variety of programs for school-age children through adult professionals. Our goals are to develop a nano-ready workforce, excite students about STEM, and develop a nano-literate public. Our outreach starts with elementary grade students and teachers and spans to adults in need of retraining and skill enhancement. In addition we have a Societal and Ethical Implications portal which has resources related to the responsible conduct of research (http://www.nnin.org/society-ethics).

To reach NNIN's goals we have established a variety of programs which include: Research Experience for Undergraduates (REU), international Research Experience for Undergraduates (iREU), Research Experience for Teachers (RET), international Research Experience for Graduate Students (iREG), teacher professional development workshops, technical workshops and symposia, online equipment training videos, K-12 outreach programs, NSE lessons for K-14, NanoExpress (a mobile nano-laboratory), and *Nanooze* (website, children's magazine, and exhibits at Disneyworld and Disneyland).

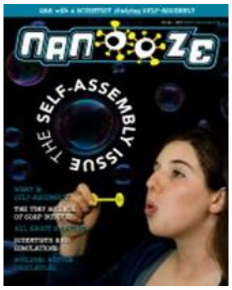
To learn more about our programs, one should visit our web site http://nnin.org/. There you will find information on our REU program (http://www.nnin.org/research-experience-undergraduates) which includes videos of student presentations at our end of the program convocation along with the *NNIN REU Research Accomplishments* –a publication of student research papers. The publication also includes the results of research done by our iREUs at Japanese and European labs.

Our education portal (http://www.nnin.org/education-training) is the primary source for our K-14 programs and resources. There you will find our searchable database of over 70 lessons for the classroom.



The majority of these lessons have been developed over the last ten years by our RETs -creating lessons developed by teachers for teachers. All lessons have been tested in the classroom and are tied to National Science Education Standards and Next Generation Science Standards.

Also on the education portal is *Nanooze* our web site for students in grades 5-8. *Nanooze* comes in three formats: a website, a magazine, and an exhibit housed at booth Disney sites. *Nanooze* began as a web based magazine (http://www.nanooze.org/), with kid-friendly text, topics, and games. It is designed for grades 5-8 but we have found that even high school students enjoy the magazine. The web edition of *Nanooze* is available in English, Spanish, and Portuguese. *Nanooze* has evolved into an 8 page printed "magazine" that is distributed directly to schools in hard copy. This children's science magazine is related to physical sciences and in particular nanotechnology. A total of 13 issues are available online or in print version, each with colorful graphics and interesting stories written at an accessible level. They are used as enrichment material at all levels from elementary to high school. Teachers may request classroom packs of any or all of these issues - free of charge (email – info@nanooze.org). Five issues are available for download in Spanish.



The NNIN site at Howard University has a mobile nanotechnology laboratory called NanoExpress. This 208 square foot lab is designed to facilitate hands-on experiments but is also capable of doing nanotechnology research. Experimental areas include: Introduction to Passive Nanoparticles, Introduction to Self Assembly, Introduction to Micro and Nanofabrication, “Chips are for Kids”, Instruments for NanoScience, Shape Memory Alloys, and Soft Lithography. The van primarily visits metro DC and East Coast locations. More information can be found at: http://www.msrce.howard.edu/nanoexpress.html.

As part of NNIN’s training of nanoscale researchers (including undergraduates, graduate students, and post-docs), NNIN provides on its website numerous equipment training videos http://nnin.org/education-training/graduate-professionals/equipment-training. These are viewed by researchers worldwide on how to use equipment found in our cleanrooms. The website also contains technical lectures and materials on special topics covered during our Winter Schools.

E.10. Nano in Nature K-5 STEM Textbook – Blended Learning
Judith Light Feather, The NanoTechnology Group

The NanoTechnology Group Inc
Consortium for Global Education

The NanoTechnology Group Inc.
Consortium for Global Education
7898 West State Hwy 7
Nacogdoches, TX 75964
www.TNTG.org
www.NanoNEWS.TV

PRESIDENT
Judith Light Feather
Judith.LightFeather@TNTG.org
936-652-3006

BOARD OF ADVISORS
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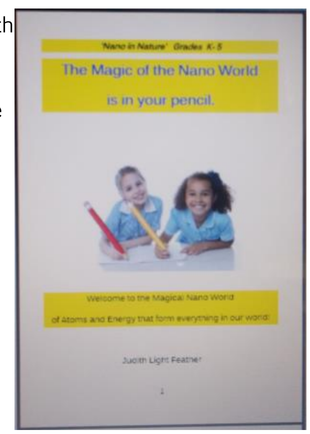
Milind.Pimprikar@CANEUS.org
514-499-3959

EU Representative
Edu &Technology Outreach
Heinrich Becker
HTCBecker@yahoo.com

NSEE Workshop – K-12 Panel -December 11-12, 2014

'Nano in Nature K-5' STEM textbook – Blended Learning

New STEM textbook combining the geometry of mathematics required in K-2, and the tiny world of nano science, is designed for blended learning. Visual and interactive elements show the movement of energy at the atomic level, where geometric shapes form the patterns in nature. Nanotechnology development is already changing our world in communication, enhanced materials, medical solutions, robotics, automotive, energy and space.



Teachers and students can expand their knowledge with videos, including a classroom experiment with the graphite in a pencil. The graphene component of carbon (C6) is visible with the atomic force microscope (AFM) of six atoms forming the hexagon shape at the nanoscale.

There are also two interactive components that students can control, showing the scales of science from the universe down to the plank scale, based on the math of the power of 10.

The book also includes four 'NanoMission' educational games to introduce bio-nanotechnology and the future of medicine at the nanoscale.

The Virtual Nano Lab at University of Virginia (UV), provides hands-on experience with SEM, AFM, and STM microscopes. The website has over 8 million global participants since it was introduced, and is one of the most important resources for all grades in K-12.

Our organization is an advocacy group that has promoted nanoscience education globally since 2002. With the advent of computerized education in the classrooms, these fantastic resources can now be utilized. The book will be published in January 2015. Review the PDF file and offer comments for back cover.

This is the first book in our series for K-5. A Teachers Guide PDF for the active links is free for download at: www.TNTG.org. The book has been published on Amazon in print version at: http://www.amazon.com/Magic-Nano-WorldpencilNature/dp/1507695349/ref=tmm_pap_swatch_0?_encoding=UTF8&sr=&qid= and the e-book version at: http://www.amazon.com/dp/B00TA2SVX2/ref=rdr_kindle_ext_tmb.

E.11. Nanoscale Video Lab Manual

Dr. George Lisensky, Beloit College

An online Video Lab Manual has been developed to illustrate more than thirty laboratory experiments involving nanoscale science and technology. While the original goal was to make these experiments accessible to students and teachers who were not familiar with the field, selecting the internet as a distribution medium made a non-traditional lab manual possible. Having high quality HTML5 videos available that show each step of the experiment means that the accompanying text can be considerably shortened and that these directions look more like a published procedure than a student manual. Since the Video Lab Manual only includes the procedure, the online portion of the experiments are useful at a variety of levels when instructors provide the context. Experiments have been developed, refined and class tested at several institutions, and this resource has been widely used by others around the world.

http://chemistry.beloit.edu/edetc/nanolab
http://education.mrsec.wisc.edu/271.htm

Two different versions are available online, developed with support by the University of Wisconsin Materials Research Science and Engineering Center, NSF DMR-1121288.

E.12. NanoTeach: Professional Development in Nanoscale Science
John Ristvey, UCAR formerly McREL

McREL International with Stanford Nanofabrication Facility, Georgia Institute of Technology, ASPEN Associates and the National Nanotechnology Infrastructure Network (NNIN) developed and tested *NanoTeach* http://www.mcrel.org/NanoTeach/index.asp, a professional development (PD) model for teachers that combines an **instructional design framework** with **nanoscale science content** using **multiple delivery methods** for high school science teachers. NS&T deals with science phenomena at the nanoscale where materials exhibit different properties than bulk materials thereby providing applications that can benefit society. The nine big ideas in NS&T that were the focus of the NanoTeach program are: (1) size and scale; (2) structure of matter; (3) size-dependent properties; (4) forces and interactions; (5) self-assembly; (6) tools and instrumentation; (7) models and simulations; (8) nano and society; and (9) quantum mechanics.

Research Question #1: Does the *NanoTeach* facilitated PD improve teachers' ability to integrate NS&T content into their classes in a manner that promotes student understanding?

Research Question #2: To what extent is the approach utilized in *NanoTeach* a viable approach to the development of PD materials and experiences that support integration of NS&T in high school science?

Methods: The research design included a pilot test experience, revision process and a field test experience with cohorts in both facilitated and team-study models. The *NanoTeach Teacher's Guide* and accompanying Google sites were designed for team-study (self-paced teams) and for use in a facilitated (face-to-face) PD model. Both groups participated in 80 hours of summer experiences with school-year interactions prior to fall and spring lesson implementations. The pilot test (2010-2011) was conducted with teachers from a national sample. The field test (2012-2013) was conducted with teachers from four locations (Colorado, Texas, Georgia, and Louisiana).

Intellectual Merit:

Outcome 1: Teachers will be able to integrate NS&T content into their classes in a manner that promotes student understanding. Findings include:

- Teachers in the facilitated and team-study approaches were equally prepared to teach the NS&T topics they had selected for their *NanoTeach* lesson.
- Teachers in both study groups *reported emphasizing* learning basic science concepts, science investigation skills, and preparing students for further study in science as their key learning goals.
- Students and teachers in both study groups reported implementing a variety of effective teaching strategies during the implementation of their *NanoTeach* lessons.

Outcome 2: Students in classrooms where teachers implement effective NS&T lessons will report high levels of interest and engagement.

- Teachers and students in both the facilitated and team-study approaches reported high levels of engagement and interest in learning science and NS&T.

Outcome 3: Teacher knowledge of NS&T will increase over the course of the project.

- Teachers in both the facilitated and team-study approaches demonstrated statistically significant *moderate to large gains* in their knowledge of NS&T from pretest to posttest.

Outcome 4: Teacher knowledge of effective instructional strategies will increase over the course of the project. Findings include:

- Data from practice guides showed that teachers from both study groups were able to effectively implement lessons using the DESI instructional strategies.
- Case study teachers from both study groups indicated that they struggled with:
    - Clearly connecting NS&T learning goals to their curricular science concepts.
    - Formatively assessing student understanding throughout the lesson.

- Guiding sense-making and discourse during inquiry-based lessons leading to conceptual understanding.

Outcome 5: Feedback from the *NanoTeach* team, partners, and teachers identified key features that benefited all participants.

- Connecting with experts and other teachers through *face-to-face interactions* and *real-time online meetings was clearly beneficial for all teachers*, and being able to share and ask questions was essential.
- *Peer groups of at least 3 teachers within the same school building* helped facilitate learning. *Self-paced work needs to be kept to a minimum, interspersed with other real-time interactions, and supported through more videos and access to other resources*, including expert advice on NS&T content and pedagogy.

Broader Impact: *NanoTeach* significantly contributed to the pool of teachers trained in NS&T, with 80 teachers completing the program. Data were collected from over 2000 students indicating science engagement with the NS&T lessons. The national cohort of teachers learned to teach NS&T in a manner that promoted deep student understanding and they also became ambassadors and mentors for integrating NS&T in high school classrooms in 20 states. Many teachers reported that the program inspired them to be better teachers and teach important emerging science concepts. The *NanoTeach* PD model was widely disseminated through presentations and publications including NSTA state, regional and national conferences, the National Association for Research in Science Teaching, and through a video collaboration with Hitachi reaching over 55,000 viewers. The project model and model lessons will be sustained through partners from NNIN. *NanoTeach* includes crosscutting concepts, science and engineering practices and disciplinary core ideas included in the Next Generation Science Standards. The PD model and resources are available to teachers and support both NGSS and STEM teaching and learning.

E.13. NanoExperiences: Pathways to Workforce Success

John Ristvey, UCAR formerly McREL

NanoExperiences: Pathways to Workforce Success is an Innovative Technologies Experiences for Students and Teachers (***ITEST) strategies project*** designed to support ***high school students*** in multiple science, technology, engineering, and mathematics (STEM) career pathways related to ***nanoscale science and technology (NS&T).*** McREL International (McREL) and project partners (Education Northwest and Stanford Nanofabrication Facility with external evaluator, Biological Sciences Curriculum Study (BSCS)) developed and evaluated *NanoExperiences*, an out-of-school-time (OST) program that combines diverse learning experiences that introduce emerging STEM content buttressed with additional supports—motivating students by establishing high expectations and deepening background knowledge—to prepare high school Career and Technical Education (CTE) students for postsecondary learning and credentials leading to participation in the STEM workforce. Through the spring (NanoSurvey), summer (Nano@Work), and fall (NanoSymposium), students work *locally* and *remotely* with nanotechnology researchers and professionals as they pursue a personal project, conducting investigations and preparing a final presentation. The project goals are to: (1) increase student knowledge of NS&T content, (2) increase student foundational knowledge, skills, and dispositions for academic and career success, (3) increase student interest in and motivation for participating in the STEM workforce, and (4) develop a replicable model for states to develop programs that prepare students for the STEM workforce.

Intellectual Merit. *NanoExperiences* advances substantial investments that the National Science Foundation (NSF) has made in NS&T and builds on the existing findings and resources generated from these projects, including *NanoLeap* and *NanoSense*. The project also builds upon McREL's long history in STEM education and out-of-school-time programming and two NSF-funded projects: *A NanoLeap into New Science* (#ESI-0426401) which developed NS&T modules for high school students, and *NanoTeach: Professional Development in NanoScale Science,* which targets the needs of STEM teachers in emerging sciences (# DRL-0822128). The project addresses several critical needs: reaching students with emerging STEM content *before* they have chosen career pathways; providing additional supports for students that helps them to pursue postsecondary learning for middle-skills jobs in the STEM workforce; meeting the demand for an educated middle-skills workforce in emerging sciences; and addressing critical reform areas in CTE—rigor, relevance, and relationships.

Broader Impacts. The project targets CTE programs, a significant component of the U.S. high school experience, and a growing national industry need for an educated "middle-skills" workforce in emerging sciences such as NS&T. This strategies project designed a model for immediate replication across Colorado and for eventual scale-up across the nation. The resulting *NanoExperiences Toolkit* provides ready guidance for Colorado high schools to replicate the program across the state with project advisors, including the Colorado Community College System (a critical link between K-12 CTE programs and postsecondary options), positioned to support these sustainability efforts. Further, the model is designed around the big ideas of NS&T to make the program adaptable to various contexts, including different states and/or STEM content areas. Project advisors who are interested in taking this strategies project to scale across the nation provide guidance to ensure the program is replicable and collaborate on future scale-up efforts.

Field Test Results. The field test year of the *NanoExperiences* project included a full test of the program in four participating high schools in the Denver Metro area. While there was significant attrition during the field test year, similar to the pilot year, external evaluators from BSCS were able to collect key data from a group of students and teachers that participated in *NanoExperiences* all the way through the program, providing valuable summative information. The field test year reflects the final year of the iterative process for design and implementation the *NanoExperiences* program, and it also allows us to better understand which characteristics of the program were most effective and engaging for students.

Throughout the implementation of the field test, the project staff used the information gathered both by the evaluation and conversations with the facilitators and coordinators to tailor and adjust the program to ensure higher engagement from students and facilitators.

- Similar to the pilot year results, students enjoyed all three components of the *NanoExperiences* program, but survey responses indicate that students were most impacted by the Nano@Work and NanoSymposium portions.
- The students, facilitators, and parents that were able to participate in the business partner experiences (Nano@Work) reported that it was an important experience for students.
- Facilitators and Parents were also very impressed with the NanoSymposium portion, specifically the NanoExpo, as it encouraged students to think through their individual NS&T projects and present the results to a large mixed audience of peers, parents, and business partners. NanoSymposium allowed students to show their abilities at communicating in scientific ways.
- The NanoSurvey proved to be a good learning experience for students; however, students wanted more hands-on experiences and real-world applications of nanotechnology.
- Students entering *NanoExperiences* already had a favorable attitude toward attending college and pursuing a STEM career; however, their motivation and attitudes toward careers improved during the program.
- Throughout the entire project, project staff has remained diligent in their efforts to adjust the program to best fit the needs of the participating schools.

Conclusions. The *NanoExperiences* project benefitted tremendously from the lessons learned during both the pilot and field test years of the project. While there was some difficulty with retention of students, staff turnover, and inconsistence data collection, overall, the project was a great success among students from all four school sites. The program's on-line platform (for both student and facilitator/coordinator components) allowed greater flexibility in delivery and engagement. The project staff made adjustments throughout the year to improve the program for all participants involved. Throughout the program, students indicated high levels of interest and satisfaction with NanoEx. Nano@Work continues to be the most influential portion of the program, although NanoExpo garnered very positive reviews as well. The background knowledge NanoSurvey evolved was integral to the success of the rest of the program. Students, parents and facilitators noted the value of real-world STEM contexts as key to its positive impact. Moving forward, it will be important to consider ways to increase the student efficacy within NanoSurvey so that it offers the depth of engagement of the other two parts of the program. However, the success of the curriculum and strategies to engage students in learning nanoscience and technology are clearly evident throughout the program.

E.14. Every Child a Maker
Dr. Lisa Regalla, Maker ED

Maker Ed's mission is to create more opportunities for all young people to develop confidence, creativity, and interest in science, technology, engineering, math, art, and learning as a whole through making. Maker Ed realizes the profound effect that educators, youth-serving organizations and communities have on the skill-development and life trajectory of underserved youth and strives to reach these audiences through professional development, community building, and dissemination of effective program models and educational research efforts. All of our efforts focus on advocacy by increasing awareness and understanding about making and its potential impact on student engagement among local stakeholders.

PROFESSIONAL DEVELOPMENT

Experienced organizations consistently reiterate the importance of investing in **people** (educators, mentors, coaches) to skillfully guide youth through making experiences. By providing adaptable professional development opportunities, Maker Ed seeks to diversify and expand the network of makers, mentors, and community leaders. Audiences include, but are not limited to: classroom and pre- service teachers, librarians, museum educators, college students, and volunteers. Maker Ed meets educators where they are and promotes their continued growth through professional development components such as:

- Collecting, documenting and sharing key **principles and practices** for facilitation of meaningful making experiences.
- A series of **modular online trainings** that address topics such as: facilitating youth-driven experiences, outfitting a makerspace, coordinating programs and clubs, understanding and facilitating a project arc, preparing for a showcase event and documenting the making process.
- I**n-person workshops** allowing educators to experience hands-on making, explore various models of making programs and makerspaces, and connect with other maker educators in the field. Another series of in-person workshops will focus on a "train the trainer" model to empower others to lead professional development opportunities in their own communities.
- A **Possibility Box** filled with tools and materials designed to spark exploration, experimentation, and projects.

COMMUNITY BUILDING

By being a safe environment where youth can imagine, explore and drive their own learning, **community makerspaces** foster quality experiences independent of the type of project or tools used. Maker Ed nurtures a national, distributed network of organizations, leaders and community connectors to increase opportunities for **all** youth to engage in making activities.

Key focus areas include:

- **Highlighting and connecting** groups of diverse partners that are committed to transform research into practice.
- Hosting an **online community** for sharing projects and practices and cultivating relationships with fellow maker educators and Maker Ed staff.
- Providing **seed grants** for needs associated with establishing sustainable makerspaces and providing making experiences for youth.
- Offering strategies and support to help communities recruit **volunteers and mentors** to facilitate maker programs and coach youth.
- Promoting and maintaining a collaborative **directory** of youth-serving makerspaces and programs nationwide.

MODEL SHARING
Successful implementation employs planning and carefully selected materials and tools through program **models** that are nurtured by accessible resources and supported through educational research. Maker Ed documents the work being done at the local and national level and shares it with the greater field.

Areas of involvement include:

- Building a field-wide understanding of best practices for **youth makerspaces** in a variety of settings.
- Developing **program models** for youth maker clubs.
- Establishing and sharing a common set of practices for **portfolio** creation, reflection, sharing, and assessment.
- Creating **case studies** that outline the "ingredients" necessary to build and sustain thriving maker communities with a focus on high needs areas.
- Collecting a robust set of best practices, program models, tools and materials, project ideas, and relevant research from the larger maker education community to share on Maker Ed's online **Resource Library**.
- Outlining best practices around educational **convenings** that can be replicated at the local level.

Maker Ed has a track record of successfully engaging diverse organizations to work toward a singular goal of promoting creative confidence in youth and is in a unique position as a thought leader in making in education. By connecting research to practice, providing professional development, creating and disseminating relevant resources and providing support through a community of practice, Maker Ed aims to realize its vision: Every Child a Maker.

E.15. Nanotechnology Education Activities
Dr. Kevin Walsh, University of Louisville Micro/Nano Technology Center

Nanotechnology Educational Activities
University of Louisville MicroNanoTechnology Center
(louisville.edu/micronano)
Prof. Kevin Walsh (walsh@louisville.edu)

KY Nanonet (kynanonet.org)

The Kentucky NanoNET (KYNN) is an educational web-based portal which coordinates all the micro and nanotechnology activities within the state of Kentucky. It began in 2008 through funding received from the NSF EPSCoR Program. The KYNN remains active today. The site identifies all the sites in the states (i.e. nano-nodes) which are involved in nanotechnology and it also provides nanotechnology services to its users. Through the KYNN web interface, one can have custom photomasks generated for the production of MEMS, microelectronics and nano-devices. The KYNN also serves as a portal for some of the more popular nanotechnology/MEMS software tools for layout, modeling and simulation. Other features of the KYNN include searchable data bases for equipment and researchers in the state, an online calendar of events, social media support, and basic information and videos about nanotechnology.

NanoDays with the Kentucky Science Center (KSC)

Nanodays is an annual event sponsored by the NISE (Nanoscale Informal Science Education) network which celebrates the nanosciences with educational programs about nanoscale science and engineering and its potential impact on the future. The University of Louisville via Dr. Walsh's KY nanoNET (Sponsored by Ky EPSCoR Grant # 0814194) has been a partner with the Kentucky Science Center to participate in this annual event since 2009.

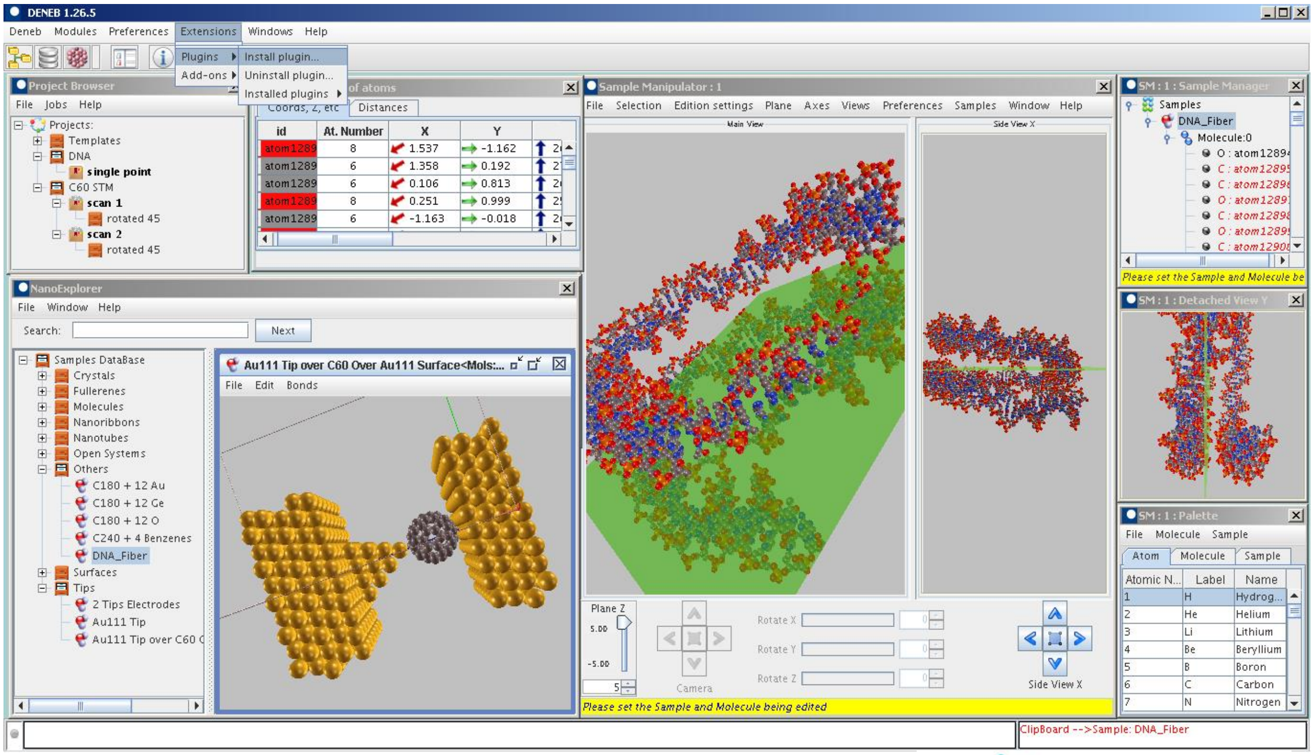
Tiny science lessons turn out to be big fun

Cleanroom Tours

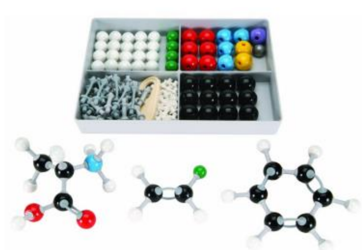
The University of Louisville is fortunate to have one of the top-ranked cleanrooms in the nation. It is an AGI-designed $30M 10,000 sq ft state-of-the-art facility. Through a carefully orchestrated collaboration with the Kentucky Science Center and the Engineering School's Development Office, we provide cleanroom tours and lectures to approximately 1,000 K-12 students a year. This is one the Science Center's more popular events. We have also installed a custom interactive touch-screen monitor outside the MicroNanoTechnology Cleanroom (MNTC) capable of providing self-guided digital tours for visitors of any age.

E.16. Experience the Nanoworld with Atelgraphics

Dr. José A. Torres; Dr. Lerwen Liu, NanoGlobe Pte Ltd



Do you remember the molecular modeling kits? It looks like this:



The shiny colorful balls in the box are atoms. When arranged in different geometries, atoms form molecules. This is a very nice toy to communicate your ideas: --"Look Bob, this is the molecule I am talking about", and you assemble in front of Bob the molecule you mean to show.

Nevertheless, it is sometimes not practical, or not quite enough, for several reasons:

- You usually cannot carry it with you. So most of the time you cannot show your new molecule idea simply because the kit is not at hand.
- You run out of C atoms again! Yes, as soon as you need to make a larger structure, a carbon nanotube for example, you use them all and you are only half way through.
- The links between atoms are sticks at certain angles, but new studies reveal new nano-things where those angles are not necessarily so … and you want to show that new model.
- The links between atoms are sticks of certain lengths, but you really want to model longer or shorter distances in many occasions (stretching a nanowire for example).

- Single plastic sticks or double sticks are ok, but they are crude representations of electron densities ... Yes, you really would like to see what the real shape of the electron cloud is that glues atoms together. What is the shape of the molecular orbitals?
- "I sometimes want to increase the size of some atoms or bonds just to highlight some parts", I would be happy even by being able to change the black color by a dark grey of just some of the C atoms, not all of them (for example)
- Once I have my molecular model defined ... how I wish that it would tell me how chemically stable it is, how hard or elastic it is, what are its vibration frequencies and modes, I wish to see it vibrating at low temperatures, and … why not, I want to see it breaking when overheated …

But of course many of these things I can only imagine …
Or do I?

All the above are easily overcome by **DENEB**, the software that spells modeling freedom and power in a 3D virtual space.

- ✓ No need to carry extra weight, it is in your personal computer.
- ✓ Never run out of C atoms, or any atom, your atom-box is endless.
- ✓ Place the atoms at will not constrained by certain angles and lengths.
- ✓ Place them with accurate mouse pointing or by accurate coordinates input.
- ✓ Customize radii and colors of atoms and bonds.
- ✓ Store and classify in several effective ways all our created molecular models.
- ✓ Share by email (for example), import models from your friends.
- ✓ Import models from standard data bases of molecules.
- ✓ Combine old models easily, cut them, paste them, duplicate them …
- ✓ **Go way beyond molecular modeling and displaying:**
  - ✓ Model periodic structures (crystals, surfaces, wires)
  - ✓ Click to recalculate and display all bonds at once
  - ✓ Click to trigger a quantum mechanical calculation that will give results for your model:
    - ✓ Its chemical stability
    - ✓ Its mechanical properties (elasticity, hardness)
    - ✓ Its electronic density (molecular orbitals, crystal orbitals)
    - ✓ Its motion, its vibrations with temperature.
    - ✓ Its magnetic properties
    - ✓ Others (Electronic transport, band structures, … all the way to professional level accuracy and details)

About Atelgraphics

Atelgraphics is a young company, founded in 2012, that recently became a member of the *Science Park of Madrid* (www.fpcm.es) the major incubator of edge-technology based companies supported by major public and private institutions (Universidad Autónoma de Madrid, Universidad Complutense de Madrid, Banco Santander, CSIC, etc ...).
Atelgraphics products are developed based on a few decades of research in quantum physical chemistry, atomistic simulations, and software design, as performed by its founding team.
Atelgraphics has recently won, in a competitive contest, a 3-year funding by the *Spain's Ministry of Science and Technology*. Its current business phase aims to attract extra funding to be able to enhance and expand its business scope in a dynamically ever growing nanotechnology-driven research and education market.

For more information refer to www.atelgraphics.com.

Atelgraphics make science sense
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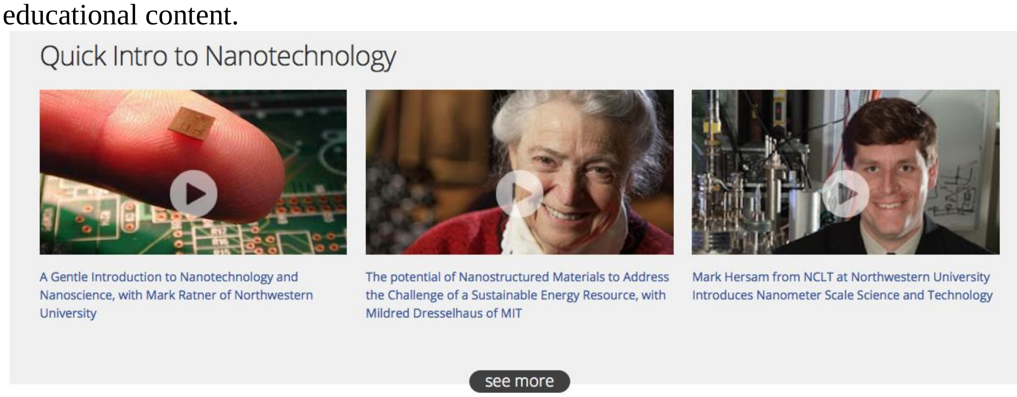
UNIÓN EUROPEA FONDO SOCIAL EUROPEO
El FSE invierte en tu futuro

E.17. Nanoeducation Activities
Dr. Tanya Faltens, nanoHUB.org

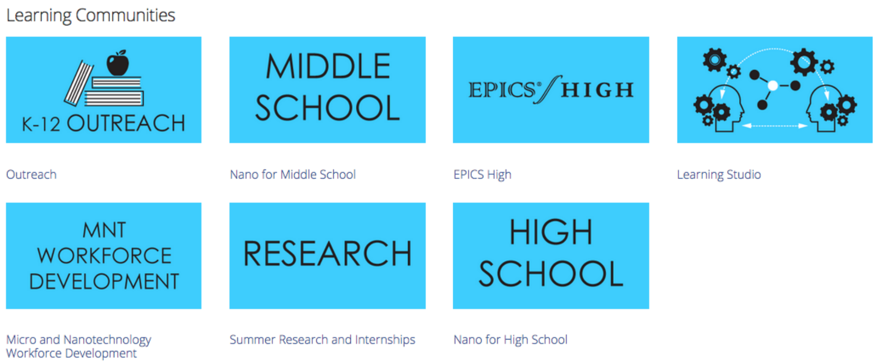
nanoHUB is an open-access science gateway that provides the ability to run simulations via a web browser as well as high-quality, cutting-edge educational resources related to nanotechnology and supporting areas. Established in 2002 and funded by the US National Science Foundation, nanoHUB's mission is to support the National Nanotechnology Initiative through its evolving cyber-platform for sharing research and educational resources with a diverse user community. nanoHUB.org is the world's largest virtual nanotechnology user facility, with over 300,000 users annually who use an ever-growing collection of 4800+ resources, including over 360 simulation tools. Many nanoHUB simulations are research-quality: nanoHUB simulation tools have been cited in over 1200 publications, of which over 1000 are research publications.

nanoHUB's paradigm integrates research and education from individual laboratories with the global community to provide resources that range from simulation tools, to online research presentations, to complete, self-contained courses that include assignments and simulations that can be used in the classroom or for self-study. Materials available cover a wide range of topics related to nano-science and engineering, including but not limited to nanoscale transport modeling (electronic, optical, and thermal), nano-materials (including quantum dots, quantum wires, and 2DEGs), nano-engineered devices (including NEMS, batteries, thermoelectrics, and photovoltaics), nano-scale biochemistry, and nanoscale characterization (including atomic force microscopy). Much of nanoHUB's educational content is at the graduate or advanced undergraduate level, but increasingly content at the first-year undergraduate and K-12 levels are being added to the resources.

nanoHUB's education page, https://nanohub.org/education, is a good entry point for users interested in educational content.



The educational page directs users to several sections, starting with overview videos that provide an idea of what the nanoscale is, and challenges that nanotechnology can address. Subsequent sections provide full courses arranged by topical area, direct links to the most popular simulation tools used for education, learning packages that contain sets of simulations that are topically related along with tutorials, assignments and other supporting material. Finally, there are Learning Communities, where educators and learners interested in K-12 education, undergraduate education, nanotechnology workforce development, and outreach can share resources, such as nanoHUB's modeling and simulation activity for elementary and middle school students, https://nanohub.org/resources/20667, and nano engineering projects in community service created through EPICS High https://nanohub.org/groups/epics, one of nanoHUB's partners.



nanoHUB's education team has been studying "how people learn nano," and the educational material they have developed, as well as research publications, are available on the Nano Education Research Page: https://nanohub.org/groups/edresearch.

Simulations, and their underlying mathematical models, are a unique component of nanoHUB's educational portfolio. The complexity of the 21st century problems that science and engineering students will be challenged to solve is such that simulations are becoming an increasingly important type of tool to understand, and should be introduced to students early on in their educational path. As a first step in this conceptual development process, the education team's research projects have created and studied first-year engineering nano Model Eliciting Activities (MEAs). MEAs are active, team-based projects where student teams create, communicate and evaluate their own mathematical models within a problem-solving context. Nano-focused MEAs have been used and studied with thousands of first year engineering students. The INSPIRE Research Institute for Pre-College Engineering http://www.inspire-purdue.org/ has recently teamed with nanoHUB to study nano-themed MEAs created for middle school students.

Other research projects are a nano-focused simulation design project and investigations that look into how undergraduate students understand concepts of size and scale and how students relate nanotechnology to their own lives and fields of study.

nanoHUB's signature educational product, nanoHUB-U https://nanohub.org/u provides short courses on cutting-edge topics that might not yet be available in current textbooks. These courses are aimed at working engineers continuing their education, engineers retraining for re-entry to the workforce, and upper division undergraduates or graduate students. Many of the nanoHUB-U courses incorporate simulations. The topics cover a wide range, from nanoelectronics to photonics, materials, nanobiosensors and atomic force microscopy. The latest nanoHUB-U courses are currently being offered in partnership with edX through PurdueX: https://www.edx.org/school/purduex.

E.18. Bringing Nanotechnology Content to over 30,000 Students: The Process Journey

Deb Newberry, Nano-Link, Dakota County Technical College, MN

Nano-Link is a National Science Foundation funded Center for Nanotechnology Education. Comprised currently of 15 components, Nano-Link is an alliance of high schools (2), colleges (12) and universities (1). The primary focus of Nano-Link is the creation of nanotechnologists (nano savvy employees) to meet the needs of industry. Within the Nano-Link Alliance over 30 nano specific college level courses have been created and are available at no charge for use. We primarily work with community colleges to help create programs that train students in the skills, knowledge and abilities required by companies involved in nanoscale work. This work can include materials science, electronics, coatings, biotechnology and energy. Technicians can work in laboratories, as independent technicians or as a part of a research or product development team.

In order to create the required technicians, a career pipeline needs to be created. Often these pipeline efforts involve student focused activities such as classroom presentations, tours to research facilities, workshops, camps and other similar outreach activities. Initially, Nano-Link followed the same path but with relatively little success – both in terms of the numbers of students reached and the impact on the students – that is, many of the participating students already had an interest in science and STEM and the various activities merely added or enhanced their interest. This is not a bad result, but the target audience should be much broader. The desired audience is actually students who are perhaps unaware of the options available in STEM or science careers, specifically nanotechnology – of students who may like science and math but have somehow been led to believe that they are not qualified, i.e., smart enough to follow a science career.

Based on the relatively small student population reached by the traditional approaches, as well as noting that there was a much larger student audience that can be reached, Nano-Link, through the Synergy Project, chose to reach the students via the educators. This approach was based on the fact that many educators truly are student mentors and guides and also would provide access to a great number of students at all levels of science. The initial Nano-Link approach involved providing educators with a great deal of technical content and slides to be used in class. Instruction for educators was provided in the form of multiday workshops at a central location. Even with the focus on educators reaching students the implementation rate for educators including nanotechnology content into their classes was low.

At this point in the effort, Nano-Link decided to survey the "customer" base. A survey was executed and responses from 250 high school and college educators showed what was desired to integrate nanotechnology content into their classes was that the content should be hands-on, fun, take 1 class period, cover basic nano and science concepts and be easy to implement. Based on these survey results Nano-Link completely modified the approach not only with regard to the content but also with respect to the professional development for the educators. This was the beginning of the Nano-Link "Nano Infusion Project" in 2009.

First, the nanoscience content was modified to include and activity. Starting with that activity, text was written that included correlation to nano and traditional science concepts, background information on the module focus topic, procedure for the activity, nano specific slides for presentation, application examples and a list of additional resources such as articles and videos. So what at one time was a rather dry, lengthy, lecture intensive nano content, the Nano Infusion Project provided content to educators in an activity based, topic specific, complete modularized package that met their needs.

The approach toward educator training was also modified. For the first few years we reached many educators through short 1.5 to 2.0 hour workshops at educator conferences. In 2013, Nano-Link began offering the option for educators to host a workshop at their location. The workshops are 6 to 8 hours in duration and educators learn and practice 8 to 10 of our most popular modules (over 20 modules are available). The impact of these shortened, home location based workshop is that the educators are more comfortable with the materials and concepts and the implementation rate is over 50%.

Through these two process improvements, Nano-Link has facilitated 15 workshops in over 10 states involving more than 190 educators. Through these workshops and educators that learn about the Nano Infusion modules in other ways, Nano-Link has provided content to over 300 educators who reach over 32,000 students. For data collection, educators fill out a survey after the completion of a module and for high school students, they also fill out a short survey. These surveys are used to assess the effectiveness and usefulness of each module.

We are currently adding NGSS alignment also creating culturally aligned module content for the Native American student base. This truly has been a successful process modification effort and we will continue to look for ways to improve the process.

E.19. I am Nano – Expanding the Scale of Understanding

Daphne Schmidt, MathScience Innovation Center, VA

MSiC
MathScience Innovation Center
Imagine. Create. Lead.

The MathScience Innovation Center (MSiC) is a leader in STEM education in the Central Virginia region with a knowledgeable and dedicated faculty and meaningful community partnerships. Through our 49 year history and a strong focus on mathematics and science, we are uniquely situated to provide high level, futuristic STEM (science, technology, engineering and mathematics) content for students and teachers. We are solid in our work, yet nimble in the development of new programs which meet division, higher education and industry workforce demands.

As the only regional math and science center in Central Virginia, we are affectionately called "the hub" and we are enthusiastically supported by our consortium members divisions, teachers and parents. With strong support, excellent programming and commitment to the educational and economic vitality of the region, we reach over 130,000 students and 3,000 teachers (and increasing) each year. We inspire students and teachers through our inquiry-based weekday and Saturday programs, and provide extended opportunities for individuals to follow their passions and expand their learning through our summer programs, Fellows Institutes, virtual lessons and other professional development opportunities. Here at the Center, students and adults gather to share and learn more about epigenetics, fractals, research design, the science of racing, computer programming, advanced manufacturing, the complexities of the number system, geocaching, issues affecting our region including ecological, environmental and energy, and more.

The MathScience Innovation Center began work on a multiyear nanoscience initiative in the summer of 2007. This initiative has grown to include workshops and conferences for teachers, model classroom lessons, and special enrichment courses and conferences for students. The MSiC Nanoscience curriculum includes ideas and concepts that explore size and scale, the structure of matter, size-dependent properties, tools and instrumentation, forces and interactions, models and simulations, quantum effects, self-assembly, and nano and society through more than fifty lessons and activities for students in grades 6-12. Thousands of students in the region engage in nanoscience lessons in their classrooms delivered by our MSiC educators as well as their own teachers. Since 2010, more than 250 middle school students also participated in our Summer Regional Governor's School 8 day course, "I am Nano" and our week long Camp Innovation course "Nanotechnology: Science of the Small".

In the summer of 2009, the MathScience Innovation Center offered a two-week Fellows Institute for middle and senior high science teachers that included speakers from universities and a field trip to a local research lab. Major concepts taught in the institute came from a draft document developed by the National Center for Learning and Teaching in Nanoscale Science and Engineering (permission was obtained to use excerpts from the document). This institute received strong evaluations from participants and resulted in the implementation of existing nanoscience materials, the development of new nanoscience lessons by participants, and teacher-led workshops at the school, regional, and state level.

This initial offering was followed by a second Fellows institute in the summer of 2012.
In order to provide increased access to teachers (within and outside of our existing partnerships with thirteen school divisions), we developed and implemented a hybrid nanoscience program. This delivery

method combined face-to-face and virtual course sessions for our Big Ideas of Nanoscience & Nanotechnology Fellows Institute during the 2014-15 school year. Simultaneous to running this hybrid course, a small team of nanoscience educators here at the Center, trained five local teachers (who had done extremely well in our previous Nanoscience Fellows Institutes) as MSiC Nanoscience Adjunct faculty. The addition of this virtual component and implementation of the "train the trainer" model of delivery has allowed us to "scale-up" our Nanoscience initiative, both in outreach capabilities to community partners and by deepening the educational experience for our Fellows Institute participants and Adjunct Faculty. It is important to note that our adjunct faculty not only assist in the delivery of our nanoscience Fellows Institute 2014, but will also engage in community outreach programs teaching nanoscience to students who typically do not have access to these kinds of opportunities.

We are excited to continue to open up the world of nanoscience and nanotechnology to students and teachers in Central Virginia. A critical mandate for the MSiC as the regional hub for STEM learning is to take concepts such as nanoscience and nanotechnology and build a framework of vertical learning experiences for both students and teachers that will prepare students for future challenges, as well as for college and career fields. Along with content, the Nanoscience & Nanotechnology program at the MathScience Innovation Center provides opportunities for teachers and students to work in teams, collaborate, and communicate their work—these are the very dispositions that education and industry leaders demand.

For more information on the MathScience Innovation Center and the Big Ideas of Nanoscience Initiative, please visit our website, www.mymsic.org

E.20. Nanoscience in Korea

Dr. Jo-Won Lee, Hanyang University, Seoul, Korea

Korea has been heavily investing to develop nanotechnology as a growth engine for a creative economy. Since 2001, the heart of the Korean nanotechnology drive has been the Korea Nanotechnology Initiative (a 10-year rolling plan). It is now in its third stage. This long-term plan pushes ahead in three areas - R&D, infrastructure, and manpower. Education is deemed one of the most important areas to secure long-term national competitiveness. In 2014, the government allocated approximately $557M for the Korea nanotechnology initiative and 8.5 percent of the total (~$47M) was given to manpower. A variety of stakeholders have been actively participating in nanotechnology education with the goals of nurturing a skilled workforce and future R&D manpower.

The Korean Institute for Standards and Technology (KIST) operates a “nano-truck” equipped with SEM, AFM, and other instruments. It has engaged over one thousand attendees since 2013.

Six national nanofabrication centers are providing hands-on experiences with a variety of nano tools for graduate students, researchers at national labs, and private sector scientists/engineers.

Nanotechnology Education at Universities

- The number of nanotechnology related departments has jumped from 3 in 2001 to 73 in 2011 and to 146 in 2013.
- The number of undergraduate students enrolled in nano-related departments was over 19,000 in 2014, almost two times higher than in 2011.
- Eight textbooks have been developed for the undergraduate and graduate levels.
- Creative MS and PhD degree programs at Universities are being nurtured.

Beginning in 2005, the Korea Nano Technology Research Society (KoNTRS) has constructed an "e-nanoschool," with an on-line lecture series for undergraduate and graduate students, as well as for private sector researchers. These include:

- e-classes for on-line lectures on basic nanotechnology (twice a week for each subject)
- e-journal clubs for recently published research outputs (monthly)
- e-tutorials for state of the art nano subjects (twice for each subject)

A roadmap for nano-education looking toward 2025 is in progress

- With the rapid growth of nano-related departments at universities, a systematic governance for nano-education is becoming an urgent necessity
- With the increase in demand for specialized nano workforces, the reinforcement and the materialization of nano-education are necessary.

E.21. Creating a Learning Environment for Developing Safety in Nanotechnology

Drs. Walt Trybula, Jitendra Tata, Craig Hanks, Texas State University, San Marcos, TX and Dr. Dominick Fazarro, University of Texas at Tyler, Tyler, TX

Nanotechnology Safety Education is focused on preparing students to be able to understand, evaluate, address, and mitigate situations involving nanotechnology that might require remediation. The issue is that nanotechnology is relatively new in the history of science. With a conservative estimate of over 10^{200} different material characteristics that might be involved, a comprehensive listing of potential dangers will not be possible. But, this is not an acceptable situation. An example of this is the City of Berkeley December 2006 resolution requiring MSDS for all nanomaterials brought into the city for research. They did not exist at the time. In order to keep research moving forward, something needed to be provided to meet the regulations. Graphite and Carbon Nano Tubes are both carbon based. There are MSDS for Graphite. Is it a substitute? This will be a growing problem as novel materials are developed.

Tomorrow's engineers and technologists will also need to assume responsibility for establishing safe practices for working with nanomaterials and for safeguarding the environment. In the absence of specialized training in issues related to health, safety and environmental impacts of nanotechnology, the tendency will be either to focus only on the optimizing performance and cost while incorporating nanomaterials without regard to health and safety concerns, or to be overly cautious and avoid using nanotechnology.

To grow a workforce of nanotechnology safety personnel, higher education institutions must provide applied learning to how to test for nanoparticle dispersion in the work environment. There must be a connection with classroom learning of nanotechnology safety and applied laboratory activities. In order to realize the full potential of revolutionary nanotechnologies and at the same time minimize undesirable consequences, engineers and technologists need to be educated in how to judge health and safety risks, how to weigh ethical considerations, and how to make informed decisions. However, the majority of NSF-NUE funded projects have focused on teaching students about the development of products, devices, systems and/or nanomaterials. Few projects focus on undergraduate students learning the essential skills to measure, analyze, and determine what direction is need to protect workers.

Working under an NSF award, two courses, each containing 9 week long modules, were developed. The modular effort was required to be able to insert some materials into existing courses at Texas State University. At the University of Texas at Tyler, the entire courses were offered to the students. The contents of both courses are on the next page with details about the contents of the *Introduction to Nanotechnology Safety* course. The second course details are available for any of the principles.

As one will notice, the content of the courses might appear to be unusual for an engineering/science course. The need to enable the students to understand how to make ethical decisions must be included in the understanding of nanotechnology safety. Consequently, there are modules on ethics and societal impacts. Early on in the development of the initial effort, it was obvious that working with nanomaterials with unknown properties required a more complete picture of potential impact than only considering if the bulk material has been shown to be harmful.

For additional information about the courses, please contact Dr. Jitendra Tate (Texas State) or Dr. Dominick Fazarro (UT Tyler). Dr. Craig Hanks (Texas State) provided the guidance and development of the societal, ethical and environmental aspects of the program. Additional information is on the NSEE web site (http://nseeducation.org/2014-exhibition/ item #20 "Nanoscale Instructional Materials").

Course 1: Introduction to Nanotechnology Safety

- 1A) what is nanotechnology and nano-ethics?
  - Defining disciplines -Historical perspective (Richard Smalley) – ASTM E2456 terminology used in nanotechnology –National agenda: US congressional testimony on societal implications nanotechnology – Role of National nanotechnology initiatives (NNI) –Societal dimensions of nanotechnology.
- 2A) Ethics of Science and Technology;
  - Ethics at intersection of science, business, and governance – Science and technology as agents of social change – Moral agents: scientist and engineers, business community and corporations, policy makers and regulators – Nanotech's promise of overcoming humanity's more pressing challenges, -What products are produced?
- 3A) Social Impacts;
  - Defining ethical and societal implications: interest groups and meanings; spheres of impact and categories of concern; moral dimensions; pace, complexity and uncertainty –Technology revolution and problem of prediction –Precautionary principle in nanotechnology– Nanotechnology and privacy: instructive case of RFID –Nanoscience as catalyst for educational reforms –Impact of nanotechnology on developing countries.
- 4A) Ethical Methods and Processes;
  - Language of ethics – research in human subject research –Ethical framework for technology assessment -Model for ethical analysis – Describing the context: scientific and engineering; legal, regulatory, and policy; economic and market; environmental health and safety – Framing ethical questions – Assessing options for action – Finding common ground.
- 5A) Nanomaterials and Manufacturing;
  - Metal-based, carbon-based, dendrimers, and composites -Processes used (e.g. etching & laser ablation) - Framing ethical questions: principles of respect for communities, common good, and social justice – Assessing options for action.
- 6A) Environmental Sustainability;
  - Searching for a sustainable future – What are the issues of nanotechnology? –Context described: environmentalism and sustainability; environment risks and nanotechnology; potential benefits of nanotechnology for sustainable development –Applying life cycle thinking – Framing ethical questions.
- 7A) Nanotechnology in Health and Medicine;
  - What are the issues? –Context described: pharmaceuticals and therapeutics; diagnostics and imaging; nanoscale surgery; implants and tissue engineering; multifunctional nanodevices and nanomaterials; personalized medicine; broader health care system.
- 8A) Military and National Security Implications;
  - -Homeland Security -New era of Weapons of Mass Destruction (WMD)? –Context described: nanotechnology and art of war; nanotechnology and national security.
- 9A) Nanotechnology Issues in the distant future.
  - Challenges and pitfalls of exponential manufacturing –Nanotechnology and life extension -Who will control this technology? -Global implications.

Course 2: Principles of Risk Management for Nanoscale Materials includes the following: 1B) Overview of Occupational Health & Safety; 2B) Applications of Nanotechnology; 3B) Assessing Nanotechnology Health Risks; 4B) Sustainable Nanotechnology Development; 5B) Environmental Risk Assessment; 6B) Ethical and Legal Aspects of Nanotechnology; 7B Developing a Risk Management Program; 8B) Presentations of Paper or Case Studies; and, 9B) Hands-on Training on Using Safety Gear in Nano-manufacturing.

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