Workshop Report

International Benchmark Workshop on K-12 Nanoscale Science and Engineering Education (NSEE)

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Sponsored by the National Science Foundation

Dr. James S. Murday,
University of Southern California,
Workshop Chair

International Benchmark Workshop

on

K-12 Nanoscale Science and Engineering Education (NSEE)

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Organizers
The workshop was organized and directed by:

Dr. James S. Murday
Office of Research Advancement
University of Southern California
murday@usc.edu

Sponsors
The workshop was sponsored by:

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:

James Murday	University of Southern California
James Batterson	Advisor to VA State Education
Robert Chang	Northwestern University
Lisa Friedersdorf	University of Virginia
Robyn Gill	University of Southern California
Deb Newberry	Dakota County Technical College, MN
Elisabeth Nilsson	Lund University, Sweden
Fuh-Sheng Shieu	National Chung Hsing University, Taiwan
Robert Thomas	Department of Innovation Industry, Science and Research, Australia

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Table of Contents

Executive Summary

The many nanotechnology initiatives around the world have fueled the explosive growth in Nanoscale Science and Engineering (NSE) knowledge and in nano-enabled marketplace technologies.[1] As a result of this growth:

a. There will be a need for an extensive, informed, skilled workforce as nanostructures become the building blocks for materials and directed self-assembly becomes a viable manufacturing process. Estimates of the global market for nano-enabled technologies are in the $1T/year range by 2015, and $3T/year by 2020.[2]
b. Graduates from secondary school must have the background to meet the NSE knowledge expectation, reflected by the "Big Ideas" of NSE. The growing incorporation of NSE into 4-year University and College education, where innovation and critical thinking toward our future are nurtured, and the growing workforce need both compel attention at K-12.
c. Workers and members of the general public may be in contact with nanomaterials in various forms during manufacturing or in products. They should be sufficiently knowledgeable to understand the benefits and risks associated with the new technological capabilities enabled by NSE.
d. Nanostructures hold the potential to have significant new physical, chemical, and biological properties that will lead to innovative products. This new knowledge needs to become part of the K-12 educational corpus in order for our citizenry, workforce, business and regulatory communities to remain competitive in the global economy.
e. Nanoscale science and engineering is largely transdisciplinary. While challenging to the traditional science and engineering education taxonomies, NSE provides clear application-inspired examples of transdisciplinary innovation (Section IV of this report).
f. The nanoscale presents a novel view of the world, and nano-enabled solutions to societal problems are fascinating so as to attract students interested in Science, Technology, Engineering and Mathematics (STEM).
g. The National Science Foundation (NSF) and other funding institutions around the world have been paying attention to education at the nanoscale. There is a broad range of new NSE instructional materials, many of which are available as cyberinfrastructure resources. There are also NSE resources for the professional development of teachers.

When testifying before the House Science and Technology Committee in March 2008, Bill Gates identified the improvements our nation needs to implement if we are to maintain an innovative and dynamic economy. "Ultimately, we need to identify a smaller set of clear, high and common state standards that reflect what young people truly need to know to be successful in the 21st century..." Nanoscale science and engineering, and nano-enabled technologies will unequivocally be major aspects of the 21st century and must be reflected in those standards.

This report benefits from insights gained from prior U.S. workshops addressing nanoscale science and engineering for K-12.[3-5] It focuses on identifying the subject matter knowledge that should be mastered by the end of high school, and not the specific grade progression. The grade in which this material should be taught is left to K-12 educators who are experts in pedagogy and age-appropriateness. The recommendations correspond to information to be incorporated into the next-generation college and career readiness standards. The report does not address accelerated learning – advanced placement, or magnet schools – where the recommended material would be developed at deeper levels. Since much of innovation comes from the best and brightest, accelerated learning is important. It was not covered because of limited time and a deliberate focus to impact the broadest possible cross section of students.

The U.S. is not alone in examining how to incorporate NSE into K-12, but a recent education article from Europe cites the U.S. as a leader.[6] The State of Virginia is introducing NSE into its K-12 curriculum framework.[7] That being said, two countries – Taiwan and Australia – are farther along in the implementation of NSE throughout their curriculum; their status is presented in Section III of this report.

Discussion amongst the workshop participants led to a slightly revised version (see **Table 1**) of the "Big Ideas in Nanoscale Science and Engineering" recommended by a 2006 workshop,[4] and integrated those ideas into the tracks developed by the National Research Council (NRC) draft Framework for Science Education (see Section II.1 and **Table 2**). Attention by the NSE community to problems/opportunities for the incorporation of NSE into K-12 education already has provided: a number of available teaching modules designed for K-12 (Appendix A), K-12 Teacher Professional Development Opportunities, and K-12 Student Education University Outreach Opportunities in NSE (Appendix B).

Table 1: Big Ideas in Nanoscale Science and Engineering

	Concept	**Number of Available K-12 Teaching Modules**
Science working with Engineering		
NS1	Sense of Scale	54
NS2	Nature/Structure of Matter - Size Dependent Properties	135
NS3	Biological Properties and Interactions	66
NS4	Forces and Interactions	76
Engineering working with Science		
NS5	Nanostructures as Material Building Blocks	7
NS6	Self-assembly – Directed, Hierarchical	6
NS7	Tools of Nanoscience	64
NS8	Modeling and Simulation leading to Materials by Design	37
NS9	Multidisciplinary, Nano-enabled Technology Applications	103
Social Sciences working with Science and Engineering		
NS10	Societal Impacts	65

Key Findings and Recommendations

The U.S. investment in nanotechnology education has spawned a new paradigm for STEM education, which if broadly implemented, will help the U.S. to maintain its global leadership in science and technology.[5] There is a compelling case for the inclusion of NSE concepts in K-12 education by infusing and/or mapping NSE into the Next Generation of Science SOL, and then continually refreshing those concepts as NSE knowledge and practice continues its rapid evolution. Key findings and recommendations include:

1. Creation of a K-12 NanoEducation Ecosystem:

Finding: There are numerous groups around the world addressing STEM education (including a U.S. National Science and Technology Council committee), and the many nanoscale science and engineering research communities, and education communities. There is an immediate challenge to integrate these various communities. A focal point is needed to identify, validate, and integrate the many NanoEducation capabilities that presently exist and to assess what is additionally needed. K-12 science/engineering education must be a high priority, and the National Governors Association (NGA) on-going common core effort - Next Generation of Science SOL – is a near term opportunity. NSE should be incorporated into those standards (and the subsequent curriculum frameworks and assessments).

Recommendation 1: The National Nanotechology Initiative's (NNI) Nanoscale Science Engineering and Technology (NSET) subcommittee, which has representation from 25 participating Federal agencies, should create a Nanotechnology Education and Workforce working group that will support the NNI efforts toward addressing education and workforce issues. An education and workforce-focused advisory board to the NSET should also be created, comprising the various principal stakeholders, including those who bring global perspectives.

Recommendation 2: Establish a network of regional hubs – the Nanotechnology Education Network – as a sustainable national infrastructure for accelerating NSE education. Just as the National Nanotechnology Infrastructure Network (NNIN) has been critical for shared access to leading edge equipment in the early days of the NNI, shared NSE resources, expertise, and training are imperative to preparing a skilled workforce and well-educated innovation leaders of the future.

2. K-12 Next-Generation Science Standards of Learning (SOL):

Finding: In the global race for nano-enabled technologies, the U.S. can be in an education leadership position. It is imperative that the U.S. develop a productive workforce literate in NSE. But without incorporating the current understanding of nanoscale science and engineering into learning standards in each of the states, action at the K-12 levels of education will be minimal, and increasing nanoscience literacy toward a productive workforce will not be maximized – it may not proceed at all in some states. The next-generation science SOL are being developed and must include NSE. Further, since NSE is constantly evolving, there is need for a forum in which subject matter experts, teamed with K-12 educators, can engage in continuing standards/curriculum/assessment development.

Recommendation 1: Appropriately introduce the nanoscale into the next-generation science SOL. Indexed to the NRC Draft Framework, the many examples in Section II of this report show how NSE ideas might be incorporated into the new science standards for college and career readiness. A few illustrations are:

Life Sciences 1A: Structure and Function
STANDARD: Students know that nanoscale molecular machines (largely proteins) are responsible for biological cell mobility (cilia and flagella), muscle movement (actin/myosin), cellular metabolic transport, and controlled flow in and out of cells via ion channels in cell membranes. Students also know that nanostructures play an important role in cell structure (cytoskeleton), adhesion/traction (Gecko) and self-cleaning surfaces (Lotus leaf).

Physical Sciences 1A: Atomic Structure of Matter
STANDARD: Students know examples of structures at the nuclear, atomic, nano, micro, and macro scales. They also know the concept of surfaces and interfaces in relation to those structures.

Physical Sciences 1B: Properties of Matter
STANDARD: Students know that material properties change as scale goes from micro to nano; that three different reasons can evoke those changes (surface/interface effects, collective effects, quantum effects); and what specific properties may change (electrical, physical, biological, etc.)

Physical Sciences 2A: Fundamental/Interactions
STANDARD: Students know the origin and nature of van der Waal forces and their importance in molecular/nanostructure assembly.

Physical Sciences 2C: Forces in the Transformations of Matter
STANDARD: Students know that surfaces, interfaces, and nanostructures behave differently than do bulk materials due to an environment that is subject to different forces.

Physical Sciences 3A: Descriptions of Energy
STANDARD: Students know that atomic, molecular and nanostructure self-assembly is an example of a total energy minimization process and that boundary conditions can be imposed to direct that assembly.

Engineering and Technology 1B: Nature of Technology
STANDARD: Students know that miniaturization into the nanoscale enables the continuing information technology revolution, and opens the possibility for close coupling of biotic and abiotic systems. It also underpins many of the potential solutions to sustainable energy and to medicine and health – both considered major economic engines for the coming decades.

Engineering and Technology 3: Technological Systems
STANDARD: Students examine nano-enabled technologies as state-of-art paradigms of technological systems.

Engineering and Technology 4A: Interactions of Technology and Society
STANDARD: Students are informed on the benefits/risks associated with nano-enabled technologies.

Recommendation 2: Establish a formal mechanism to enable NSE subject matter experts to work with K-12 educators and workforce experts toward the continuing evolution of NSE content in standards, curriculum, and assessment. International participation should be involved.

3. K-12 Curricula and Teaching Aids:
Finding: There are many web sites (such as those listed in Appendices A and C) with materials that address curricula supplements, teaching aids, and science and engineering fair projects. In particular, the NSF-funded efforts have been very productive at developing innovative approaches to K-12 NanoEducation. However, the materials are widely dispersed, are of non-uniform format, have varying degrees of refinement, and are not integrated into a learning progression. Taiwan and Australia have a better-developed NSE learning progression. As the new Framework for K-12 Science Education and the associated standards are adopted, it is imperative that we move from stand-alone, one-off teaching aid modules to a coherent, progressive sequence. In his 2011 State-of-the-Union speech President Obama spoke to connecting every part of America to the digital age… a student who can take classes with a digital textbook.[8] With its rapid progress, NSE is a perfect topic to utilize digital textbooks where continual updates are more readily implemented.

Recommendation 1: Create a central web site that provides a registry for NSE materials. The web site materials need to be of high quality in a format readily usable by K-12 teachers, carefully indexed to the Next Generation of Science SOL, and readily accessible from the National Science Teachers Association (NSTA) web site.

Recommendation 2: Additional well-designed, highly interactive, media-rich, online learning tools should continue to be developed with attention to utilizing the new approaches being widely utilized by youth.

Recommendation 3: Creation of a National NanoFlexbook with free electronic modules for teachers and students. A national competition might be used to stimulate additional high quality "flexbook" materials to provide a coherent, vetted learning progression.

4. K-12 Teacher Education and Training:
Finding: There will be growing inclusion of nanoscale science, engineering, and technology into standards of learning. There are also growing learning resources for K-12 audiences that address nanoscale science, engineering, and technology. Teachers will need to be trained to use these resources.

Recommendation 1: Provide funding for teacher professional development in NSE topics, which are not yet included in the traditional venues. That professional development might include the creation of new teaching modules as part of the effort.

Recommendation 2: The various NanoCenters can be a vital resource to provide materials, training, and information. They should be encouraged to be more proactive toward K-12 teacher training, particularly in their states.

Recommendation 3: A recurring international workshop should be held for K-12 NSE educators to share experiences and ideas. These workshops must include K-12 teachers, college/university professors, science and engineering professional societies representation, and leaders from state and federal education agencies.

I. Why Nanoscale Science and Engineering (NSE) in K-12 Education

I.1. U.S. K-12 Next Generation Science SOL

The need to improve U.S. K-12 student performance in STEM is well documented by many studies in the last 5 years.[9-18] In many countries, including the U.S., local authorities determine education at the K-12 levels. In the U.S., the National Governors Association (NGA)[19] and the Council of Chief State School Officers[20] have instituted a common core standards effort to create internationally benchmarked K-12 standards.[21,22] Forty-eight states have agreed to consider adopting these standards as their own. Common Core standards for mathematics[23] and English language arts[24] have been released, and have been adopted by over 40 states. The process used to develop the mathematics and English language arts standards is illustrated in **Figure 1**. The College and Career Readiness Standards are established by working groups selected for that task. Different working groups develop progressive standards for the various grade levels.

To address the problem of assessing student K-12 achievement, leaders from 25 states have formed the Partnership for the Assessment of Readiness for College and Careers (PARCC) to create a next-generation assessment system that will ensure students across the country are expected to meet common, high standards that will prepare them for their futures. States in the Partnership share one fundamental goal: building their collective capacity to dramatically increase the rates at which students graduate from high school prepared for success in college and the workplace.[25]

A joint effort between Achieve Inc., the NSTA, the American Association for the Advancement of Science, and the NRC is underway to create the foundations for all students to have a solid K-12 science education. A report on internationally benchmarked Next Generation of Science SOL has been released (which does not mention nanoscale science and engineering).[26] The second step toward the Next Generation of Science SOL was a National Academy of Sciences study "A Framework for Science Education." A draft report was released for public comment in July 2010 (nanotechnology is mentioned once in the Engineering core); the comment period closed 2 Aug 2010. The revised report is due in spring 2011.[27] Once the final version is released, Achieve, Inc. will develop—along with states and other interested stakeholders—next-generation science education standards that are faithful to the NRC Framework, internationally benchmarked, and rigorous.

By 2020, when present K-12 students are finishing their primary/secondary education, the impact of NSE will be pervasive. The Next Generation of Science SOL efforts present an opportunity, likely a once-in-a-decade opportunity, to influence an important, widely used document that will shape K-12 STEM education. **It is crucial to insert information about nanoscale science, engineering and technology that will be a major factor during the adult life of these students.** NSE is relatively new and evolving rapidly; it is premature to consider it as a discipline of its own. In fact, as NSE is pervasive to all areas of science, both conceptually and in application, it may be best addressed by embedding it throughout all science courses. The most effective approach to inserting NSE into the standards will be to adapt the recent NRC recommendations for K-12 engineering education:[18] by infusion (embed relevant learning goals for NSE into the pertinent science and engineering standards), and by integration (mapping) of "big ideas" in NSE into the pertinent standards.

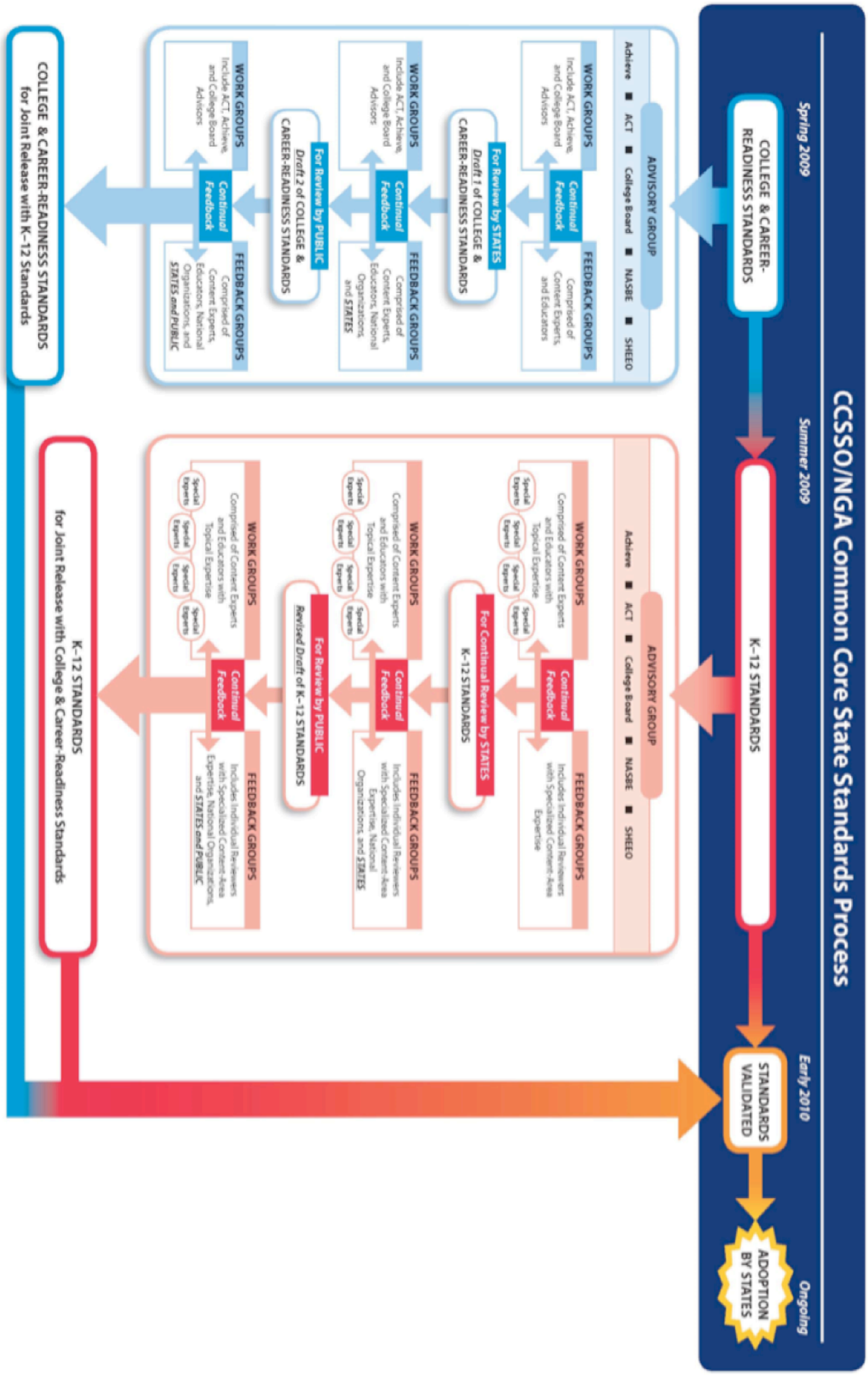


Figure 1: Schematic approach to the development of K-12 common core standards.

I.2. Status of Nanoscale Science and Engineering Education (NSEE) in K-12

"Nanotechnology" (nanoscale science and engineering, and nano-enabled technologies) is the understanding and control of matter with atomic precision at dimensions between approximately 1 and 100 nanometers, where unique phenomena enable novel applications. It includes measuring, manipulating, modeling, and manufacturing matter at this length scale.[28]

The NNI has addressed an informed citizenry, a skilled workforce, and job creation through technological innovation since its inception.[29,30] In the U.S., the NSF has been the principal funding agency for NSEE.[31] Over the past 10 years (**Figure 2**), the focus has moved from graduate programs to K-12 and workforce. The Nanotechnology Center for Learning and Teaching (NCLT)[32] was created in 2005 specifically to address K-12 issues, and the Nanoscale Informal Science Education Network (NISE Net)[33] to address informal education (supporting in part the K-12 efforts).

A number of assessments have been published on the K-12 NSEE challenges.[6,34-40] NCLT and SRI International led an effort to assess what and how NSE might be introduced into K-12 and originated the concept of "Big Ideas in Nano Science.[41] But progress toward inclusion of NSE into K-12 education has been slow, largely because the focus on teaching to science content standards, developed independently by each state and often lagging the state-of-the-practice, effectively precludes the use of the NSE materials. Currently, only a few motivated teachers use the materials developed over the past decade because they know how to use, and where to find them.

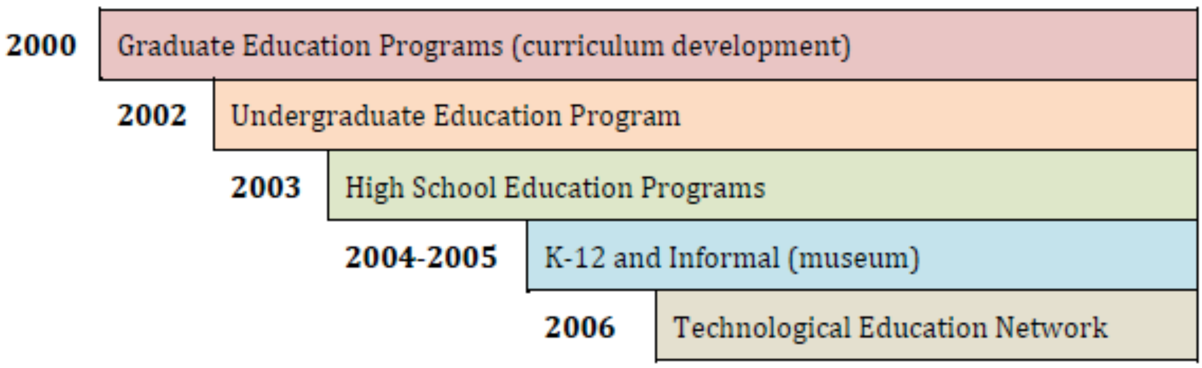


Figure 2: Schematic of NSF investment in NSEE, moving over time to broader and earlier education and training.

Not only in the U.S., but worldwide, there has been a concerted effort to develop education modules that address NSE at different grade levels (see Appendix A for K-12 modules, Appendix D for Workforce (2-year Community and Technical Colleges), and Appendicies E and F for 4-year College/University efforts, and Appendix G for selected College Textbooks respectively). A number of websites provide access to K-12 NSE information (see Appendix C) and a new book on K-12 resources has been published.[42]

Following the creation of the NCLT, there have been three NSEE workshops. The first in 2005 addressed K-12 and informal NSEE in the U.S., with an emphasis on communication amongst the various NSF Center efforts.[43] The second in 2007 addressed perspectives in NSEE, strategies to engage teachers and students in NSEE, challenges for engaging others in NSEE, evaluation and assessment, and networking and collaborations.[44] The third was held in November 2008; it incorporated perspectives from other countries. It also connected key leaders from various regions with the aim of stimulating collaboration and networking on major NSEE initiatives.[45]

To stimulate greater stakeholder involvement in NSEE, NSF funded a "Partnership for Nanotechnology Education" workshop on the University of Southern California campus, 26-28 April 2009, bringing together a wide range of stakeholders in NanoEducation. It was envisioned as the first of a series to address the challenges facing nanoscale education. The workshop was to: a) broaden the nanoscale education efforts to include the many stakeholder groups and communities; b) establish an enduring infrastructure beyond the NSF-sponsored NSEE workshops; and most important, c) develop partnerships toward meeting the challenges and identifying the opportunities provided by the global advances at the nanoscale. The workshop reported a number of findings and recommendations,[5] some of which have been subsequently incorporated into the new NNI strategic plan.[46] A strong recommendation from that workshop was to work toward the appropriate insertion of nanoscale science/engineering into the K-12 curriculum.

Since nanoscale science and engineering is relatively new, there is high risk NSE will not achieve the presence in the pending K-12 Next Generation of Science SOL warranted by its rapidly growing impact. Despite its importance to 21st century science, engineering, and technology, the nanoscale is explicitly mentioned in the NRC draft Framework for Science Education report only as a topic for grades 9 to 12 engineering and technology - "Using Tools and Materials". Yet nanoscale science/engineering knowledge and nano-enabled technologies will be pervasive by the time students presently in the K-12 grades enter the adult world.[1]

A second NSF funded workshop, the International Benchmark Workshop on K-12 NanoEducation, met on December 6-7, 2010 in Washington, DC, to explore mechanisms for the incorporation of NSE into K-12 education. The participants (Appendix J) were chosen to represent the many stakeholder communities and International perspectives. While the on-going U.S. Next Generation of Science SOL process motivated the workshop timing, this is a continuing and global issue.[39,47-49]

I.3. Impact of NSE Content in K-12 Education

With the many demands placed on K-12 education, why is nanoscale science and engineering so important as to warrant explicit inclusion in standards and curricula? How does the nanoscale fit into the science and engineering picture? The Next Generation of Science SOL effort will provide college and career readiness standards. Achieve Inc. points out that:[50]

> "College today means much more than just pursuing a 4-year degree at a university. Being "college ready" means being prepared for any postsecondary education or training experience, including study at 2- and 4-year institutions leading to a postsecondary credential (i.e., a certificate, license, Associates or Bachelor's degree). Being *ready* for

college means that a high school graduate has the knowledge and skills necessary to qualify for and succeed in entry-level, credit-bearing college courses without the need for remedial coursework.

Further, in today's economy, a "career" is not just a job. A career provides a family-sustaining wage and pathways to advancement and requires postsecondary training or education. A job may be obtained with only a high school diploma, but offers no guarantee of advancement or mobility. Being *ready* for a career means that a high school graduate has the knowledge and skills needed to qualify for and succeed in the postsecondary job training and/or education necessary for their chosen career (i.e., technical/vocational program, community college, apprenticeship or significant on-the-job training)."

The many nanotechnology initiatives around the world have fueled the explosive growth in NSE knowledge and in nano-enabled marketplace technologies.[1] As a result of this growth:

a. There will be a need for an extensive, informed, skilled workforce as nanostructures become materials building blocks and directed self-assembly becomes a viable manufacturing process. Estimates of the global market for nano-enabled technologies are in the $1T/year range by 2015, and $3T/year by 2020.[2] (See Section I.3.a)
b. Graduates from secondary school must have the background to meet the NSE knowledge expectation, reflected by the "Big Ideas" of NSE. The growing incorporation of NSE into 4-year universities and colleges education, where innovation and critical thinking toward our future are nurtured, and the growing workforce need both compel attention at K-12. (see Section I.3.b)
c. Workers and members of the general public may be in contact with nanomaterials in various forms during manufacture or in products. All citizens must be able to separate science fact from fiction in making decisions regarding the benefits and risks associated with the new technological capabilities enabled by advances in NSE. (See Section I.3.c)
d. Nanostructures can have important new physical, chemical, and biological properties that will lead to innovative products. Our citizenry, workforce, and business communities will need this new knowledge in the K-12 educational corpus to be competitive in the global economy. (See Section I.3.d)
e. Nanoscale science and engineering is largely transdisciplinary. Although challenging to the traditional science and engineering education taxonomies, NSE provides clear application-inspired examples of transdisciplinary innovation. (See Section I.3.e)
f. The nanoscale holds sufficient novelty, and nano-enabled solutions to societal problems, to attract STEM interest in students. (See Section I.3.f)
g. The NSF and other funding institutions around the world have been paying attention to education at the nanoscale. There is a broad range of new instructional materials, many of which are available as cyberinfrastructure resources. There are also teacher professional development resources. (See Section I.3.g)

This report will be focused on an informed citizenry, i.e., “STEM for all” - what an informed citizen should know when graduating high school to enable career and college choices and to make cognizant decisions on societal issues. As pointed out in some recent reports,[15,17] it will also be necessary to develop standards/curricula for those individuals who will populate the science and engineering innovation workforce - “All STEM for Some.” Advanced placement tracks and magnet schools, although important for these students, will not be specifically addressed in this report because of limited time and a deliberate focus to impact the broadest possible cross section of students.

I.3.a. Future Workforce Needs
It is known that workforce development is critical to economic development via technology innovation.[51] Already in 2001 Roco had estimated the marketplace for nano-enabled products to be more than $1T per year by 2015. He also estimated workforce requirements.[52] Nanotechnology jobs were projected to be nearly two million workers worldwide by 2015 with a distribution of:

- 0.8-0.9 million – USA
- 0.5-0.6 million – Japan
- 0.3-0.4 million – Europe
- 0.2 million – Asia Pacific (excluding Japan)
- 0.1 million – other regions

In addition, nanotechnology is projected to create another five million jobs worldwide in support fields and industries.[53]

Subsequently there have been other market estimates, with the size ranging from $1-3T per year by 2020.[54,55] Studies of patent applications support that marketplace growth.[56] While there is some debate on the actual market size,[57] most appraisals allow that nanotechnologies will transform many aspects of our lives.[58]

A 2009 National Center for Manufacturing Sciences (NCMS) Study of Nanotechnology in the U.S. Manufacturing Industry concluded that nanotechnology is no longer a technology in waiting – a great breadth and diversity of nanotechnology products and applications are being pursued with the potential for disruptive economic, social, environmental, and military advantage.[59] New product applications are being developed for the semiconductor, consumer electronics, energy generation/storage, chemical catalysis, and pharma/biomedical/biotechnology application sectors. These will eventually mature into nanotechnology-enabled products with greater sensory sophistication, predictive certainty, and autonomous functionality, advancing toward visionary applications and large-scale economic and societal impact.

The NCMS report also cites the results of a survey highlighting the need for a skilled workforce. Nano-enabled technologies will address a broad range of applications (see Section IV) and a concomitant broad range of skills. How do companies hire employees with appropriate skill sets for *emergent technologies* that are so new that little experience exists to identify what new skill sets are appropriate?

NSE Career Opportunities
The NNIN website provides a perspective of the potential career areas. Current applications of nanoscale science and technology, and thus career opportunities, exist in areas such as:

- Electronics/semiconductors
- Optoelectronics
- Materials science and development
- Auto and aerospace industries
- Sports equipment
- Pharmaceuticals including drug delivery, cosmetics, among others
- Biotechnology and medical fields
- Environmental monitoring/control
- Food science
- Forensics
- University and federal laboratory research
- National security and defense

Nanoscale science and technology are fueling a revolution in manufacturing and production, creating new materials and novel processes. See Section IV for additional areas with expected impact.

The centers' case-study research with two pharmaceutical firms—Merck and Schering-Plough—reinforces earlier survey findings in other industries: the need for specifically "nanotechnology-trained" workers is still limited, and employers continue to hire workers with degrees in traditional scientific disciplines. However, both companies are planning more comprehensive nanotechnology training for incumbent workers, and both reported the need for workers to have greater interdisciplinary knowledge. Moreover, this study found that nanotechnology presents different skill and knowledge needs for different classes of workers, including those in non-technical positions. One employer noted that non-technical workers in marketing, sales, legal and general management need to become better educated on both the basic science behind nano-technology as well as the social, legal, ethical, health and safety concerns associated with its use.

The breadth of potential NSE knowledge needed, and its place in traditional course content, has evoked a debate in academic circles on what is needed for NSEE at the community and technical colleges,[60-62] as well as in the four year institutions. As can be seen in Appendices D, E and F, there are a growing number of post-secondary institutions with certificates, minors, or degrees associated with NSE. These can be presently viewed as experiments in addressing the needs for NSE education at the post secondary level. However, the existence of the many and growing NSE degree programs,[63-72] and the real expectation of dramatic penetration of nano-enabled technology in to the marketplace, demonstrate the need for incorporation of “Big Ideas in NSE” into K-12, so that high school graduates will have the needed college and career knowledge base expected for the near future.

I.3.b. Big Ideas in NSE

Mapping big ideas into current standards can be an effective approach to introduce NSE. A 2006 NSF funded workshop developed a suite of big ideas for NSE.[41] Some 4 years later, those ideas have been refined and extended. In Section II they are related to the NRC draft Framework for Science Education.

I.3.b.i. Science with Engineering
As indicated in the definition of NSE, nanostructures can have unique properties that are of interest to the scientific community efforts to understand the behavior of matter, while engineering provides new experimental capabilities to develop and apply that understanding:

NS1 - Size and Scale: Concepts of size and shape form the cognitive framework used to make sense of phenomena. The nanoscale fills in a critical gap between atoms/molecules and bulk (continuum) materials.

NS2 - Properties of Matter: The properties of matter can change with scale. In particular, as materials approach the nanoscale in size, they often exhibit unique functionality and properties.

> NS2a - Surface/Interface Effects: The surface atoms of a nanostructure have a different environment that leads to atomic rearrangement and to compensation of dangling bonds (e.g., bonds disrupted by the absence of continued core atoms). The disruption may extend for some distance and, when this happens, gives rise to the concept of interphase. The prevalence of composites in the market (whose properties depend crucially on these interfaces/interphases) makes these effects critical to modern materials (see Section I.3.d.i).
>
> NS2b - Collective Effects: A number of phenomena depend on the interaction with neighboring atoms beyond the nearest neighbors (see sidebar on color and Section I.3.d.ii).
>
> NS2c - Quantum Effects: When the nanostructure physical size is equivalent to particle (electron, phonon, photon) wavelengths or to tunneling barriers, quantum effects can become dominant (see sidebar on color and Section I.3.d.iii).

NS3 - Biological Properties and Interactions: The macromolecules that are the machinery of living systems have dimensions in the nanoscale and match the size of current information technology device structures (which enables effective interactions).

NS4 - Forces and Interactions: The relative importance of forces that govern interactions between objects changes with the scale of objects involved.

I.3.b.ii. Engineering with Science
As scientific understanding progresses, and in fact to assist in that progression, it is possible to engineer nanostructures toward the development of useful new materials:

NS5 - Nanostructures as Material Building Blocks: Engineered nanostructures provide a new suite of building blocks, supplementing atoms and molecules, for the construction of materials with innovative properties (**Figure 3**).

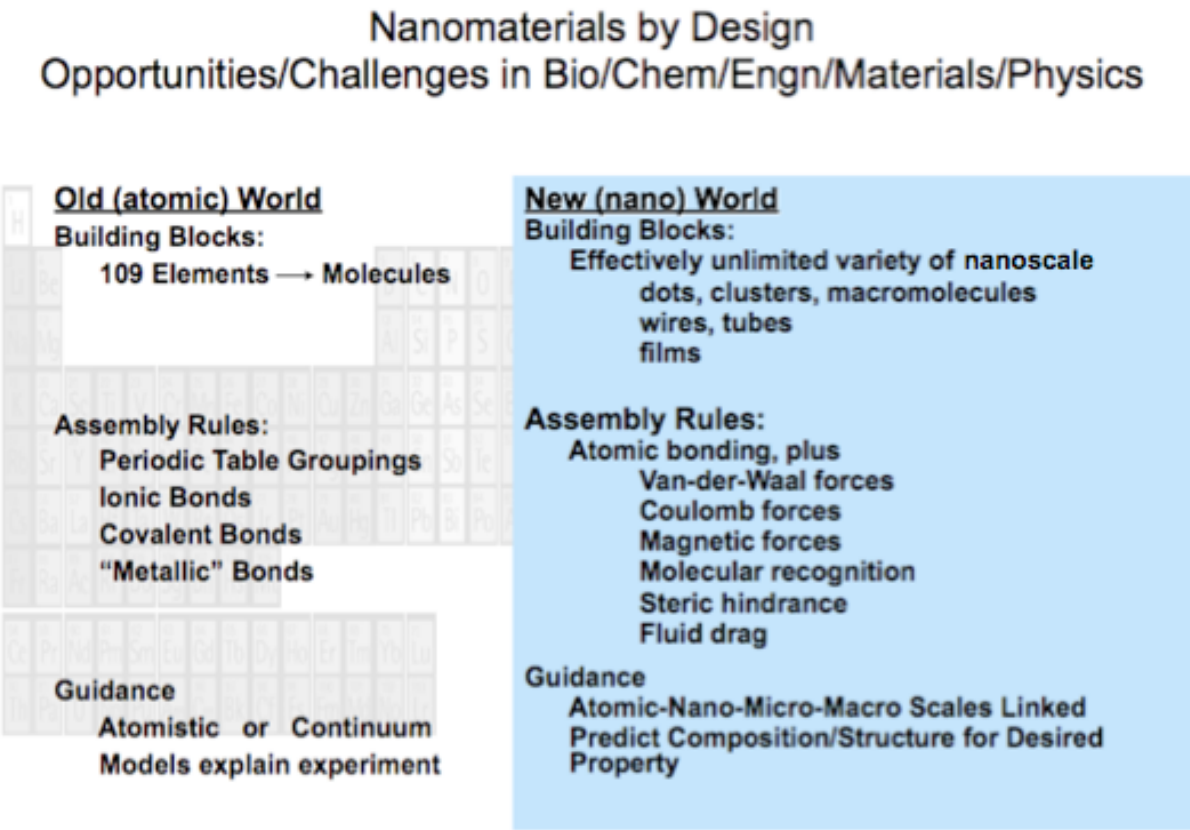


Figure 3: Schematic illustrating the evolution of chemical approaches to new materials from the creation of molecules into the creation and use of nanostructures. For cost effective assembly of nanostructures, we must come to understand the forces involved and how to exploit them toward directed, hierarchical self-assembly. Understanding nanoscale phenomena opens the possibility to connect the atomistic models (chemistry and atomic physics) and continuum models (materials science and engineering) of materials behavior.

NS6 - Self-Assembly: Under certain conditions, some materials spontaneously assemble themselves into organized structures at a lower equilibrium state. This process provides a useful means for manipulating matter at the nanoscale, but to be fully useful needs to incorporate directed and hierarchical assembly (e.g., crystal growth is self assembly, but the result is highly uniform structure).

NS7 - Tools of Nanoscience: Recently developed tools such as force microscopy allow the measurement and manipulation of matter at the nanoscale, leading to the development of new understandings and creation of new structures. These tools drive the progress in nanoscale science, engineering and technology.

NS8 - Modeling and Simulation: Models help us understand, visualize, predict, hypothesize and interpret data about natural and manufactured nanoscale objects and phenomena, which by their very nature are too small to see. As such, modeling and simulation are implicitly part of NS1-4. But in addition, the nanoscale provides opportunity to marry models/simulations at the atomic/molecular and the continuum size scales, and at various time scales. This marriage is a crucial step toward the concept of materials by design where a material is specifically designed and created to provide the optimal properties needed for an application.

NS9 - Nano-enabled Technology Applications: The nanoscale is critical to technological approaches toward the solution of many of societal problems, for instance sustainable energy, clean water, ample food and agriculture, environmental remediation, information management, medicine/health, and national security and defense. It will also be an engine for innovative technologies that create new jobs.

I.3.b.iii. Science and Engineering with the Social/Economic Sciences
Since nano-enabled technologies will be pervasive, it is important for the science and engineering communities to engage with the social and economic sciences toward their most effective, sustainable utilization:

NS10 - Societal Impact: Nanotechnology is driven by the processes of science and engineering to solve problems. As with any new technology, the products of nanotechnology may impact our lives in both positive and negative ways and individuals should be sufficiently knowledgeable to make informed value judgments.

I.3.c. Informed General Public
Nano-enabled technologies are becoming pervasive; potential negative environmental and health impact is a concern. The public is being exposed to a wide range of opinion – and has to be sufficiently knowledgeable to ascertain the right way forward:

- The ETC Group proposes a moratorium on NSE: *Since our call for a moratorium, science has cast nano's safety even further in doubt, with hundreds of studies now demonstrating harmful effects from exposure to nanoparticles.*[73]
- Greenpeace is concerned, but more balanced: *In the long term we can expect major applications in telecommunications, computing, pharmaceuticals, warfare, and energy sectors. Greenpeace is concerned about some current applications and the longer-term possibilities of environmental damage. Our concern extends to a moratorium on so-called 'nanoparticles'. But there is also scope for environmental benefit in the long term as well and we are keen to see that materialize.*[74]
- Friends of the Earth is also concerned: *Nanotechnology is being commercialized largely outside of general public awareness or debate, and without any serious attempt to involve the community in decision making about its introduction. Issues of ethics, democracy, and nanotechnology's broader socio-economic impacts have yet to register in the debate.*[75]
- The PEN Woodrow Wilson Center Project on Emerging Nanotechnologies is cautious but positive: *Dedicated to helping ensure that as nanotechnologies advance, possible risks are minimized, public and consumer engagement remains strong, and potential new benefits are realized.*[76]

- Allianz, a European based financial services company is also cautious but positive: *Given the fact that nanotechnologies have an enabling character and will penetrate almost every industry over the coming years, we expect that nanotechnology risks will be part of the industrial insurance portfolio.*[77]
- Lloyd's of London, a global insurance company, has greater concern: *The precautionary principle is now accepted to apply to the degradation of human health as well as the environment, and suggests the use of this technology should be risk assessed appropriately before consumption by the public.*[78]

The NNI has addressed societal impact from its inception,[29,79] but there clearly are still concerns. Citizens must be sufficiently knowledgeable to make benefit/risk decisions.[80,81]

I.3.d. New Physical, Chemical, and Biological Properties of Nanostructures
Chemists view the nanoscale as a step up in size scale. For several centuries chemistry has been creating new materials through the synthesis of new molecules. Molecules are fully defined structures with specific elements (atoms) and with their atomic positions defined by bonds to neighboring atoms. Most molecular dimensions are nanoscale and smaller. Larger molecules – e.g., macromolecules, polymers – can have physical dimensions in the nanoscale. NSE is providing a new suite of materials building blocks. Nanostructures have many more atoms than do most molecules – a cube with 1nm sides would house about 100 atoms; 10nm sides about 100,000 atoms; 100nm sides, 100,000,000 atoms. The structure can have a much greater degree of variance in time and shape than with molecules. And, whereas the bonds of a molecule are fully specified, and the surface bonds of a bulk material can be largely ignored, the surface atoms/bonds for nanostructures pose a challenge and opportunity.[82]

In contrast to chemists, materials scientists and engineers view the nanoscale as a significant and important step down in size. For macroscale structures, the bulk properties are not different if the dimensions are changed – cut it in half and the properties are the same. There are uncompensated bonds for the surface atoms, but how they are tied off does not affect the desired prime material properties. For instance, no one worries about how the surface atoms of a cleaved diamond surface are compensated; it doesn't affect the diamond's luster or hardness. Coatings (usually micrometer thick, rather than nanometer) are applied to enable desirable multi-functional properties such as a structural material with corrosion/wear resistance, low friction and/or some specific color.

Properties of nanostructures can be different from bulk materials with the same atoms due to at least three different effects:

i. Surface/interface effects at the boundary of the nanostructure
ii. Collective effects due to the limited (but relatively large) number of atoms present in the nanostructure
iii. Quantum effects due to the small physical dimensions of the nanostructure

I.3.d.i. Surface/Interface Effects

Surfaces and interfaces are important components in real world materials behavior. Friction at the interface between two materials allows us to walk without slipping; it also dissipates energy (bad for engines, good for brakes). Dissolution is the migration of a material from the surface of a solid into a solvent (sugar in water is a classic example). Crystallization from a solution is the inverse and is an example of self-assembly – the sugar molecules precipitate into an ordered crystalline form. Heterogeneous chemical reactions occur at surfaces – a charcoal briquette burns as oxygen converts its carbon into carbon dioxide; corrosion converts metallic iron surfaces to another less desirable material (rust).

For nanostructures many, if not most of the atoms are at the surface/interface, so how those bonds are compensated will dramatically affect the core properties. In contrast to molecules (subnanoscale structures) the number of atoms present provide a large variety of possible shapes and configurations[83] – e.g., spheres, cubes, rectangles, tetrapods, stars, flowers, ribbons, belts, etc. The nanostructure surface bonds must be compensated, and their number provides greater degrees of freedom to tailor the structure for multiple functions. So one can envision one or more "shells" around the core nanostructure (**Figure 4**). In contrast to the macroscale coatings, these shells that impart multi-functionality are generally nanometer in thickness.

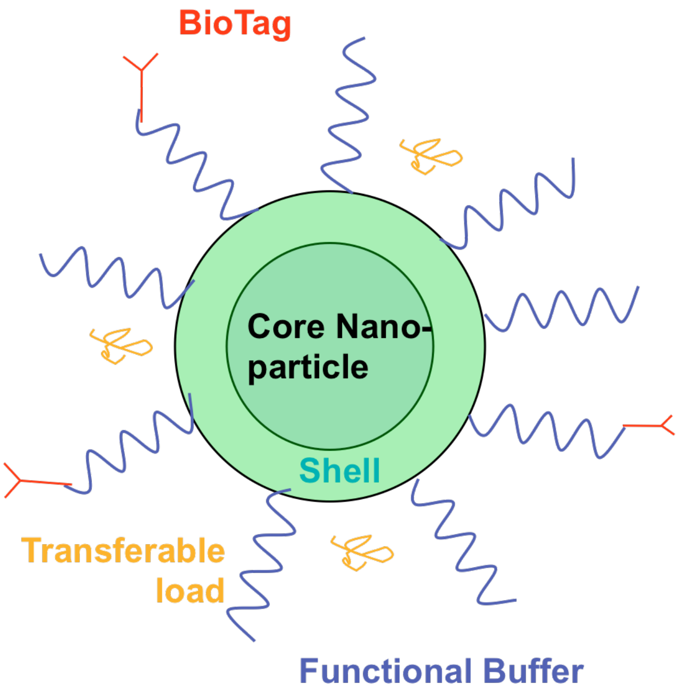


Figure 4: Schematic representation of an engineered nanoparticle to illustrate some of the many possibilities. The first shell might be used to protect and/or enable key nanoparticle characteristics. The yellow color indicates materials that can migrate from the nanoparticle into its environment; while it is depicted here as residing on the periphery, it might be stored in the core as well. The blue color indicates surface modifications that enable processing such as tailored solubility. The red color indicates surface modifications that enable site-specific interactions, illustrated as a biological tag,

I.3.d.ii. Collective Effects

An example of collective effects is the transition from the ferromagnetism (e.g., the magnetic property of a compass needle) of macroscale numbers of iron atoms to the paramagnetism in nanostructures of iron. For large numbers of iron atoms, once magnetized by the presence of an external magnetic field, the collective interaction of the individual iron atom spins will retain their relative magnetization even when the external field is removed. When there are not a sufficient number of neighboring iron atoms (e.g., in a nanostructure), the individual iron spins are not locked into a common direction and reorient after the external magnetizing field is removed. This behavior is called paramagnetism. The transition from paramagnetism to ferromagnetism happens for the number of iron atoms contained in a nanostructure.[84]

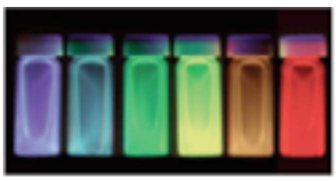
Another example of collective effects is the melting temperature. The commonly cited melting temperature for a material refers to its bulk phase transformation. But atoms at the surface of that bulk material, lesser confined by the absence of atoms on one side (a collective effect), will become mobile (i.e., melt) at far lower temperatures.[85] Nanostructures, with their large number of surface atoms, melt at lower temperatures than bulk materials.

Yet another example is the change in color of gold nanoparticles with size and shape (see the Sidebar on Color). The color of gold is determined by the way in which its electrons move together; that changes with particle size and shape.

Color of Nanostructures

The color of a nanostructure can depend on other properties than composition and atomic structure. Gold nanoparticles have been used to impart red color in stained glass windows for over 1,000 years; we now know that gold nanoparticles can show different colors depending on their size and shape. The coloration is due to collective effects between the electrons in the nanoparticle. The shape dependence is illustrated in the picture with nanoparticles below right; all the particles are close to the same size. To the left of the nanoparticle image, the jars have suspended gold nanoparticles of 30, 60, 90nm diameter from left to right. This size dependent color change is currently used in pregnancy tests available at your drugstore.

Semiconductor nanoparticles (also referred to as quantum dots; cadmium selenide pictured here) can also be tailored to emit light at different colors by changing the particle size and exploiting quantum effects.



"Nanoplasmonics: the Physics Behind the Applications," MI Stockman, Physics Today 64(2), 39-44 [2011].

I.3.d.iii. Quantum Effects

One example of quantum phenomena used in our technologies is the color of semiconductor nanoparticles – quantum dots.[86] At the nanoscale, the size of the structure can constrain the allowed electron configurations. The wavelength of emitted light from a freestanding atom is determined by the allowed electron orbitals; so light emitted from atoms has characteristic colors that cannot be easily varied. But by varying the size of a nanoscale particle, one can alter the allowed bonding electron states and change the light absorbed or emitted from that particle. When that happens in the visible region of the spectra, the nanoparticle will change its color (see the Sidebar on Color).

Another quantum effect is the transmission of an electron through an insulating barrier. An insulator will normally not allow electron transport, but when the insulator thickness is sufficiently thin (in the low nanometer range), an electron can cross it due to a quantum phenomena called tunneling. This is a problem for the continued miniaturization of nanoelectronic devices; the tunneling contributes to heat generation. Heat generation is limiting the continued improvement of computer processors. New computer processing units must use multiple cores[87] to spread out the heat being generated in the chip.

I.3.e. Transdisciplinary

The NRC Framework for Science Education emphasizes interconnections between traditional science and engineering disciplines.[88-90] NSE is an exemplar for interdisciplinary science and engineering. One can view the evolution of the traditional physics, chemistry, materials and biology disciplines as a march toward being integrated at the nanoscale as illustrated in **Figure 5.**

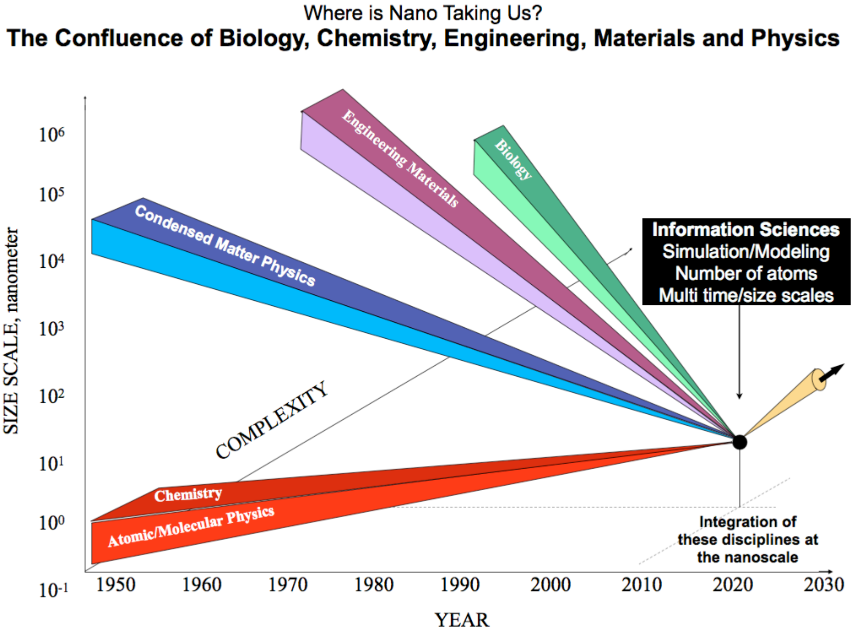


Figure 5: Chemistry and Atomic Physics have addressed structures smaller than nanometer in the past and are now attacking larger structures – nanoscale. Condensed matter physics has been working from continuum models at the macroscale, through microscale structures and now to the nanoscale. Materials and biological scientists/engineers have been coping with highly sophisticated systems, gradually teasing apart their components. The nanoscale is where all of these traditional approaches to dealing with matter meet.

As one example of transdisciplinarity at the nanoscale, biological cells are on the order of 10 microns in size. The cells are crammed with molecular machinery that performs the many activities necessary for living systems. Those molecular machines have size scales of nanometer – the same size scale of current electronic devices.

For instance, the structure of DNA comprises two helical chains each coiled round the same axis, and each with a pitch of 3.4 nanometers and a radius of 1.0 nanometer; but when extended its length is around 10^7 nm. There are several efforts to sequence DNA by pulling it through nanoscale holes in electronic devices (physics, chemistry and engineering) where the nanoscale devices can read off the individual nucleic acids (biology and medicine).[91] Conversely, porosity in living system membranes ranges from nanometer (kidney) to hundreds of nanometers (vasculature in cancer tumors). Engineered nanoparticles are being constructed (chemistry and engineering) to leak into the tumors, provide contrast for imaging, and deliver therapy (medicine and health). In yet another example, the molecular motors of biological systems (biology, chemistry) have been extracted and made to perform *ex-vivo* on semiconductor wafers (physics, engineering).[92]

I.3.f. Student STEM Interest

Flagging student interest in science and engineering careers is a problem, not only in the U.S., but also in many developed nations.[93] The Relevance of Science Education (ROSE) project was an international comparative research project to shed light on factors of importance to the learning of science and technology – as perceived by the learners (~15 years of age). Some of the study data is presented in **Figure 6**, illustrating the attitudes of students toward science and technology in general, and the disinterest in becoming a scientist in the developed countries.

The ROSE study spoke to science and technology relevance as a student motivator. Theoretical concepts in science and engineering, although imperative, often appear to be unrelated to daily life and inadvertently come across as uninteresting. **Students tend to be more attracted to knowledge and careers that impact their lives.** Highlighting the impact that the nanoscale will have, and in many cases is already having, on issues of interest to young people may help engage them to learn science and engineering. Some of the many nano-enabled technology impacts on societal problems are illustrated in Section IV. Potential key areas include medicine, energy, smart phones and other electronics, consumer products, and environmental issues such as clean water. Nanotechnology affords examples – e.g., nanoparticles targeting individual tumor cells! tissue regeneration for wound repair! solar fabrics to charge your cell phone in your pocket! clean renewable energy! - which can be used to excite students about the possibilities. The nanoscale is sufficiently new and novel so as to pique student and teacher interest. The NCLT, NNIN and other nano centers have hosted many well-attended teacher professional development events with enthusiastic participation.

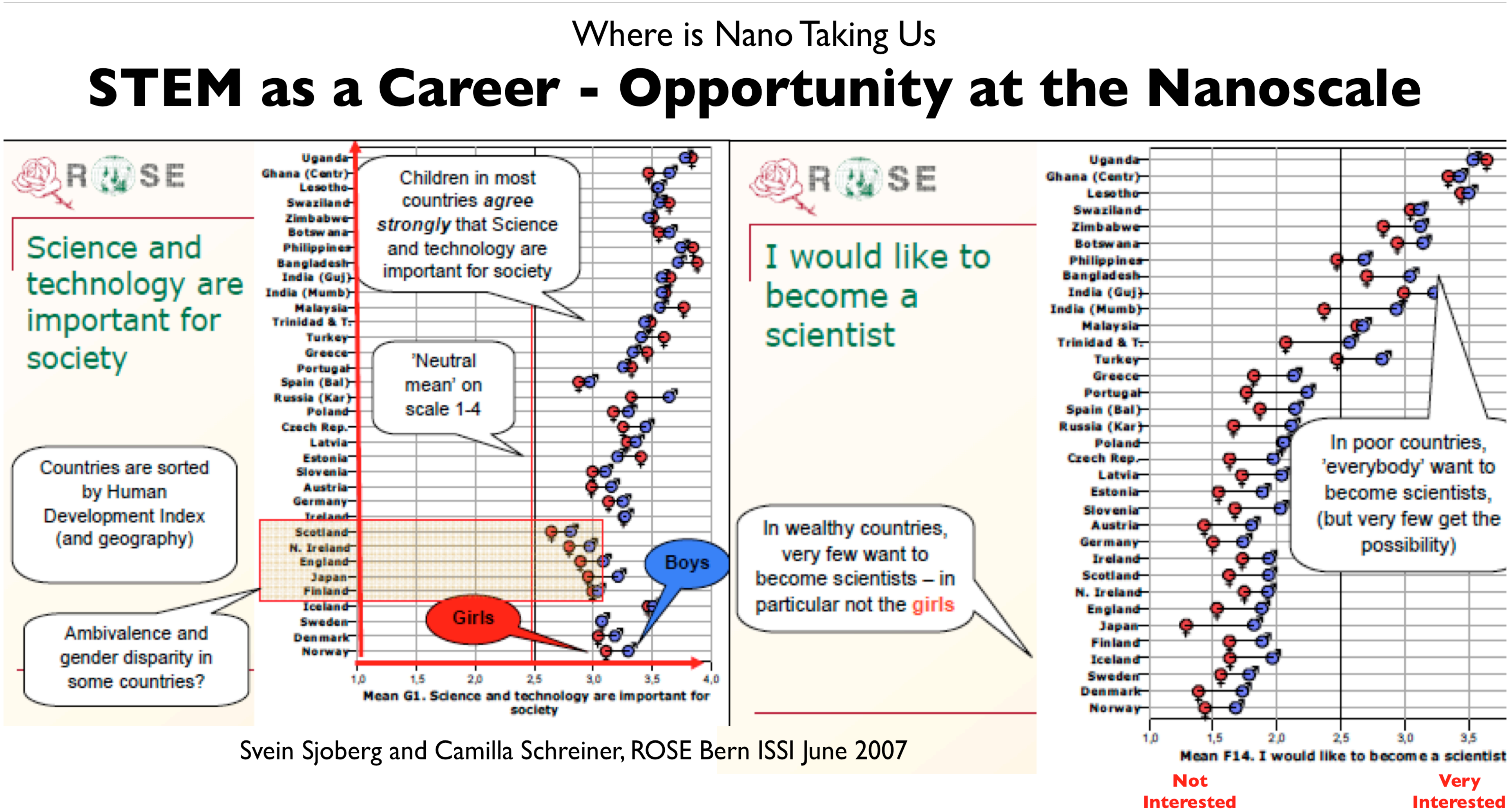


Figure 6: Student responses (on a scale ranging from not interest to very interested) to the questions in green, plotted by country

I.3.g. K-12 NSE Resources

Investments over the last decade, largely by NSF in the U.S., have provided K-12 NSE instruction modules and teacher professional development resources.

I.3.g.i. Available NSE K-12 instruction modules

A global survey (largely web-based but supplemented by individual queries) of the resources available for K-12 education shows about 300 NSE teaching modules; they are parsed by the Big Ideas taxonomy in **Table 1**.

Table 1: Big Ideas in Nanoscale Science and Engineering

	Concept	**Number of Available K-12 Teaching Modules**
Science working with Engineering		
NS1	Sense of Scale	54
NS2	Nature/Structure of Matter - Size Dependent Properties	135
NS3	Biological Properties and Interactions	66
NS4	Forces and Interactions	76
Engineering working with Science		
NS5	Nanostructures as Material Building Blocks	7
NS6	Self-assembly – Directed, Hierarchical	6
NS7	Tools of Nanoscience	64
NS8	Modeling and Simulation leading to Materials by Design	37
NS9	Multidisciplinary, Nano-enabled Technology Applications	103
Social Sciences working with Science and Engineering		
NS10	Societal Impacts	65

Figure 7 shows the distribution of K-12 NSE modules by grade level; each module is attributed to all grades that it purports to address. Those modules identified for K-5 tend to be game oriented, where a concept or device championed by the developing institution is highlighted. More extensive information on the modules is contained in Appendix A. Appendix C has websites that provide K-12 education resources.

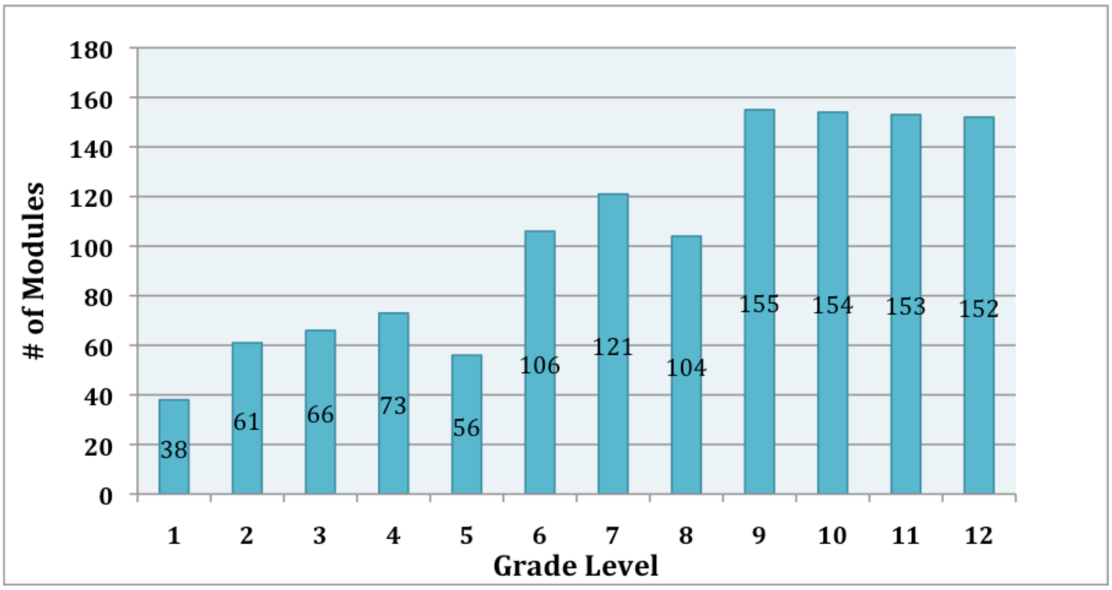


Figure 7: Bar chart showing the number of NSE modules appropriate for each grade level. Since a module might be used for more than one grade, the sum of the numbers above is greater than the number of modules.

Locating these modules took a great deal of effort, and demonstrated the need for a central repository that provides ready access, especially for K-12 teachers who do not have the time to hunt for them.

There is a great deal of repetitiveness in the modules, the quality levels and topic coverage (**Table 1**) are uneven, correlation to standards are missing for many, and there is little-to-no correlation with learning progressions. Only a small subset of these modules has been accepted for use in the K-12 Flexbook series, or in the NSTA Science Store. With the advent of the coming Next Generation of Science SOL, it is time for an effort to cull these modules, improve them, tie them to the new standards, and provide a central web presence.

I.3.g.ii. Teacher Training in NSE

The existence of standards and training aids are only part of the challenge toward including NSE in K-12. Teachers must be trained and comfortable with the materials or they won't be used.[94,95] Many of the NanoCenters have teacher professional development activities as noted in Appendix B. These range from the NSF Research Experience for Teachers (RET), to course development workshops,[96] to a K-12 Nanotechnology Teacher Conference.[97]

II. Nanoscale Core Discipline Knowledge Requirements

II.1. Relationship to the NRC Framework for Science Education Taxonomy

The example content standards in this Section are aligned with Chapters 3 and 4 of the NRC publication, “A Framework for Science Education – Preliminary Public DRAFT” that was released in July 2010. At the International Benchmark Workshop on K-12 NanoEducation, a compendium of Big Ideas or Concepts of Nanotechnology was accepted by the participants, and a sample set of standards statements was developed and aligned with the “Prototype Learning Progressions” in Chapter 7 of the NRC Framework Preliminary Public DRAFT. Those standards are presented in this section (see **Table 2**); the page reference associated with each standard in this section is from the NRC July draft document.

Each suggested standard is also correlated with the appropriate “Big Idea,” with existing K-12 modules (using Appendix A notation), with Wikipedia entries that provide information on the topic (and illustrate growing awareness of the nanoscale beyond the professional literature), and with recent reviews in the NSE professional literature. These reviews are summaries of the extensive literature base; especially in their introduction sections they present the important new insights an informed citizen should be aware about (as well as suggestions for additional research to the NSE community). The number of those reviews in the last couple of years, and the broad range of professional journals in which they were published, testify to the omnipresence of the nanoscale in science, engineering and technology.

Because the K-12 NanoEducation workshop participants were subject matter experts/teachers, and not experts in the writing of K-12 content standards, the K-12 science standards of the State of California were emulated. Each standard was identified by the subject matter expert authors only at the grades 9-12 level, with the appropriate progression through earlier grades to this “graduation standard” left for K-12 teachers and other experts in pedagogy and age or developmental appropriate learning.

The standards presented in this draft are intended as a starting point for the development of a complete set of standards and are meant to suggest some concrete ideas to a standards writing team. While specific examples from the physical sciences and engineering and technology are more extensive in this report, with only a couple of examples in life sciences and earth and space sciences, standards writing teams should develop a full range of standards in each discipline as they see appropriate.

Table 2: **Framework Track Concept / NSE Big Idea**

	NS 1	NS 2	NS 3	NS 4	NS 5	NS 6	NS 7	NS 8	NS 9	NS 10
Life Sciences (LS)										
Molecules to Organisms: Structure & Process	x	x	x	x	x	x	x	x	x	x
Heredity – Inheritance and Variation of Traits			x				x			x
Ecosystems: Interactions, Energy & Dynamics	x	x	x	x						
Biological Evolution: Unity and Diversity										
Earth and Space Sciences (ESS)										
The Solar System, Galaxy, and Universe							x			
Planet–sized Structures, Processes & History							x			
Earth's Surface Processes and Changes							x			
Human Interactions with Earth										x
Physical Sciences (PS)										
Structure and Properties of Matter	x	x	x		x		x	x		
Forces: Interactions, Stability, & Change		x	x	x		x	x	x		
Energy and Transformation				x		x	x	x		
Waves – Energy and Information		x					x	x		
Engineering and Technology (ET)										
The Designed World					x	x		x	x	
Engineering Design							x	x	x	
Technological Systems							x	x	x	x
Technology and Society			x							x
Cross–cutting Scientific Concepts										
Patterns, Similarity and Diversity	x	x	x							
Cause and Effect: Mechanism and Prediction			x		x		x	x		
Scale, Proportion, and Quantity	x	x			x			x		
Systems and System Models			x		x	x	x	x	x	x
Energy & Matter: flows, cycles & conservation				x		x	x	x	x	
Form and Function		x	x		x		x	x	x	x
Stability and Change										x
Topics in Science/Engineering/Technology (SET) and Society										
History and Cultural Roles										x
Impacts of SET on Society										x
Impact of Societal Norms and Values on S&E										x
Professional Responsibilities of S&E										x
Careers and Professions Related to S&E										x

II.2. NSE Concepts in Life Sciences (LS)

II.2.a. LS1.A Structure and Function (Grades 9-12, pg 7-9)

STANDARD: Students know that nanoscale molecular machines (largely proteins) are responsible for cell mobility (cilia and flagella), muscle movement (actin/myosin), cellular metabolic transport, and control flow in and out of cells via ion channels in cell membranes. Students also know that nanostructures play an important role in cell structure (cytoskeleton), adhesion/traction (Gecko) and self-cleaning surfaces (Lotus leaf).

Big Ideas: NS2, NS3
Selected, relevant NSE modules: G2 (Gecko); B7 (Lotus), Q2, W17, U29

Pertinent Wikipedia entries:
http://en.wikipedia.org/wiki/Molecular_machine
http://en.wikipedia.org/wiki/Lotus_effect
http://en.wikipedia.org/wiki/Cytoskeleton
http://en.wikipedia.org/wiki/Cell_membrane
http://en.wikipedia.org/wiki/Synthetic_setae
http://en.wikipedia.org/wiki/Metabolism
http://en.wikipedia.org/wiki/Active_transport
http://en.wikipedia.org/wiki/Endocytosis
http://en.wikipedia.org/wiki/Molecular_recognition

Selected illustrations of growing NSE knowledge and its pertinence:
Cells as factories with nanoscale molecular machinery[98,99]
Synthetic molecular machinery with biomimetic applications[100]
Nanopore transport through membranes for cellular processes[101,102]
Nanoscale protein folding/misfolding and disease implications[103]
Molecular recognition and surface templating[104]
Nanostructures for tissue engineering to promote healing[105]
Nanostructure role in bones/teeth[106]
Potential toxicity of nanostructures[107]
Nanostructured forces in Lotus leaf hydrophobicity and self-cleaning[108]
Nanostructured mechanisms in Gecko mobility[109]

II.2.b. LS1.C Optimization of Matter/Energy Flow in Organisms (Grades 9-12, pg 7-11)

STANDARD: Students know the role of nanostructures in photosynthesis.
Big Ideas: NS1, NS4
Selected, relevant NSE modules: none
Pertinent Wikipedia entries:
http://en.wikipedia.org/wiki/Photosynthesis

Selected illustrations of growing NSE knowledge and its pertinence:
Photosynthesis (utilizes 4 different nanostructures)[110]

II.2.c. LS2.B Variation of Traits (Grades 9-12, pg 7-14)

STANDARD: Students know that various methods (polymerized chain reaction, lasers, nanopores, etc.) can be used to determine the sequence of the nucleic bases in strands of DNA, and that nanostructures can be used to facilitate the modification of genetic information in cells.
Big Ideas: NS3, NS7
Selected, relevant NSE modules: D15, J2, J3
Pertinent Wikipedia entries:
http://en.wikipedia.org/wiki/Nanopore
http://en.wikipedia.org/wiki/Polymerase_chain_reaction
http://en.wikipedia.org/wiki/Human_genetic_engineering

Selected illustrations of growing NSE knowledge and its pertinence:
Chips with nanopores for low-cost, rapid DNA sequencing[91,111]
Nanostructure role in gene therapy[112]

II.3. NSE Concepts in Earth and Space Sciences (ESS)

II.3.a. ESS1.A The Universe (Grades 9-12, pg 7-22)

STANDARD: Students know that the development of recent nanoscience has been influenced by other sciences such as astronomy and cosmology (e.g., Buckyballs – fullerenes – were discovered while looking for unique forms of carbon hypothesized from spectral images of distant galaxies) and that our new ability to measure at the nanoscale opens new observation capabilities.

Big Ideas: NS2

Selected, relevant NSE modules: none

Pertinent Wikipedia entries:

http://en.wikipedia.org/wiki/Younger_Dryas_event

http://en.wikipedia.org/wiki/Fullerene

Selected illustrations of growing NSE knowledge and its pertinence:

Nanodiamonds in meteorites – star origins[113]

Earth and Planetary materials - nanoscale composition/structure[114]

II.4. NSE concepts in Physical Sciences (PS)

II.4.a. PS1.A Atomic Structure of Matter (Grades 9-12, pg 7-41)

STANDARD: Students know examples of structures at the nuclear, atomic, nano, micro, and macro scales. They also know the role of surfaces and interfaces in structures at the nano, micro and macro scales.

Big Ideas: NS1 and NS2

Selected, relevant NSE modules: D1, H17, O1, U1, U10

Pertinent Wikipedia entries:

http://en.wikipedia.org/wiki/Nanomaterials

http://en.wikipedia.org/wiki/Surface_science

http://en.wikipedia.org/wiki/Interface_and_colloid_science

Selected illustrations of growing NSE knowledge and its pertinence:

Surface/interface structure/composition and technology implications[115]

Novel nanocrystalline material mechanical properties [116]

II.4.b. PS1.B Properties of Matter (Grades 9-12, pg 7-42)

STANDARD: Students know that material properties change as scale goes from micro to nano, that three different effects can evoke that change (surface/interface effects, collective effects, quantum effects), and what specific properties may change (electrical, physical, biological etc.)

Big Ideas: NS2

Selected, relevant NSE modules: A4, H10, K2, W19, W20

Pertinent Wikipedia entries:

http://en.wikipedia.org/wiki/Nanoparticle

http://en.wikipedia.org/wiki/Nanowire

http://en.wikipedia.org/wiki/Quantum_dot

http://en.wikipedia.org/wiki/Dendrimer

http://en.wikipedia.org/wiki/Superlattice

Selected illustrations of growing NSE knowledge and its pertinence:

Synthesis of a wide variety of nanostructures with novel properties[117]

"Periodic Table" of nanostructures[118]

Core/Shell approaches to nanostructure multifunctionality[119]

II.4.c. PS2.A Fundamental Interactions (Grades 9-12, pg 7-43)

STANDARD: Students know that forces are dependent on number of atoms, mass and electrical/magnetic properties, and that the level of dependency is related to size scale and structure.

Big Idea: NS2 and NS4

Selected, relevant NSE modules: F6, J8, S8

Pertinent Wikipedia entries:

http://en.wikipedia.org/wiki/Synthetic_setae
http://en.wikipedia.org/wiki/Lotus_effect
http://en.wikipedia.org/wiki/Double_layer_%28interfacial%29
http://en.wikipedia.org/wiki/Ferromagnetism
http://en.wikipedia.org/wiki/Paramagnetism
http://en.wikipedia.org/wiki/Molecular_recognition
http://en.wikipedia.org/wiki/Steric_effects
http://en.wikipedia.org/wiki/Adsorption

Selected illustrations of growing NSE knowledge and its pertinence:

The roles of various forces at the nanoscale[120,121]
Nanostructure effects on surface forces – Gecko,[109] Lotus leaf[108]
Surface templating for molecular recognition (adsorbents, diagnotics)[104]

STANDARD: Students know the origin and nature of van der Waals forces and their importance in molecular/nanostructure assembly.

Big Ideas: NS4

Selected, relevant NSE modules: F6, T5, W18

Pertinent Wikipedia entries:

http://en.wikipedia.org/wiki/Van_der_Waals_force
http://en.wikipedia.org/wiki/Molecular_self-assembly
http://en.wikipedia.org/wiki/Self-assembly
http://en.wikipedia.org/wiki/Colloid

Selected illustrations of growing NSE knowledge and its pertinence:

Intermolecular and Surface Forces[120]
Peptide-Amphiphile Nanostructures[122]

STANDARD: Students demonstrate that modeling and simulation can be used at multiple size scales – macro, micro, nano and atomic.

Big Idea: NS8

Selected, relevant NSE modules: U6

Pertinent Wikipedia entries:

http://en.wikipedia.org/wiki/Multiscale_modeling

Selected illustrations of growing NSE knowledge and its pertinence:

Theory, Modeling and Simulation at the nanoscale[123]
NanoHub modeling/simulation modules[124]
Liquid flow simulation with boundary effects[125]

II.4.d. PS2.C Transformations of Matter – Forces and Stability (Grades 9-12, pg 7-46)

STANDARD: Students know that surfaces, interfaces and nanostructures behave differently than do bulk materials due to different forces in their environment.

Big Ideas: NS2, NS4

Selected, relevant NSE modules: B7, T9, AA5

Pertinent Wikipedia entries:

http://en.wikipedia.org/wiki/Premelting
http://en.wikipedia.org/wiki/Nanomaterials
http://en.wikipedia.org/wiki/Transparent_ceramics
http://en.wikipedia.org/wiki/Capillary_action
http://en.wikipedia.org/wiki/Ferrofluid

Selected illustrations of growing NSE knowledge and its pertinence:

Sintering of nanostructures at lower temperatures[126]
Magnetism at the nanoscale[127]
Fluid flow boundary effects (rheology)[128]

STANDARD: Students know that molecules and nanostructures can assemble through collective forces, and that imposed boundary conditions can affect that assembly

Big Ideas: NS2, NS4, NS6

Selected, relevant NSE modules:

Self Assembly: B5, T5, W18
Liquid Crystal: D14, Q5, S27

Pertinent Wikipedia entries:

http://en.wikipedia.org/wiki/Nanochemistry
http://en.wikipedia.org/wiki/Self-assembly
http://en.wikipedia.org/wiki/Surfactant
http://en.wikipedia.org/wiki/Micelle
http://en.wikipedia.org/wiki/Liquid_crystal
http://en.wikipedia.org/wiki/Copolymer

Selected illustrations of growing NSE knowledge and its pertinence:

Block-copolymers – novel properties and role in surface patterning[129]
Surfactants and their roles in biology and cleaning[130]
Liquid crystal and their use in displays[131]

STANDARD: Students know how surface area of the constituents affects the rate with which a process occurs (e.g. a sugar cube versus granulated sugar dissolving in hot tea or ice cubes versus chipped ice in soda).

Big Ideas: NS1, NS2, NS7

Selected, relevant NSE modules: U9, U15, Z3

Pertinent Wikipedia entries:

http://en.wikipedia.org/wiki/Dissolution_%28chemistry%29
http://en.wikipedia.org/wiki/Catalysis
http://en.wikipedia.org/wiki/Adsorption
http://en.wikipedia.org/wiki/ALICE_%28propellant%29
http://en.wikipedia.org/wiki/Nano-thermite

Selected illustrations of growing NSE knowledge and its pertinence:

Catalytic rates and energy conservation[132]

Nanoscale adsorbents and their role in environmental clean-up[133]
Nanostructure role in energy release rates with propellants/explosives[134]

II.4.e. PS3.A Descriptions of Energy (Grades 9-12, pg 7-48)

STANDARD: Students know that atomic, molecular, and nanostructure self-assembly is an example of a total energy minimization process and that boundary conditions can be imposed to direct that assembly.

Big Ideas: NS4, NS6
Selected, relevant NSE modules: B5, T5, W18
Pertinent Wikipedia entries:
http://en.wikipedia.org/wiki/Self-assembly
http://en.wikipedia.org/wiki/DNA_nanotechnology
http://en.wikipedia.org/wiki/Patterning_by_etching_at_the_nanoscale
Selected illustrations of growing NSE knowledge and its pertinence:
Patterning block-copolymer assembly through boundary conditions[129]
Micelle structural transformations[135]
DNA graffiti and scaffolding[136]

STANDARD: Students know that energy can be transformed (dissipated) into heat through frictional losses and that surface structure at all size scales, but especially the nanoscale, may contribute to the dissipation.

Big Ideas: NS2, NS4
Selected, relevant NSE modules: D8
Pertinent Wikipedia entries:
http://en.wikipedia.org/wiki/Friction
Selected illustrations of growing NSE knowledge and its pertinence:
Tribology at the nanoscale[137]

II.4.f. PS4.B Electromagnetic Radiation (Grades 9-12, pg 7-50)

STANDARD: Students know how the relationship between the impinging energy and the system dimensions affect and define the specific interaction (between the energy and the system).

Big Ideas: NS7 and NS2
Selected, relevant NSE modules: D10, H9, S41, U23, U25
Pertinent Wikipedia entries:
http://en.wikipedia.org/wiki/Plasmonic_metamaterials
http://en.wikipedia.org/wiki/Nanophotonics
http://en.wikipedia.org/wiki/Refractive_index
http://en.wikipedia.org/wiki/Scattering
Selected illustrations of growing NSE knowledge and its pertinence:
Nanoscale plasmonics to enable revolutionary optical devices[138]
Negative index of refraction enabling lenses, cloaking[139]
Nanophotonics as approach to modify light propagation in solids[140]

II.4.g. PS4.C Detection and Interpretation, Instrumentation (Grades 9-12, pg 7-54)

STANDARD: Students know the characteristics and capabilities of the optical microscope (standard, near-field), force microscope (mechanical, magnetic) and electron microscopes (scanning, transmission and tunneling).

Big Ideas: NS7
Selected, relevant NSE modules: J6, S23, W14, AA2, AA7, BB1
Pertinent Wikipedia entries:
http://en.wikipedia.org/wiki/Atomic_force_microscopy
http://en.wikipedia.org/wiki/Magnetic_force_microscope
http://en.wikipedia.org/wiki/Kelvin_probe_force_microscope
http://simple.wikipedia.org/wiki/Scanning_tunneling_microscope
http://en.wikipedia.org/wiki/Magnetic_resonance_force_microscopy
http://en.wikipedia.org/wiki/Scanning_tunneling_microscope
http://en.wikipedia.org/wiki/Scanning_tunneling_spectroscopy
http://en.wikipedia.org/wiki/Near-field_scanning_optical_microscope
http://en.wikipedia.org/wiki/Scanning_electron_microscope
http://en.wikipedia.org/wiki/Transmission_electron_microscopy
Selected illustrations of growing NSE knowledge and its pertinence:
Nanoparticle Characterization[141]
Force Microscopy[142,143]
Scanning Tunneling Microscopy/Spectroscopy[144,145]
Near Field Optical Microscopy[146,147]
NanoProfessor[148] and NanoEducator[149] teaching instruments

II.5. NSE Concepts in Engineering and Technology (ET)

II.5.a. ET1.B Nature of Technology (Grades 9-12, pg 7-56)

STANDARD: Students know that miniaturization into the nanoscale underpins modern information technology devices, enables the continued information technology revolution, and opens the possibility for close coupling of biotic and abiotic systems. It also underpins many of the potential solutions to sustainable energy and to medicine and health – both considered major economic engines for the coming decades.

Big Ideas: NS8, NS9
Selected, relevant NSE modules:
Information technology: D6, U13, V4
Biotechnology: A6, H2, Q3, T7
Energy: B6, E7, H15, P3, U19
Pertinent Wikipedia entries:
http://en.wikipedia.org/wiki/Nanobiotechnology
http://en.wikipedia.org/wiki/Green_nanotechnology
http://en.wikipedia.org/wiki/Nanotechnology
http://en.wikipedia.org/wiki/Nanosensor
http://en.wikipedia.org/wiki/Moore%27s_law
http://en.wikipedia.org/wiki/Nanoelectronics
http://en.wikipedia.org/wiki/Semiconductor_memory
http://en.wikipedia.org/wiki/Racetrack_memory
http://en.wikipedia.org/wiki/Flash_memory
http://en.wikipedia.org/wiki/Liquid_crystal_display
http://en.wikipedia.org/wiki/Nanocrystal_solar_cell
http://en.wikipedia.org/wiki/Nanobatteries
http://en.wikipedia.org/wiki/Lab-on-a-chip
Selected illustrations of growing NSE knowledge and its pertinence:
See the many examples in Section IV

II.5.b. ET1.C Using Tools and Materials (Grades 9-12, pg 7-57)

STANDARD: Students know engineered nanostructures are newly created materials building blocks, enabling a broad range of new materials properties and that directed, hierarchical self-assembly techniques will be necessary to fully exploit affordable manufacturing.

Big Ideas: NS5, NS6, NS9

Selected, relevant NSE modules: B4, B5, D12, S6

Pertinent Wikipedia entries:

http://en.wikipedia.org/wiki/Nanostructure
http://en.wikipedia.org/wiki/Nanoparticle
http://en.wikipedia.org/wiki/Quantum_dot
http://en.wikipedia.org/wiki/Copolymer
http://en.wikipedia.org/wiki/Self-assembly
http://en.wikipedia.org/wiki/Superlattice
http://en.wikipedia.org/wiki/Nanolithography
http://en.wikipedia.org/wiki/Nanoimprint_lithography
http://en.wikipedia.org/wiki/Dip-Pen_Nanolithography

Selected illustrations of growing NSE knowledge and its pertinence:

"Periodic Table" for nanostructures[118]
Nanoscale roll-to-roll printing[83]
Block copolymer self-assembly and applications[129]
Peptide and protein as nanomaterial building blocks[150]
Liquid crystal self-assembly, displays[131]
Creation of nanoscale superlattices and their role in optoelectronics[151]
Approaches to manufacturing affordable, reproducible structures[83,152]

STANDARD: Students know that instruments must be specially designed to make, measure and manipulate at the nanoscale, and that the critical parts of these instruments will be micron in size scale.

Big Ideas: NS7

Selected, relevant NSE modules: J6, W14, AA2

Pertinent Wikipedia entries:

http://en.wikipedia.org/wiki/Single-molecule_experiment
see also II.4.g

Selected illustrations of growing NSE knowledge:

Feynman's talk Plenty of Room at the Bottom[153]
Scanned probes for measurements at surfaces and nanostructures[154]
Electron microscopy – aberration corrected for atomic precision[155]
Single molecule specific spectroscopy (not ensemble averaged data)[156]
See also II.4.g.

II.5.c. ET2.B Generating and Evaluating Solutions (Grades 9-12, pg 7-59)

STANDARD: Students know that the integrity of the metrology applied to any measurement or experiment can impact the validity of the results and models.

Big Ideas: NS8

Selected, relevant NSE modules: A3, U22

Pertinent Wikipedia entries:

http://en.wikipedia.org/wiki/Nanometrology

Selected illustrations of growing NSE knowledge and its pertinence:

Nanoscale challenges to metrology and standards[157]
Nanoscale reference materials[158]
U.S. NSE standards[159]
International Standards Organization NSE standards[160]

II.5.d. ET2.C Optimizing and Making Tradeoffs (Grades 9-12, pg 7-60)

STANDARD: Students know that manufacturing at the nanoscale requires different processes and procedures.

Big Ideas: NS8 and NS9

Selected, relevant NSE modules:

Patterning: B4, H16, L7

Self Assembly: B5, L8, T5, W18

Pertinent Wikipedia entries:

http://en.wikipedia.org/wiki/Nanomanufacturing
http://en.wikipedia.org/wiki/Self-assembly
http://en.wikipedia.org/wiki/Nanoimprint_lithography

Selected illustrations of growing NSE knowledge and its pertinence:

Materials and design[161]
Multicomponent self-assembly[162]

II.5.e. ET CORE IDEA 3: Technological Systems

STANDARD: Students know selected examples of nano-enabled technologies as State-of-Art paradigms of technological systems

Big Ideas: NS9, NS10

Selected, relevant NSE modules: all of H, J7, S25, W26

Pertinent Wikipedia entries:

http://en.wikipedia.org/wiki/List_of_nanotechnology_applications
http://en.wikipedia.org/wiki/Nanoelectronics
http://en.wikipedia.org/wiki/Nanomedicine
http://en.wikipedia.org/wiki/Nanobatteries
http://en.wikipedia.org/wiki/Environmental_implications_of_nanotechnology

Selected illustrations of growing NSE knowledge and its pertinence:

See the many examples in Section IV.

II.5.f. ET4.A Interactions of Technology and Society (Grades 9-12, pg 7-64)

STANDARD: Students know the benefits/risks associated with nano-enabled technologies.

Big Ideas: NS9, NS10

Selected, relevant NSE modules: N5, W28, W29, W36

Pertinent Wikipedia entries:

http://en.wikipedia.org/wiki/Nanotoxicology
http://en.wikipedia.org/wiki/Nanotechnology
http://en.wikipedia.org/wiki/Environmental_implications_of_nanotechnology

Selected illustrations of growing NSE knowledge and its pertinence:

Exposure to engineered nanoparticles[163]
Nano-enabled medical intervention[164]
Nanoparticles in contaminated site clean up[165]
Nano-enabled approaches to sustainable energy[166]

STANDARD: Students know that nanoscale science/engineering will enable human intervention in the transfer of genetic information, and the role of RNA and DNA therapies in medicine.

Big Ideas: NS3

Selected, relevant NSE modules: none

Pertinent Wikipedia entries:

http://en.wikipedia.org/wiki/Gene_therapy

http://en.wikipedia.org/wiki/DNA_sequencing

Selected illustrations of growing NSE knowledge and its pertinence:

Nanoparticles to enable RNA and DNA medical therapies[167]

III. International Benchmarks for NSE in K-12 Education

III.1. U.S. K-12 NSE efforts

Over the past decade of the National Nanotechnology Initiative, considerable effort has been devoted to education in parallel with, and in support of, research activities. For instance, a search of the NSF awards database shows nearly 30 Research Experience for Teachers (RET) programs have focused on nanotechnology since 2000. Many of these efforts have resulted in the development of teaching kits and outreach materials as discussed in Section I.2 and detailed in Appendix A.

However, there has been little formal introduction of nanotechnology into the individual state science standards, which speaks to the urgency and timeliness of this report. There has been some progress in Virginia. Following guidance developed by a series of workshops,[168] the State of Virginia has introduced NSE content into its K-12 Standards of Learning Curriculum Framework, with implementation expected by 2012-2013.[169] Efforts are also underway to design and implement a dual-enrollment (high school - community college) introductory nanotechnology class to be piloted in Central Virginia and later disseminated statewide.[170]

NSF funded three research projects to evaluate nanoscale education for both middle and high school students – the NanoSense project by SRI International,[171] the NanoLeap Modules by McREL[172] and Stanford Nanofabrication Laboratory,[173] and the Nano Modules of the NCLT.[174] Each of these projects developed a series of modules for classroom use. Some of those modules have been incorporated into the CK-12 flexbook materials.[175] Other modules are available through the National Science Teacher Association.[176] However, the degree of in-depth experience in "nano" by the students varied from project to project, ranging from power point presentations to hands-on experience with design projects.

As benchmarks for the U.S. status, we pose three important questions:

1. Can K-12 students learn NSE?
2. Are nanoscale concepts important to science education?
3. Do we have good content ready for the classrooms?

Can K-12 students learn NSE? The simple answer is an unqualified 'yes', if they can learn science, they can learn NSE. But the level of understanding depends on many independent variables, some of which include: the student's knowledge of math, science and English; the way the assessment questions are given; and the ability of the teacher to teach the basic science concepts (in the textbooks) and at the nanoscale (something not in the standard textbooks). Each of the three research projects mentioned above reflect some of the variables, but not all of them.

Are nanoscale concepts important to science education? As highlighted in this workshop report, nanoscale concepts are essential to K-12 science education. However, the current mandate for teachers is to teach what is in the standards. Thus, there must be a strong impetus to include nanoscience in the K-12 Next Generation of Science SOL. From the perspective of those who are developing nanoscale instructional modules, nanoscale concepts will enhance the learning of basic science concepts that are currently mandated. That is to say most of the present standards cover nanoscale concepts only implicitly, at best, and need to be revised.

NSE is a perfect approach toward meeting the current national priority to improve STEM education since it illustrates the integration of STEM subjects. Science and engineering at the nanoscale does not separate physical sciences from biological sciences, engineering and math are very much an integral part, and there is clear societal impact. This approach is termed horizontal integration of STEM. Thus, there is an opportunity for designing nanoscale modules to fill this need.

Do we have good NSE content for the classrooms? Some good content in NSE has been developed (see Appendix A). Most of these modules are for supplementary purposes, since the teachers are not currently required to teach nano and thus view the topic as something extra or supplemental. The present K-12 NSE modules must be revised and extended to address deficiencies such as - they do not adequately cover all of the big ideas, do not yet address learning progressions, nor have they been sufficiently vetted by K-12 teachers. Good instructional materials are costly and time consuming to develop. There are many parameters to take into consideration: level of students; connection to science classes; safety (for experiments), cost (affordability); linkage to standards and learning goals; student interest; relevance to society or job opportunity; good assessment process; ease of use by teachers; building student knowledge base and self-esteem; teach teamwork and leadership; taking the latest research into the classrooms; and real design experience based sound science concepts and understanding. In addition, the instructional materials need to be field tested in different classrooms in different regions (states) of the country.

III.2. International K-12 NSE efforts:

III.2.a. Taiwan

Taiwan started its National Nanotechnology Program (NNP) in 2003, encompassing four sectors - industrialization of nanotechnology, academic research, core facility sharing, and human resource development. The aim, through the establishment of common core facilities and education programs, is to achieve academic excellence in nano research, to create innovative industrial applications, and to speed up the commercialization of nano-enabled technology. There were ten government agencies - including the Ministry of Economic Affair, the National Science Council, the Ministry of Education, the Department of Health, and the Environmental Protection Agency – that sponsored Phase I of this program with a total budget of about US$ 620 million for a period of 6 years (2003 to 2008). Beginning in 2009, Phase II of the NNP was launched for another 6 years.

The ultimate goals of the NNP human resource development program (HRDP) are:

- Cultivating leaders and researchers for nanoscience and technology
- Nurturing experts and entrepreneurs for nanoindustries and business
- Educating general public that understand and support nanotechnology
- Imbuing a lifelong learning subject and education environment

The human resource development program can be classified into three categories as shown in **Figure 8**:

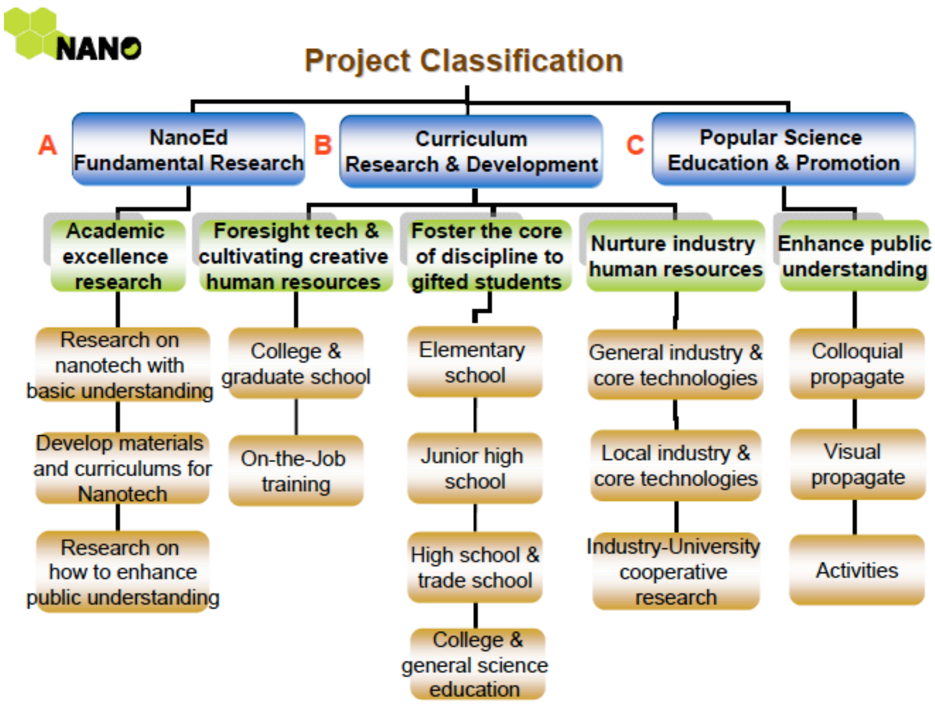


Figure 8: Categories for human resource development in the Taiwan NNP.

To carry out the human resource development program efficiently and to spend the budget effectively, a program office was established to take charge of the planning, coordinating, administrating and auditing work. Ten regional centers along with an e-learning platform were created and sponsored across the country. Five of them were devoted to advanced education, i.e., college level and beyond, the others for K-12 education. It is the first time in Taiwan that advanced science and technology has been introduced to K-12 education through a national human resource development program.

Unlike other countries, Taiwan extended its nanoeducation into K-12 from the very beginning of its NNP in 2003. It has the most mature nanoeducation effort with the goals of:

- Cultivating K-12 seed teachers by offering lectures, workshops, and lab training courses
- Developing universal K-12 teaching and learning materials on nanotechnology
- Promoting international academic collaboration on K-12 nanotechnology education
- Collaborating with the National Taiwan Science Educations Center, the National Museum of Natural Science, and the National Science and Technology Museum to promote nanotechnology education for the general public

The range of Universities, schools and K-12 teachers engaged in the nanoeducation effort is shown in **Figure 9**. In addition to the above-mentioned activities, there are annual K-12 Teacher Workshops, Nano Innovation Contests, and the Taiwan Nano Exhibition.

NANO

K-12 Nanotechnology Education

K-12 Nanotechnology Education	
Universities (2003-2009)	**401**
leading schools (2003-2009)	**364**
K-12 active seed teachers (2003-2009)	**1,082**
K-12 potential seed teachers (2003-2009)	**8,270**
Activities 2003-2009	
Conferences	**235** (86,765 participants)
Seminars, competitions, exhibitions, workshops, speeches	**2,245** (26,5797 participants)

Figure 9: K-12 Nanotechnology education statistics.

Seed teachers with science background from K-12 schools were recruited to nearby universities or colleges for training in the form of lectures, hands-on experiments, and lab training courses on a regular basis for a period of six months to one year. With this nano knowledge, the K-12 seed teachers were encouraged to develop a wide variety of teaching materials, experimental kits, animated cartoons, etc. suitable for K-12 students. More than 1,600 books, cartoons, teaching plans, lecture notes, teaching kits, and references have been developed. Many of the K-12 NanoEd materials, such as *A Fantastic Journey of Nana and Nono, NM Magic House, The Wonderland of Nanotechnology*, have been translated into different languages and have gained great popularity. This effort in K-12 NSE education is now in the process of being evaluated.

III.2.b. Australia (Access Nano)

The Melbourne Declaration on Educational Goals for Young Australians was signed by State, Territory and Commonwealth Ministers for Education in 2008. The agreement highlighted objectives for Australian education, including the development of a National Australian Curriculum.

Previously the curriculums were determined by each state and territory. For nanoeducation this posed a challenge in that some states or territories included nanotechnology in the curriculum and others did not. However, nanotechnology has been specified under the new curriculum.

The Australian Curriculum for science years K-10 was released in December 2010; it details what students are expected to learn for each year and to what competency. Assessment of the curriculum is still determined by the state and territories, as is how to apply the curriculum in their classrooms. Currently state and territory education departments are assessing existing curriculums and education resources while trialing the new curriculum in select schools.

On a national level the Department of Education, Employment and Workplace Relations (DEEWR) and the Ministerial Council for Education, Early Childhood Development and Youth Affairs (MCEECDYA) has engaged Education Services Australia (ESA), a not-for-profit government corporation, to develop two tools to assist Australian teachers with the new curriculum; Scootle[177] and Curriculum Connect.[178] Both resources are available to teachers and educators through their local education department, educational organization or association, or by registering with the ESA. The websites are not available outside Australia and New Zealand.

Both sites are portals accessing a pool of digital resources for teachers to use. Scootle allows teachers to seek out resources by search terms or resource content. Curriculum Connect, which is still in trial format, showcases resources suitable for each component of the Australian Curriculum.

In 2009 the Department of Innovation, Industry Science and Research (DIISR) also released the innovation agenda *Powering Ideas: An Innovation Agenda for the 21st Century*. Part of the Agenda was the creation of the National Enabling Technologies Strategy (NETS). Its purpose is to provide a responsible framework for the development of enabling technologies, which is defined as nanotechnology, biotechnology and other emerging technologies.

A component of NETS is the Public Awareness and Community Engagement section (NETS-PACE). NETS-PACE provides factual information to the public while seeking feedback on public attitudes towards these technologies. Towards this end NETS-PACE undertakes web 2.0 activities, community events and surveys, material publication and develops education resources for K-12 students.

For its education projects NETS-PACE maintains and develops two online education resources, Biotechnology Online (www.biotechnologyonline.gov.au) and AccessNano (www.accessnano.org). Both resources were developed with consultation with stakeholders and contain editable downloadable content and curriculum maps for each state and territory.

NETS-PACE is currently redeveloping Biotechnology Online and AccessNano into a single enabling technologies resource, which will be reflective of the content of the National Curriculum.

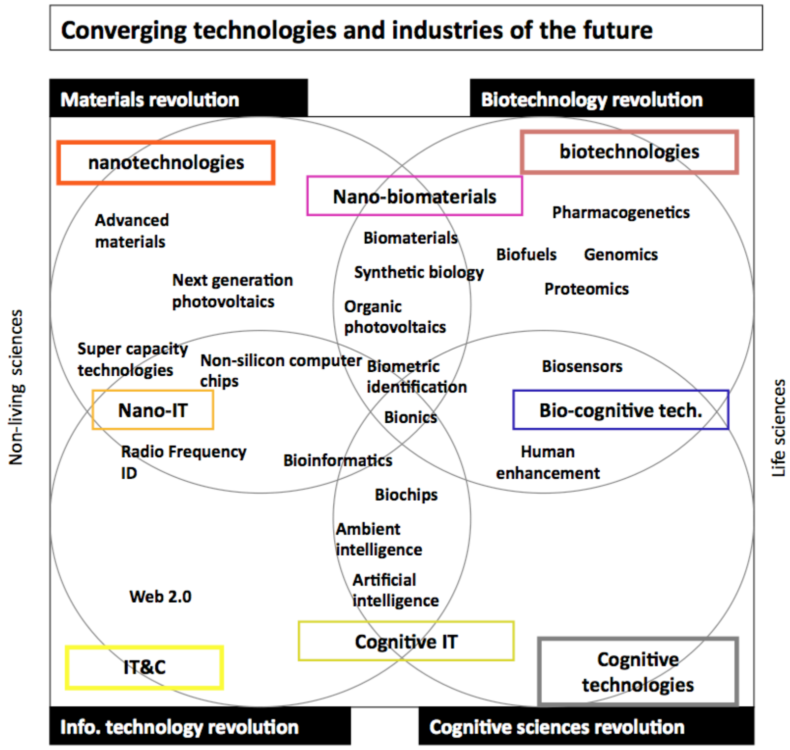


Figure 10 (above): Format 1 of Nanotechnology and Biotechnology Resources

Figure 11 (below): Format 2 of Nanotechnology and Biotechnology Resources

Year 10 Content descriptions

Science Inquiry Skills	Science as a Human Endeavour	Science Understanding
1. Questioning and predicting	1. Nature and history of science	1. Evolution
Research information from a variety of sources to formulate scientific questions and develop testable hypotheses	Ideas of the world change as scientific theories and models develop	Evolution by natural selection and the diversity of plants and animals
2. Investigation methods	2. Influence of science	2. DNA
Choose the most appropriate investigation type for the question including experimental investigations involving repeat trials and replicates and multiple variables	Science provides reliable knowledge and enables valid predictions and conclusions to inform choices	The structure and function of DNA, genes and chromosomes
3. Using equipment	3. Contribution of scientists	3. Genetics
Select and use specialised equipment and materials that are suitable for the investigation	Scientists are recognised by society in various ways for their contribution to human understanding	The role of genes in determining patterns of inheritance and the chemical processes in cells
4. Managing risk	4. Collaboration in science	4. The Universe
Conduct a risk assessment of a practical activity	Science research commonly involves teams of scientists with expertise from a diversity of specialisations	The evidence supporting the big bang theory and the major processes that have produced galaxies and planetary systems
5. Observing and measuring	5. Science and culture	5. Plate tectonics
Collect data in a consistent, efficient, and ethical manner, including methods that use ICT	The knowledge of a cultural group can contribute to scientific understandings in areas such as agriculture, sustainability and technological design	Plate tectonics explains global patterns of geologic activity, continental movement, and the characteristics of the Australian continent
6. Analysing results	6. Science careers	6. Forces and motion
Represent and analyse data appropriately including using simple statistical methods and ICT	Science, engineering and technology are interdependent in the work of many careers and industries	Forces, motion and conservation of energy, their interactions and how they can be described qualitatively and quantitatively
7. Developing explanations		7. Matter and energy
Draw conclusions that are consistent with the evidence and critique these conclusions with reference to scientific concepts		Large and small scale physical systems rely on dynamic interactions between matter and energy
8. Communicating		8. Atoms
Communicate scientific ideas and information for a particular audience and purpose, including making evidence-based arguments		The periodic table as an organiser based on the electronic structure of elements
9. Reflecting on methods		9. Chemical change
		Chemical reactions can be represented by symbolic equations and are affected by factors such as temperature, catalysts

e

= Biotechnology
= Nanotechnology

NETS-PACE intends to host the new resource on Scootle, Curriculum Connect and its own website which will be open to the general public both in Australia and overseas. The website will present the resource in two formats. Figure 10 (format 1) displays how the resource relates to the various applications of nanotechnology and biotechnology and where the two fields overlap. Figure 11 (format 2) directly relates the resource to the requirements of the National Curriculum.

Each format has different benefits. Format 1 shows the diversity of applications of the fields, while Format 2 allows opportunity to reveal how these technologies relate to more traditional disciplines, such as physics and chemistry's relevance to nanotechnology. The different displays also cater to different audience needs. Format 1 is for teachers who wish to explore the technologies and applications; Format 2 is for teachers who simply wish to find relevant material for their classroom plans.

In November 2010 NETS-PACE launched its education redevelopment project with the Stakeholders Advisory Workshop (SAW). A day long workshop for stakeholders to discuss their needs in relation to the National Curriculum, and what they would desire in a new resource on biotechnology and nanotechnology. The workshop consisted of representatives from each state and territory education department and Science Teacher Associations (STAs), DEEWR, the ESA, the Catholic Education Office, the Australian Council for Deans of Science, and the Association of Independent Schools. The group determined it wanted the following attributes to any new resource:

- Highly editable and downloadable material with multiple entry points to the website,
- Enquiry based learning to develop critical thinking, and a combination of pracs and hands on learning with virtual labs for high science using real University data,
- Games with different difficulty levels with and saveable progress,
- Contemporary issues, such as water purification, addressed using current science, and showcasing scientists and careers,
- Teacher professional development (TPD) workshops to support the resource using the train the trainer model with the assistance of local STAs and Education Departments.

NETS-PACE is currently mapping the Australian Curriculum to identify areas in which the existing AccessNano and Biotechnology Online resources can be suitably transferred over to the new resource. The resource will then be developed along the directions provided by the SAW and presented to a group of science teachers and school lab technicians from differing backgrounds in April/May 2011. This group will assess the resource and its suitability in terms of classroom application. Feedback from this second group will lead to adjustments in the resource for its online launch in June 2011.

After the launch the resource will be trialed in select schools over the second half of 2011. From this trial, further adjustments will be made, and a full launch with a supporting teacher professional development program will begin in early 2012.

III.2.c. Europe

The European Commission, in its document “Nanosciences and nanotechnologies (N&N): An action plan for Europe 2005-2009”, calls upon Member States to: “...foster interdisciplinary training and education for R&D in N&N, focusing on physics, chemistry, biology, toxicology and ecotoxicology and engineering, but also including entrepreneurial studies, risk assessment, and social and human sciences where appropriate.”[179] In line with this, the GENNESYS initiative has devised a new education scheme and training structure and made a distinct proposal of how to establish a European education in nanomaterials science, which involves all sectors engaged in GENNESYS.[48]

The initiatives above could, together with the Bologna Process,[180] which has facilitated cooperation between and comparison of European Higher Educations, form a common European strategy for the education of future N&N scientists and engineers. However, so far only national and/or local initiatives exist, and they range from single university courses to full 5-year science or engineering programs. True interdisciplinarity is reflected in those educations where N&N have been built-in from the beginning,[181,182] and where courses from different subjects are fully concerted or integrated. These pioneering programs could preferably act as models for a more general initiative on creating a European scheme for higher nanoeducation. This was discussed at the GENNESYS conference in May 2010;[183] however, it has not yet been formally suggested.

To ensure some sort of impact, most European Union (EU) initiatives on education aim at reforming the uniform higher education area, or at highlighting educational needs of the society in very general terms. Examples of the latter are the Key Competences Framework,[184] the European Qualifications Framework[185] and the project New Skills for New Jobs.[186] They all intend to improve the educational systems within Europe so as to better match the supply of skills to the needs of the labour market. In the latter of these projects there is a focus on development of the vocational education sector.

NSE for K-12

When it comes to introducing NSE at a K-12-level, the development of common standards should be a possible way forward. However, difficulties occur in terms of developing and adopting common core (science) standards within the EU. Not only will it have to be formulated in 23 different languages, the work will also involve authorities and organizations at a national level or, in some European countries, even at a local level. Since no two European countries have similar organizations of their K-12 education, this is not likely to happen.

One of the underlying reasons for differences in K-12-education is the variation in educational attainment within the population of Europe. All European countries have a common goal in raising the educational attainment in general, but the strategies for doing this necessarily differ.[187] One should also keep in mind other significant demographic and historical differences, which always will be reflected in a lack of clarity in official messages delivered by the EU. European initiatives on education, e.g., the “Strategic framework for education and training,”[188] thus mainly result in descriptive policy documents and statistics. When looking for “priority areas” within the European

Commission's work on education and training, one finds priorities such as "... teacher education, key competences, language learning, information and communication technologies, math, science and technology, active citizenship and social cohesion." All this can be agreed upon generally among the states. However, narrowing subject areas by identifying nanoscience and nanotechnology as priority areas in K-12-education, probably would lead to endless discussions between the member states, thus paralyzing further work.

Several European countries are in the process of developing new (science) K-12-curriculums. These show hardly any sign of NSE, and from the writings one can conclude that the degree of interdisciplinarity in the science curriculums (still) decreases when moving from K towards year 12.

Teacher's Education

That interdisciplinarity is more prominent in the first years in school, is in line with the way most European teacher's educations are structured. Science for the teachers of the early grades transforms into biology, chemistry and physics for the grades 7-12 teachers. It would require a fundamental change of most European teacher's educations to fully include the engineering perspectives of STEM education and to promote interdisciplinarity in grades 7-12. Since the time-scale for such changes is long, a more viable approach would be to strongly invest in further training for teachers. This strategy has been adopted for example in Sweden, where the equivalent of U.S. $3,000 per teacher is being spent on further education between the years 2007 and 2014. However, the money is primarily invested in developing the teaching of mathematics, Swedish (first language) and English (second language) since these subjects in Sweden are considered "key subjects."

In 2007 the McKinsey report on the world's best performing schools concluded: "Above all, the top performing systems demonstrate that the quality of an education system depends ultimately on the quality of its teachers."[189] With this in mind, it is surprising that so few European countries invest in reforming and developing their teacher's education to make it up to date and an attractive choice for young people.

Resources Outside School

Within Europe there are only a few official EU-web resources presenting NSE for young people. Timefornano[190] is a website financed by the European Commission's 7th Framework Programme, FP7, and run by a consortium of European Science Centers. The content is a mix of pure information, pictures, competitions and quizzes. Which age group the site is targeting remains to be discovered. But to reach younger kids in the smaller European countries, the content has to be translated into more than the eight languages.

Nanoyou[191], the most extensive web resource, is an initiative financed within the FP7 as well, and aiming at "young people" in the 11-25 age group. Partners in this initiative include the nanoscience centers in Aarhus (DK), Barcelona (E), Cambridge (UK), and Grenoble (F) which all are involved in higher education on NSE. The website is one arena where NSE students can act as ambassadors for NSE in the K-12 age group.

Future Opportunities for Interaction

The platform Nanoyou could be developed to become the arena where NSE students meet teachers, pupils and the public. But the critical mass is yet to be reached – and overcome. Only about 50 European schools have this far become partner schools of Nanoyou. The platform also lacks connections to industry. Such cooperation, showing applications – examples from reality – would appeal to young people, school kids as well as students.

The project Nano Connect Scandinavia[192] is a resource aiming at supporting networks and spreading knowledge to "tie universities, businesses, scientists and students together, creating a world class nano cluster in south-western Scandinavia." It is mainly used by students of NSE, especially the newly graduated ones looking for jobs within the nano industry of Scandinavia.

The Scandinavian NSE programs, which truly focus on interdisciplinarity, e.g., the ones at the universities of Lund (SE) and Aarhus (DK), so far seem to be the ones most successful in providing the developing nano industry with a highly skilled workforce. The success of these university programmes could be used to further promote interaction between students, K-12 teachers and industry. Nano Connect Scandinavia is a possible platform for this interaction, but to reach a greater impact, a European arena with long sustainability is needed. This necessarily has to be influenced by interdisciplinarity and a true bottom-up perspective. The use of ideas and experiences by our kids and students is crucial.

IV. Cross-Cutting STEM Element Concepts - Examples at the Nanoscale

NSE is a showcase for highlighting cross-cutting, interdisciplinary concepts in nano-enabled technologies toward the solution of societal problems. Modules/labs/videos with multidisciplinary contributions at the nanoscale are identified in Appendix A.

IV.1. Medicine

It has long been appreciated that nanostructures and their properties are critical as tools to understand biological systems and as therapeutic agents. However it has only been in the last five years that "nanomedicine" as a field has been created and rapid progress observed. NSE is expected to make major contributions across the entire medicine/health scene with respect to mortality rate, the level of suffering that an illness imposes on a patient, the prevalence of disease, and the burden put on society.[162]

NSE modules applicable to Medicine: A6, I14, K7, M11, U7, X25

Selected illustrations of growing NSE knowledge and its applications:

- Diagnostics (*in-vivo,* arrays *in-vitro*)
  - NP for biomedical imaging[193]
  - Proteomic chip arrays for inexpensive, rapid diagnostics[194]
  - Sensing in Clinical applications[195]
- Therapeutics
  - Dental Restorative[106]
  - Targeting specific, localized sites[196]
  - NP treatment of cancer[197,198]
  - Drug carriers[199]
  - Gene Therapy[200]
- Implants and Tissue Regeneration
  - Self-assembled proteins – hemostasis, tissue regeneration, [201]
  - Bone/Joint replacement and healing[202]
  - Tissue regeneration[203]
- Prevention
  - Personalized medicine - DNA sequencing through nanopores[204]
  - Ag NP for antibiotics in wound dressings and surfaces[205]
- Medical Instrumentation and Devices
  - NP to guide surgical resection[206]
  - Next generation prosthetics – self powered, central nervous system controlled[207]

IV.2. Sustainable Energy

The world demand for energy is expected to double from 14 terawatts (TW) in the year 2000 to 28 TW by the year 2050.[208] Driving this need is both the expanding economies and the expanding world population that is expected to grow to 10 billion people within that same time frame. Since this population increase will be concentrated in the developing countries, it will have an impact not only on energy consumption patterns, but also on the environment (e.g., on green house gas production). These factors compound the energy challenge with the growing need to protect the environment, requiring renewed efforts and novel approaches to increasing energy efficiency and developing “clean” energy sources. A number of reports address the critical role for nanoscale science and engineering in addressing these problems;[209] **Figure 12** illustrates the breadth of NSE impact.

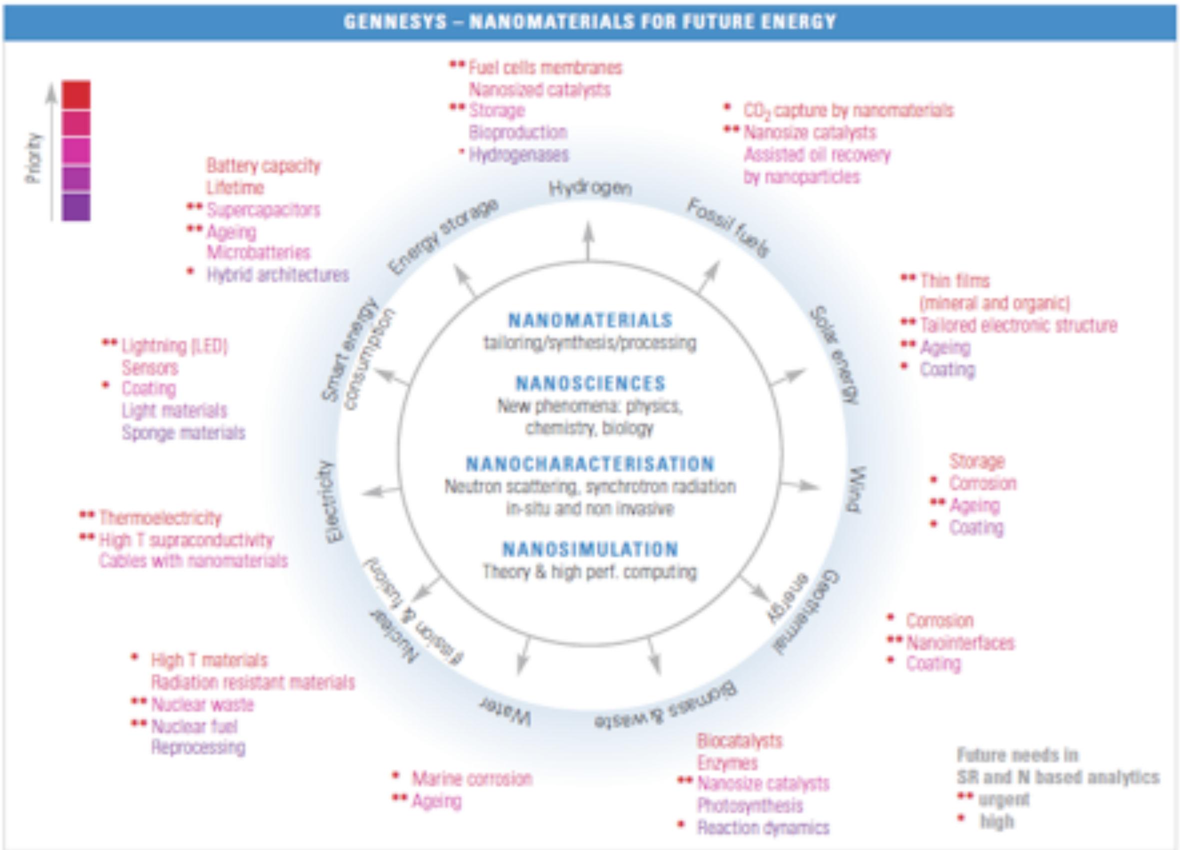


Figure 12: Infrastructure needed to create materials for the many energy applications identified in the Gennesys report.[48]

NSE modules applicable to sustainable energy: F7, Q3, T2
Selected illustrations of growing NSE knowledge and its applications:

- Building Insulation / thermal transport in nanostructured aerogels[210,211]
- Solar photon conversion[212] to chemical (photosynthesis)[110] and to electrical (solar cell) energy[212]
- Chemical energy conversion to electrical energy[213]
- Energy storage by ultacapacitors[214]
- Waste heat recovery – thermoelectric[215]
- Fuel cell membranes/electrodes[216]
- Solid-state lighting – LED/OLED[217]
- Piezoelectric generators[218]

IV.3. Environmental Sustainability, including Food/Water/Agriculture

Although the Earth has experienced many cycles of significant environmental change, during which civilizations have arisen, developed, and thrived, the planet’s environment has been stable during the past 10,000 years. This stability is now threatened as the world’s population has reached about 6 billion in 2010, and industrial output per capita continues to increase. Since the industrial revolution, human actions have become the main drivers of global environmental change and could put the “earth system” outside a stable state, with significant or catastrophic consequences.[219] Nanotechnology has the potential to address each of these areas of global sustainability, with the greatest impact likely to be in: sustainable water supplies, food security and sustainability, sustainable habitats, sustainable mineral extraction and use.[220]

Nanotechnology, as a new enabling technology, has the potential to revolutionize agriculture and food systems in the United States. Agricultural and food systems security, disease treatment delivery systems, new tools for molecular and cellular biology, new materials for pathogen detection and protection of the environment are examples of the important links of nanotechnology to the science and engineering of agriculture and food systems. Some overarching examples of nanotechnology as an enabling technology are: [221]

- Production, processing, and shipment of food products can be made more secure through: the development and implementation of nanosensors for pathogen and contaminant detection;
- The development of nanodevices can allow historical environmental records and location tracking of individual shipments;
- Systems that provide the integration of “Smart Systems” sensing, localization, reporting and remote control can increase efficiency and security;
- Agricultural and food systems security is of critical importance to homeland security. Our nation’s food supply must be carefully monitored and protected. Nanotechnology holds the potential of such a system becoming a reality.

NSE modules applicable to environmental sustainability: I1, J3
Selected illustrations of growing NSE knowledge and its applications:

- NP site remediation (Zero Valent Iron (ZVI),…)[105]
- Oil spill clean up[222]

NSE modules applicable to water/food/agriculture: I7, Q4, U6, V17
Selected illustrations of growing NSE knowledge and its applications:

- Packaging materials to control O_2 permeation[223]
- Sensing – farm fields, food packages[224]
- Water purification (desalination, grey water, …)[225]

IV.4. Information Devices and Management

In the last 10 years, the state of the art in nanoelectronics, including nanomagnetics and nanooptics, has rapidly gone from devices at or above 100 nm to the realm of 30nm and below, with a well-defined pathway to devices (including transistors for logic and memory) of about 15nm. In the process of reaching this size, the thickness of the critical layers in many structures is approaching 1 nm; the threshold voltage of a metal-oxide semiconductor field effect transistor (MOSFET) device is now controlled by fewer than 100 atoms. In the sub-10nm world, there will be no choice but to embrace the new nanoscale phenomena and focus on how to utilize them for new functionality beyond the complementary metal oxide semiconductor (CMOS) device. This will not only mean taking advantage of new nanoelectronic phenomena, but increasingly it will also mean manipulating the magnetic, spintronic, and other properties of matter at the nanoscale as state variables for computation and new forms of storage. The semiconductor industry is now ~$250 billion worldwide and driving the economies of most of the developed world.[226]

NSE modules applicable to information devices and management: V13, W4
Selected illustrations of growing NSE knowledge and its applications:

- The extension of present microelectronic device gate lengths[227]
- Hybrid circuits utilizing nanoelectronics to continue “Moore’s Law” [228]
- Coupling optoelectronics and electronics[229]
- Next generation logic/memory devices based on spintronics[230]
- Next generation logic/memory devices based on memristors [231]
- Memory storage increased to Terabit/cm^2 (25nm size) [232]
- Stretchable, bendable, very low cost electronic circuits[233]
- Application of electronic devices to medical uses[234]
- Quantum Dot enhanced sensing[235]
- Sensing with single event sensitivity[236]
- Display (QD phosphors, touch, transparent conductor electrode,..)[237]

IV.5. Innovative Materials - Materials by Design

The field encompassed by the term “nanomaterials” has changed dramatically over the past 10 years.[238,239] While it was useful in 2000 to describe nanomaterials on the sole basis of our ability to understand and control matter at the nanoscale where material properties possess a distinct size-dependence, the field has new grown well beyond that definition. For example, it is evident in 2010 that additional factors beyond constituent nanoparticles (e.g., high surface/interface area, proximity, and novel chemical, physical, and/or biological moieties) are also playing major roles. The worldwide scientific focus on nanostructured hybrid material systems based upon synthetic or natural polymers, combined with metal, ceramic, carbon, or natural (e.g., clay) nanostructures represents a truly revolutionary change in our thinking and in our ability to create nanostructured materials and coatings to solve real problems to benefit society.

NSE modules applicable to material innovation: A5, E12, all of I, R4, V5, V8, X23

Selected illustrations of growing NSE knowledge and its applications:

- Carbon nanotube based yarns/sheets[240]
- Cellulose-based nanomaterials[241]
- Nanocomposite materials[242]
- Concrete incorporating nanostructures[243]
- Metamaterials[244]
- Nanocrystalline metals[245]
- Nanoscale contributions to materials life cycle – wear, friction, corrosion, fracture[246]

IV.6. Consumer Products

Nanoscale materials are being incorporated into consumer products to provide innovative function,[247] as illustrations: colorless sunscreens, mechanical advantages in tennis racket, hockey sticks, baseball bats; disinfectant properties to surfaces, wound dressings, socks.

NSE modules applicable to consumer products: A8, C11, I7, I13, L4, V12
Selected illustrations of growing NSE knowledge and its applications:

- Sunscreen[248,249]
- Textiles[250]
- Disinfectant[251]
- Cosmetics[252]
- Adsorbents[253]

IV.7. Manufacturing

Nanomanufacturing has been identified as a signature initiative of the NNI. It is contributing commercial products ranging from nanostructured coatings and cosmetics to textiles and magnetic storage devices, among others. There has also been important work addressing the synthesis, fabrication, and patterning of nanostructures, in addition to work on bio-inspired synthesis and directed self-assembly.[254] Some nanofabrication techniques developed over the past decade rely on the constructive delivery of materials and integration of bottom-up synthetic strategies rather than top-down destructive approaches. These methods include dip-pen lithography, polymer pen lithography, inkjet printing, the transfer printing technique, and scanning probe block copolymer lithography. Of special importance is the low cost and scale up to high throughput roll-to-roll processes.

NSE modules applicable to manufacturing: B4, B5, I16, M7, M8
Selected illustrations of growing NSE knowledge and its applications:

- Nanoparticle quality control (size, shape, surface chemistry, ….)[255]
- NP core/shell/ligand to impart multifunctionality[256]
- Nanoscale patterning[129]
- Top down (lithography, etch) vice bottom up (directed self assembly)[257]
- Roll-to-roll at nanoscale[258]
- Catalysis – improved yield (saving energy, by-product waste)[259]

IV.8. Environmental/Safety/Health (ESH)

Although exposure to engineered nanomaterials (ENM) in the workplace, laboratory, home and the environment is likely more widespread that previously perceived, no specific human disease or verifiable environmental mishap has been ascribed to these materials to date. Perceptions of ENM hazard have evolved from “small is dangerous” to a more realistic understanding that ENM safety should best be considered in terms of the specific-use contexts, applications, exposures, and the specific properties of each nanomaterial. It is necessary to develop an integrated, validated scientific platform for hazard, exposure, and risk assessment at a scale commensurate with the growth of this technology.[260]

The Strategy for Nanotechnology-Related Environmental, Health, and Safety Research describes the NNI's approach for addressing priority research on EHS aspects of nanomaterials.[261]

NSE modules applicable to ESH: T33, X29
Selected illustrations of growing NSE knowledge and its applications:

- NP in auto emissions[262]
- Chemical spill[263]
- Toxicity[264]
- Risk assessment[265]

V. Conclusions and Recommendations

The U.S. investment in nanotechnology education has spawned a new paradigm for STEM education, which if broadly implemented, will allow the U.S. to maintain its global leadership in science and technology. There is a compelling case for the inclusion of NSE concepts in K-12 by infusing and or mapping NSE into the Next Generation of Science SOL, and then continually refreshing those concepts as NSE knowledge and practice evolves.

V.1. Creation of a K-12 NanoEducation Ecosystem

Finding: There are numerous groups around the world addressing STEM education (including a National Science and Technology Council committee), and the many nanoscale science and engineering research communities. There is an immediate challenge to integrate these various communities. A focal point is needed to identify, validate, and integrate the many NanoEducation capabilities that presently exist and to assess what is additionally needed. K-12 science/engineering education must be a high priority, and the NGA common core effort – K-12 Next Generation of Science SOL – is a near term opportunity. NSE should be incorporated into those standards (and the subsequent curriculum frameworks and assessments). This will require the NSE subject matter experts to work closely with educators who will know best when and how to present the materials, and with standards writers who will know best how to frame the standards.

The NSE education reflects a challenge for the Federal agencies. Any K-12 science and engineering program development needs to be integrated with career and college expectations. Workforce requirements fall under the Department of Labor. NSF funds the NSE subject matter experts through its Research Directorates, and the education experts through its Education and Human Resources Directorate. The U.S. Department of Education has an Institute of Education Sciences, an Office of Postsecondary Education and an Office of Vocational and Adult Education under the Office of the Under Secretary, and an Office of Innovation and Improvement and an Office of Elementary and Secondary Education under the Office of the Deputy Secretary. There needs to be formal mechanisms for these various groups to work together.

Principal Stakeholders include: The Executive Office of the President, including the Office of Science and Technology Policy (OSTP) and the National Science and Technology Council (NSTC), NNI participating Federal agencies, National Science Teachers Association (NSTA), National Parent Teachers Association; Council of Chief State School Officers (CCSSO), National Governors Association (NGA), International Technology Education Association (ITEA) and the state-based affiliates, professional science and engineering organizations (e.g., American Chemical Society, American Institute of Physics, Society of Manufacturing Engineers, etc.), NanoBusiness Alliance, STEM Education Coalition, and International representatives.

Recommendation 1: The NSET, which has representation from about 25 participating Federal agencies, should create a Nanotechnology Education and Workforce working group that will support the NNI efforts toward addressing education and workforce issues. An education and workforce-focused consultative board to the NSET should also be created, comprising the various principal stakeholders, including international perspectives.

<u>Recommendation 2:</u> Establish a network of regional hubsites – the Nanotechnology Education Hub Network - as a sustainable national infrastructure for accelerating nanotechnology education. Just as the National Nanotechnology Infrastructure Network (NNIN) has been critical for shared access to leading edge equipment in the early days of the NNI, shared NSE resources, expertise, and training are imperative to preparing a skilled workforce and well-educated innovation leaders of the future. Each hubsite would connect and serve a number of research universities, 2-year and 4-year colleges, public school districts, and government and industrial laboratories. Each hubsite would focus on activities most pertinent to its locale. The hubsites would host teams of visiting professors, school teachers, and researchers from around the country to carry out: a) integrated content development for K-16 from the R&D stage through publication and dissemination; and b) related professional development, assessment and evaluation, learning research and networking for teachers, faculty, and other stakeholders.

V.2. K-12 Next Generation Science SOL

<u>Finding:</u> In the global race to nano-enabled technologies, the U.S. can be in an education leadership position. But without incorporating the current understanding of nanoscale science and engineering into learning standards in each of the states, action at the K-12 levels of education will be minimal, and increasing nanoscience literacy toward a productive workforce will not be maximized. The NGA has approached Achieve Inc. with the task of preparing the Next Generation Science SOL that might be adapted by each state for its own learning standards. Since NSE is constantly evolving, there is need for a forum in which subject matter experts, teamed with K-12 educators, can engage in continuing standards/curriculum/assessment development.

<u>Principal Stakeholders include:</u> OSTP/NSTC, NSF, Department of Education, CCSSO, NGA, Achieve Inc., NSET's Nanotechnology Public Engagement and Communications Working Group (NPEC), Association of Science and Technology Centers (ASTC), NSTA and the state-based affiliates, International Technology Education Association (ITEA) and the state-based affiliates, American Association for the Advancement of Science (AAAS), and National Research Council (NRC).

<u>Recommendation 1:</u> The NSET work with the NGA, the CCSSO, and Achieve Inc. to foster an effort to appropriately introduce the nanoscale into the Next Generation Science SOL. NSE subject matter experts should be incorporated into the Next Generation working and feedback groups. The examples in Section II demonstrate explicitly how NSE ideas could be incorporated into the new standards for college and career readiness.

<u>Recommendation 2</u>: Establish a formal mechanism to enable NSE subject matter experts to work with K-12 educators and workforce experts toward the continuing evolution of NSE content in standards, curriculum, and assessment. International participation should be involved.

Recommendation 3: Participants in the many U.S. NanoCenters (see Appendix H), which cover essentially all States, should begin working with their own State Education Departments toward science learning standard revisions.

V.3. K-12 Curricula and Teaching Aids

Finding: There are several web sites (such as those listed in Appendices A and C in this report) with materials that address curricula supplements, teaching aids, and science and engineering fair projects. In particular, the NSF-funded efforts have been very productive at developing innovative approaches to K-12 NanoEducation. However, the materials are widely dispersed, are of non-uniform format, are not integrated into a learning progression, and have varying degrees of refinement. Taiwan and Australia have a better-developed NSE learning progression. As the new Framework for K-12 Science Education and the associated standards come into place it is imperative that we move from stand-alone, one-off teaching aid modules to a coherent, progressive sequence.

Principal Stakeholders include: NSF, Department of Education, NSET's Nanotechnology Public Engagement and Communications Working Group (NPEC), NSTA and the state-based affiliates, and International Technology Education Association (ITEA) and the state-based affiliates.

Recommendation 1: Create a central web site that provides a registry for NSE materials. The NSTA might serve as the evaluator for quality control to ensure web site materials are of high quality, are in a format readily utilized by K-12 teachers, are carefully indexed to the various state learning standards, and can be readily accessed from the NSTA web site. NSE aids must be transparently aligned with standards. Teachers must be aware of the registry and find it easy to use.

Recommendations 2: Additional well-designed, highly interactive, media-rich, online learning tools should continue to be developed with attention to utilizing the new approaches being widely utilized by youth such as Facebook, Twitter, and YouTube.

Recommendation 3: Creation of a National NanoFlexbook with free electronic modules for teachers and students. A national competition might be used to stimulate additional high quality "flexbook" materials to provide a coherent, vetted learning progression.

Finding: The physical sciences (biology, chemistry, physics) require hands-on experiences as part of the learning process. While inclusion of laboratory work at the local schools is a necessity, some laboratory learning may be beyond the capability and/or budget of local schools and personnel. Initial efforts at nanoscale probes are still too expensive for wide spread application in high schools.

Recommendation 1: Stimulate the further development of affordable K-12 nanoscale instrumentation, including simulations that might supplement for hands-on experimentation.

Recommendation 2: The NSF NNIN and NSECs, the Department of Energy NanoCenters, and the National Institute of Standards Technology (NIST) Center for Nanoscale Science and Technology work with the NSTA and the Department of Education Office of Elementary and Secondary Education (OESE) toward the preparation of on-site and/or remote access to higher end facilities that might contribute to the K-12 education process.

Finding: Person to person contact remains the most effective approach to education.

Recommendation 1: The various university-based NanoCenters mobilize their undergraduate and graduate students to engage in K-12 education at the nanoscale. Federal funding agencies must provide an adequate budget allowance for this work. Universities must recognize the faculty supervisory efforts in tenure and promotion decisions.

Recommendation 2: Create a network of student-run clubs at universities and Colleges across the country to promote science, technology and innovation. Activities might include: seminar series, faculty/student research mixers, university/industry/national laboratory facility tours, and outreach to local schools.

V.4. K-12 Teacher Education and Training

Finding: There will be growing inclusion of nanoscale science, engineering, and technology into standards of learning. There have been and will continue to be growing learning resources for K-12 audiences that address nanoscale science, engineering, and technology. Teachers will need to be trained to use these resources.

Principal Stakeholders include: NSTA, Dept of Education OESE, NSF, other Federal agencies whose mission supports teacher training and workforce development, CCSSO, ASTC, and ITEA.

Recommendation 1: The various NanoCenters can be a vital resource to provide materials, training, and information. They should be encouraged to be more proactive toward K-12 teacher training.

Recommendation 2: Funding for teacher professional development in NSE topics, which are not included in the traditional teacher training venues. This development might include the creation of new teaching modules as part of the effort.

Recommendation 3: A recurring international workshop for K-12 NSE educators to share experiences and ideas, perhaps embedded in a teacher's conference.

Appendix A: K-12 Teaching Modules Addressing NSE Topics

Module	Grade level	Video	Labs	Teaching Aids	Map to Standards	S	T	E	M	Inquiry Learning	Big Ideas in Nanoscale S&E									
											1	2	3	4	5	6	7	8	9	10
A. Access Nano (Australia)	http://www.accessnano.org																			
1. The Space Elevator	7-8	x		x		x						x	x		x				x	x
2. Shape Memory Alloy	7-8		x	x		x				x		x	x		x				x	x
3. Scale and Measurement	9-10		x	x		x			x	x	x						x	x		
4. Properties	9-10		x	x		x			x	x		x							x	
5. Performance Materials	9-10			x		x				x		x	x						x	
6. Health and Medicine	9-10			x		x													x	x
7. Glass	9-10		x	x		x						x	x						x	
8. Personal Care Products	9-10		x	x		x						x							x	x
9. Gold	11	x	x	x		x						x	x						x	
B. California NanoSystems Institute	http://www.cnsi.ctrl.ucla.edu/nanoscience/pages/homepage																			
1. Biotoxicity	9-12		x	x	x	x		x		x		x		x				x	x	
2. Magnetic Fluids	9-12		x	x	x	x		x		x		x	x	x				x	x	x
3. Nanowire pH Sensors	9-12		x	x	x	x		x		x		x	x	x				x		
4. Photolithography	9-12		x	x	x	x		x	x	x		x	x	x			x	x		
5. Self Assembly	9-12		x	x	x	x		x		x		x				x		x		
6. Solar Cells	9-12		x	x	x	x		x		x		x	x	x				x		
7. Super Hydrophobic Surfaces	9-12		x	x	x	x		x		x		x						x	x	
8. Water Purification	9-12		x	x	x	x		x		x		x	x	x				x		
C. DragonflyTV	http://www.dftvpress.org																			
1. Size and Scale	all	x		x		x			x		x									
2. Forces at the Nanoscale	5-12	x		x		x								x						
3. Applications of Nanotechnology	5-12	x		x		x													x	x
4. Structure of Matter	5-12	x		x		x						x								
5. Nanotechnology and Society	9-12	x		x		x														x
6. Small is Different	5-12	x		x		x														
D. IN-VISEE Arizona State University	http://invsee.aus.edu/invsee/invsee.htm																			
1. Size and Scale		x		x		x		x	x	x	x						x			
2. Scanning Probe Microscopy		x		x		x		x		x							x			
3. The Music of Spheres		x		x		x			x	x		x								
4. The Allotropes of Carbon		x		x		x				x		x		x						
5. What does a Light Buib Burn Out		x		x		x		x	x	x			x						x	
6. Modern Information Storage Media		x		x		x	x			x									x	
7. The Five Kingdoms of Biology (yeast)						x						x		x						

Module	Grade level	Video	Labs	Teaching Aids	Map to Standards	S	T	E	M	Inquiry Learning	Big Ideas in Nanoscale S&E									
											1	2	3	4	5	6	7	8	9	10
8. What is Friction						x			x					x			x			
9. What is that in Your Dog Dish (microbes and biofilms)				x		x				x			x							x
10. Iridescence						x							x							
11. Biominerals	11-12				x	x							x							
12. Biological Structural Materials		x				x							x							
13. Engineered Materials						x		x		x		x	x							
14. The World of Liquid Crystals				x		x				x		x	x							
15. DNA - Infinite Variety in Such Small Packets	11-12				x	x							x							
16. The Morphology and Use of Gold Films	11-12				x	x						x	x							
17. Osmotic Pressure in Red Blood Cells & Plant Cells	11-12				x	x						x	x							
E. Institute for Chemical Education	http://www.ice.chem.wisc.edy/Nanoscience.html																			
1. Exploring the Nanoworld Kit	5-12		x	x		x				x		x					x			
2. LED Color Strip Kit	5-12		x	x		x				x		x	x						x	
3. Solid-State Model Kit	7-12		x	x		x			x	x		x	x					x		
4. Polyhedral Model Kit	7-12		x	x		x				x			x					x		
5. DNA Optical Transform Kit	5-12		x	x		x				x							x	x		
6. Optical Transform Kit	7-12		x	x		x				x			x				x			
7. Nanocrystalline Solar Cell Kit	9-12		x	x		x				x			x					x		
8. Nanoworld Presenter's Guide with "Try This" Packet	all		x	x		x				x							x	x		
9. Nanoworld "Try This" Packets with Handout	all	x		x	x	x				x							x	x		
F. McRel Nanoleap	http://www.mcrel.org/nanoleap																			
Physical Science: Investigating Static Forces in Nature																				
1. How Can a Gecko Walk on a Ceiling		x		x	x	x				x										
2. What Do We Mean When We Speak About Surfaces in Contact			x	x	x	x			x	x				x						
3. What are Your Ideas About Small Sizes			x	x	x	x			x	x							x		x	x
4. What Do We Learn When We Look More Closely			x	x	x	x			x	x				x						
5. What Types of Forces Can Hold Objects Together				x	x	x				x				x						
6. How Much Force is Needed to Make an Object Stick			x	x	x	x				x				x						
7. How Do We Measure Forces at the Nanoscale Level?		x	x	x	x	x	x			x				x			x			
8. How Can a Gecko Walk on a Ceiling (advanced)		x	x	x	x	x				x		x	x	x			x			x
Chemistry: Nanoscale Materials and Their Properties																				

	Module	Grade level	Video	Labs	Teaching Aids	Map to Standards	S	T	E	M	Inquiry Learning	Big Ideas in Nanoscale S&E									
												1	2	3	4	5	6	7	8	9	10
9.	What is it?		x	x	x	x	x	x			x	x		x						x	x
10.	Metallic and Ionic Nanoparticles: Extendable Structures				x	x	x						x	x							x
11.	Neat and Discrete Nanoparticles				x	x	x						x								x
G.	**Molecularum (RPI)**	http://www.moleculestothemax.com/Educators.html																			
1.	Molecules to the Max	1-4	x		x	x	x					x	x	x	x						
2.	Riding Snowflakes	1-4		x	x	x	x				x										
H.	**Materials World Modules (Northwestern)**	http://www.materialsworldmodules.org																			
1.	Biodegradable Materials	9-12		x	x	x	x	x	x	x	x		x	x	x				x	x	
2.	Biosensors	9-12		x	x	x	x	x	x	x	x		x	x	x				x	x	
3.	Ceramics	9-12		x	x	x	x	x	x	x	x		x	x	x						
4.	Composites	6-12			x	x	x	x	x	x	x		x	x	x				x		
5.	Concrete: An Infrastructure Material	6-12		x	x	x	x	x	x	x	x		x								
6.	Environmental Catalysis	9-12		x	x	x	x	x	x	x	x		x	x	x					x	
7.	Food Packaging	6-12		x	x	x	x	x	x	x	x								x	x	
8.	Intro to the Nanoscale	6-12		x	x	x	x	x	x	x	x	x	x					x			
9.	Manipulation of Light in the Nanoworld	9-12		x	x	x	x	x	x	x	x		x		x						
10.	Nanotechnology	9-12		x	x	x	x	x	x	x	x	x	x						x		
11.	Polymers	9-12		x	x	x	x	x	x	x	x		x	x	x						
12.	Smart Sensors	9-12		x	x	x	x	x	x	x	x		x		x					x	
13.	Sports Materials	6-12		x	x	x	x	x	x	x	x		x							x	
14.	Drug Delivery at the Nanoscale	9-12		x	x	x	x	x	x	x	x		x		x					x	
15.	Dye Sensitized Solar Cells	9-12		x	x		x	x	x	x	x								x	x	
16.	Nanopatterning	9-12		x	x	x	x	x	x	x	x		x								
17.	Nanosurfaces	9-12			x	x	x						x		x						
I.	**Nanotechnology: The Power of Small**	http://ffh.films.com/id/15906/Nanotechnology_The_Power_of_Small-A_Fred_Friendly_Seminar.htm																			
1.	Watching Me Watching You: Nanotechnology and Civil Liberties	9-12	x		x	x	x	x												x	x
2.	Forever Young: Nanotechnology and Medicine	9-12	x		x	x	x	x												x	x
3.	Clean, Green, and Unseen. Nanotechnology and the Environment	9-12	x		x	x	x	x												x	x
J.	**NCLT (Northwestern)**	http://www.nanoed.org/																			
1.	Apples to Atoms	6-9		x	x		x	x	x	x	x	x	x					x			
2.	DNA Fingerprinting Activity	8-12		x	x		x						x	x							x
3.	DNA and Models	6-9			x		x				x		x	x	x		x		x		

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4.	Teaching Module using "Macro-AFM"	9-12			x		x			x	x	x						x			
5.	Instruc. Resources on 3D Body Force	9-12			x		x		x		x				x						
6.	LEGO Atomic Force Microscope and Magnetic Force Microscope	9-12		x	x		x			x	x							x	x		
7.	Insights in Nanomedicine: Fighting Cancer with Gold Nanoshells	9-12	x		x		x	x												x	
8.	Investigating Static Forces in Nature: the mystery of the Gecko	9-12		x	x	x	x			x	x	x	x		x			x			
9.	Nanopattern Formation of 2D Weakly charged Telechelic Gels by Self Assembly	>12					x	x							x		x				
K.	**Nano-Link (NDSCS)**	http://www.ndscsnano.com/kits.html																			
1.	LED Colorstrip Kit	7-12		x	x		x		x		x							x			
2.	Color Changing Beads / UV Light Module	5-12		x	x		x				x			x						x	
3.	Memory Metal Module	9-12		x	x		x		x		x		x	x							
4.	Stain Resistant Fabric Module	5-12		x	x		x						x	x						x	
L.	**Nano4me (PSU)**	http://www.nano4me.org																			
1.	Introductory Level Modules																				
2.	Nanotechnology: What Is It, and Why Is It So "BIG" Now?		x		x		x					x						x			
3.	A Brief History of Nanotechnology				x		x					x	x					x		x	
4.	A Snapshot of Nanotechnology Today				x		x						x		x					x	x
5.	The Uniqueness of the Nano-scale				x		x		x				x		x			x			
6.	How Do We "See" Things at the Nano-scale		x		x		x	x										x			
7.	How Do You Make Things So Small				x		x						x		x						
8.	How Do You Build Things So Small				x		x						x		x						
9.	Nanotechnology, Biology, and Medicine		x		x		x		x				x		x					x	x
10.	High School Level Experiments																				
11.	Silver Nanoparticles (Part 1)			x	x	x	x				x		x		x						
12.	Silver Nanoparticles (Part 2)			x	x	x	x				x		x	x	x						
M.	**NanoKids (Rice)**	http://www.nanokids.rice.eu																			
1.	NanoKids	1-7	x		x		x														
N.	**NanoProfessor**	http://www.nanoprofessor.net																			
1.	Nanoscale Fundamentals	5-12			x		x			x		x						x		x	
2.	Nanochemistry	7-12			x		x						x		x					x	
3.	Nanobiology	7-12			x		x						x	x		x				x	
4.	Nanophysics	9-12			x		x						x		x					x	
5.	Technological Evolution and Social Issues	7-12			x		x													x	x

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O.	**NanoSchoolBox (Europe)**	http://www.nisenet.org/catalog/programs/nano_school_box																			
1.	From the Lotus effect to the technical application of monolayers	9-12	x	x	x		x				x		x							x	
2.	Functionality through nanotechnology	9-12	x	x	x		x				x		x								
3.	Use of TiO2 in nanotechnology	9-12	x	x	x		x				x		x								
4.	Ferrofluids	9-12	x	x	x		x				x		x		x					x	
5.	Nanoscale gold Colloids	9-12	x	x	x		x				x		x		x						
6.	Memory effect	9-12	x	x	x		x				x		x							x	
7.	From sand to chip	9-12	x	x	x		x				x		x		x					x	
8.	The smaller the particle, the greater the effect	9-12	x	x	x		x				x		x								
P.	**NanoSense**	http://www.nanosense.org/activities.html																			
1.	Size Matters: Intro to Nanoscience			x	x	x	x	x	x	x	x	x	x					x		x	x
2.	Clear Sunscreen: How Light Interacts with Matter			x	x	x	x				x									x	
3.	Clean Energy: Converting Light into Electricity		x	x	x	x	x				x									x	x
4.	Fine Filters: Filtering Solutions for Clean Water			x	x	x	x				x				x					x	x
Q.	**NanoYou (Europe)**	http://nanoyou.eu.en																			
1.	Nanoyou: Virtual Nano Lab	7-12			x		x							x						x	
2.	Experiment with Superhydrophobic Materials	7-12			x		x				x		x							x	
3.	Experiment with Colorimetric Gold Nanosensor	7-12	x	x	x		x				x		x								
4.	Experiment with Natural Nanomaterials	7-12	x	x	x		x				x		x		x					x	
5.	Experiment with Liquid Crystals	9-12	x	x	x		x				x		x				x	x	x		
6.	Nano to Touch	all	x	x	x		x														
R.	**Nanozone**	http://nanozone.org																			
1.	Seeing Small	2-7	x		x	x		x										x			
2.	What is Nano?	2-7	x			x	x														
3.	Measure Yourself	2-7			x	x				x	x	x									
4.	Look Familiar?	2-7			x	x	x					x									
5.	Shoop the NanoMall	2-7			x	x			x											x	x
6.	Scientiest Stat Cards	2-7			x	x	x						x								
7.	Zoom In	2-7			x	x		x										x			
8.	Life Stories	2-7			x	x															
9.	Green Milk Games	2-7			x	x															
10.	Save Ratty	2-7			x	x	x							x						x	
11.	Chester McZoom	2-7			x	x															
12.	Nano Fab Lab	2-7				x	x				x										
13.	Fishing for Fun	2-7				x					x										

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												1	2	3	4	5	6	7	8	9	10
14.	Talk to the Scientist	2-7			x	x	x				x										
15.	Nanowire Demo	2-7				x	x	x												x	
16.	Biocapsule Demo	2-7				x	x	x										x			
17.	Scanning Probe Demo	2-7				x	x	x										x			
18.	How Small is Small?	2-7			x	x	x					x									
19.	How Small is That?	2-7				x							x					x			
S.	**NISE Network**	http://www.nisenet.org/catalog																			
1.	Biomimicry: Synthetic Gecko Tape through Nanomolding	9-12		x	x		x	x	x	x	x									x	x
2.	Energy & Nanotechnology slide show	6-12			x		x													x	x
3.	Experiment on Natural Nanomaterials	6-12		x	x		x				x		x								
4.	Experiment with Superhydrophobic Materials	6-12	x	x	x		x	x			x							x		x	x
5.	Exploring Materials - Thin Films	all		x	x	x	x				x		x								
6.	Exploring Fabrication - Self-Assembly	all		x	x	x	x				x						x				
7.	Exploring Forces - Gravity	all		x	x	x	x				x		x								
8.	Exploring Forces - Static Electricity	all		x	x	x	x			x	x		x								
9.	Exploring Materials - Ferrofluid	all		x	x	x	x				x		x								
10.	Exploring Products - Nano Sand	all		x	x	x	x				x		x								
11.	Exploring Products - NanoFabrics	all		x	x	x	x				x		x								
12.	Exploring Products - Sunblock	all		x	x	x	x				x									x	
13.	Exploring Products - Surface Area	all		x	x	x	x				x		x								
14.	Exploring Size - Measure Yourself	all		x	x	x	x			x	x	x									
15.	Exploring Size - Memory Game	all		x	x	x	x			x		x									
16.	Exploring Size - Powers of Ten Game	all		x	x	x	x			x		x									
17.	Exploring Size- Scented Balloons	all		x	x	x	x				x	x									
18.	Exploring Size- Scented Solutions	all		x	x	x	x				x	x									
19.	Exploring Size - Stretchability	all		x	x	x	x			x		x									
20.	Exploring Size - Tiny Ruler	all		x	x	x	x			x	x	x									
21.	Exploring Structures - Buckyballs	all		x	x	x	x			x	x		x								
22.	Exploring Tools- Mitten Challenge	all		x	x	x	x		x		x	x						x			
23.	Exploring Tools - Special Microscopes	all		x	x	x	x				x							x			
24.	High School Nanoscience Program - Self Assembly	5-12		x	x		x										x				
25.	Introduction to Nanomedicine Video	2-12	x				x					x									x
26.	It's a Nano World	all			x		x														
27.	Liquid Crystals	all		x	x	x	x	x	x		x		x								
28.	Mixing Molecules	5-12	x				x						x	x							
29.	Multimedia Zoom into a Human Hand	5-12			x		x					x	x								
30.	Multimedia Zoom into a Nasturtium Leaf	5-12			x		x						x								
31.	Mysterious Soap Bubbles	5-12		x	x		x				x		x	x							

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												1	2	3	4	5	6	7	8	9	10
32.	Nano Dreams and Nano Nightmares	all			x	x	x			x		x	x	x							
33.	Nanosilver: Breakthrough or BioHazard video	5-12	x		x		x													x	x
34.	Nanotechnology Class Materials	all	x		x		x														
35.	Sights Unseen: Images of the Nanoworld	all			x		x														
36.	Talking Nano	1-12	x		x		x					x	x							x	x
37.	The Amazing Nano Brothers Juggling Show	all	x		x	x	x					x	x	x				x			x
38.	Three Drops	all	x		x		x					x	x								
39.	TryNano	all	x		x	x	x														
40.	What Happens in a Nano Lab Video	all	x		x		x											x			
41.	Zoom into a Butterfly Wing	5-12			x		x					x		x							
T.	**NNIN Education Portal**	http://www.nanooze.org/main/Nanooze/																			
1.	Nanotechology Primer	4-8			x		x			x		x	x				x	x			x
2.	More Nanotechnology	4-8			x		x									x				x	x
3.	Zoom into Nanotechnology	9-12			x		x							x		x		x		x	x
4.	Five Senses	4-12			x		x							x						x	x
5.	Self Assembly	4-12			x		x						x				x	x	x	x	
6.	Nano Food	4-12			x		x													x	x
7.	Nano Medicine	4-12			x		x							x		x		x		x	x
U.	**NNIN Nanotechnology Education**	http://www.nnin.org/nnin_k12teachers.html																			
1.	Size and Scale	5-8		x	x	x	x			x	x	x						x			
2.	Hydrophilic/Hydrophobic Surfaces	9-12		x	x		x				x		x	x	x						
3.	Exploring Nanotechnology Through Consumer Products				x	x	x				x									x	x
4.	Exploring Magic Sand			x	x		x				x		x		x						
5.	Shape Memory Alloys	6-12		x	x	x	x				x		x							x	
6.	Modeling Self-Assembly	6-12		x	x	x	x				x						x		x		
7.	Reading and Analyzing Nanotechnology	8-12		x	x	x	x				x									x	x
8.	Design Challenge	8-12		x	x	x	x		x		x								x		x
9.	Catalysis	9-12			x	x					x		x		x						
10.	Surface to Volume Ratio	6-12		x	x	x	x				x		x	x	x						
11.	Scanning Probe Microscopy	4-12		x	x	x	x		x		x							x	x		
12.	Nanotechnology and Cosmetics	9-12												x					x	x	
13.	Magnetism and Nanotechnology	8-12		x	x	x	x				x		x		x						
14.	Changing Conductive Properties By Diffusion	8-12		x	x	x	x				x		x	x	x					x	
15.	Effect of Size on Chemical Reactions	9		x	x	x	x			x	x	x						x			

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16.	Using Media to Explore Social and Ethical Issues in Nanoscience and Nan	9-12			x	x	x													x	x
17.	Water Purity and Filtration	6-12		x	x	x	x				x				x				x	x	
18.	The SI System and Nanoscale Science	6-8			z	x	x			x	x							x			
19.	Heat and Solar Energy	6-12		x	x	x	x				x		x		x						
20.	Deposition	9-12		x	x	x	x		x		x		x	x	x						
21.	Nanobacteria	6-8		x	x	x	z			x	x		x	x							
22.	Metric Measurement	6-12		x	x	x				x	x	x						x			
23.	Understanding Waveguides	6-12		x	x	x	x			x	x				x			x	x		
24.	Catalytic Converters and Nanocatalysts	9-12		x	x	x	x		x										x		
25.	CDs and DVDs as Diffraction Gratings	9-12		x	x		x				x									x	
26.	Hiding Behind the Mask	9-12		x	x	x	x		x		x		x		x						
27.	How Big is a Nanometer	9-12			x	x	x			x	x	x						x			
28.	Electrolysis	9-12		x	x	x	x		x		x		x		x						
29.	Nanomotors	9-12		x	x	x	x		x		x		x		x				x		
30.	Understanding Wave Motion and Power Loss	6-12		x	x	x	x		x		x		x		x						
31.	Properties of Fluids	6-12		x	x	x	x				x		x		x						
V.	**NC State University Nanoscale Education Group**			http://ced.ncsu.edu/nanoscale																	
1.	Scale and Scaling	2-12				x	x			x		x									
2.	Nanotechnology Education	6-12					x														
3.	Haptics: Learning through Touch						x						x					x			
4.	Spintronics	6-12																			
W.	**NSTA Learning Center**			http://learningcenter.nsta.org/products/																	
1.	Big Ideas of NSE: A Guidebook for Secondary Teachers	9-12			x	x	x					x	x		x		x	x	x		x
2.	Extreme Science: from Nano to Galactic	6-12		x	x	x	x				x	x	x		x		x	x	x		
3.	Science Sampler: Nanoscale in Perspective	6-8		x	x	x	x				x	x						x			
4.	Nanoscale Science: Activities for Grades 6-12	6-12		x	x	x	x				x	x	x		x			x		x	x
5.	Fact or Fiction: Exploring the Myths and Realities of Nanotechnology	6-12			x	x	x				x									x	x
	Size and Scale																				
6.	That's Huge	6-12			x	x	x				x	x									
7.	One in a Billion	6-12		x	x	x	x				x	x									
8.	Nano Shapes: Tiny Geometry	6-12			x	x	x			x	x		x								
9.	Biological Nanomachines: Viruses	6-12		x	x		x				x		x	x	x		x		x		

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											1	2	3	4	5	6	7	8	9	10
Tools and Techniques																				
10. What's in Your Bag? Investigating the Unknown	6-12		x	x	x	x				x								x		
11. Nanomagnets: Fun with Ferrofluid	6-12		x	x	x	x				x		x							x	
12. Scanning Probe Microscopy	6-12			x	x	x				x							x			
Unique Properties and Behaviors																				
13. It's a Small World After All: Nanofabric	1-8			x	x	x						x							x	x
14. Biomimicry: The Mystery of the Lotus Effect	6-12			x	x	x				x			x						x	x
15. How Nature Builds Itself: Self Assembly	6-12		x	x	x	x				x						x				
16. Physics Changes with Scale	6-12		x	x	x	x				x		x		x						
17. Shrinking Cups: Changes in the Behavior of Materials at the Nanoscale	1-8		x	x	x	x			x	x	x			x						
18. Limits to Size: Could King Kong Exist?	6-12			x	x	x				x		x								
Nanotechnology Applications																				
19. Nanomaterials: Memory Wire	6-12			x	x	x				x				x					x	x
20. Nanotech, Inc.	6-12			x	x	x				x									x	x
21. Nanomedicine	6-12		x	x	x	x				x									x	x
22. Building Small: Nano Inventions	6-12			x	x	x				x									x	x
Societal Implications																				
23. Too Little Privacy: Ethics of Nanotechnology	9-12			x	x	x													x	x
24. Promise or Peril: Nanotechnology and the Environment	6-12			x	x	x													x	x
25. Putting Nano-Tex to the Test	6-8			x	x	x													x	x
26. Collaboration at the Nanoscale	9-12			x	x	x						x	x	x			x			
27. Conceptualizing Nanoscale	9-12		x	x	x	x				x	x									
28. Applications of Nanotechnology to Cosmetics and Foods	6-12	x		x	x	x	x												x	x
29. Fats, Oils and Colors of Nanoscale Materials	9-12		x	x	x	x				x		x								
30. Idea Bank: Students as Nano-Detectives	9-12			x	x	x													x	x
31. Linking Science, Technology, and Society by Examining Impact of NT on a Community	6-12			x	x	x	x												x	x
32. Nanomedicine: Problem Solving to Treat Cancer	6-8		x	x	x	x				x									x	x

	Module	Grade level	Video	Labs	Teaching Aids	Map to Standards	S	T	E	M	Inquiry Learning	Big Ideas in Nanoscale S&E									
												1	2	3	4	5	6	7	8	9	10
33.	Podcast: Appl of NT to Cosmetics and Foods	all	x		x	x	x													x	x
34.	Podcast: Nanoscale Fact or Fiction	6-12	x		x		x														
35.	Podcast: Nanotechnology Benefits and Threats to the Environment	6-12	x		x		x													x	x
36.	Podcast: Properties of the Nanoscale NanoScience	6-12	x		x		x					x	x		x			x		x	x
X.	**NSTEP-National Sci. and Technology Education Partnership**				http://www.nstep-online.org/default.asp																
1.	Nanotechnology						x	x												x	x
Y.	**Taiwan Nanoscience and Nanotechnology**				http://nanotaiwan.sinica.edu.tw/index.php?eng=T&lid=58																
1.	Nanotechnology Symphony	10-12			x		x														
2.	NanoBlasterMan	2-8			x		x														
3.	Nana and Nono	1-6	x		x		x														
Z.	**TryNano**				http://www.trynano.org/lesson_plans.html																
1.	Exploring at the Nanoscale	3-8		x	x	x	x		x		x	x								x	x
2.	What is a Nanometer	3-6		x	x	x	x		x	x	x	x						x			
3.	Sugar Crystal Challenge	3-8		x	x	x	x				x		x			x					
4.	Nano Waterproofing	3-12		x	x	x	x		x		x		x							x	
5.	Waterproof that Roof	3-12		x	x	x	x		x		x									x	
6.	NanoMission Game Series				x							x									
7.	Duckboy in Nanoland				x							x									
8.	Virtual Microscope				x		x	x			x							x			
AA.	**Univ Wisc**				http://mrsec.wisc.edu/Edetc/modules/index.html																
1.	Using Vectors to Construct Carbon Nanotubes	10-12		x	x		x			x	x		x					x		x	
2.	Scanning Probe Microscopy and Xray Diffraction	10-12		x	x		x				x							x			
3.	Nickel-Titanium: A Shape Memory Alloy	10-12		x	x		x				x		x	x						x	
4.	Light Emitting Diodes (LEDs)	10-12		x	x		x			x	x		x	x						x	
5.	Synthesis of Ferrofluid	10-12		x	x		x				x		x	x							
6.	What is Smaller than a Pygmy Shrew	7-9		x	x		x			x	x	x									
7.	How can we "see" what we can not see?	7-9		x	x	x	x			x	x		x					x			
8.	Magnetism	7-9		x	x		x				x		x	x						x	
9.	Memory Metal: Using Shape Memory Metals in Simple Machines	7-9		x	x	x	x				x		x	x	x					x	

Module	Grade level	Video	Labs	Teaching Aids	Map to Standards	S	T	E	M	Inquiry Learning	Big Ideas in Nanoscale S&E									
											1	2	3	4	5	6	7	8	9	10
BB. Virtual Lab: Nanoscience Class Homepage (UVA)		http://virlab.virginia.edu/Nanoscience_class/Nanoscience_for_elementary_and_middle_schools.htm																		
1. Microscopy Lesson	5-8	x	x	x		x				x	x						x			
TOTALS		**61**	**150**	**263**	**161**	**273**	**39**	**51**	**60**	**175**	**53**	**134**	**66**	**70**	**7**	**13**	**61**	**37**	**101**	**62**

Note:
S: Science
T: Technology
E: Engineering
M: Mathematics

Big Ideas in Nanoscale S&E – See Table 1

Appendix B: K-12 Teacher Professional Development in NSE and K-12 NSE Student Education University Outreach

Center	Institution	State	RET	Teacher Resources	Teacher Training Workshops	Teacher Summer Program	Other Teacher Program	Student Outreach	Student Summer Program	Student Internship	Other Student Program
Nano4Me and MATEC Networks											
NetWorks	Maricopa Community College	AZ		X							
Center for Nanotechnology Education and Utilization	Penn. State Univ.	PA		X	X		X				
NASA											
Center for Nanotechnology	Ames Research Center	CA									
National Science Teachers Association (NSTA)											
National Science Teachers Association	NSTA	VA		X	X		X				
NSF Advanced Technological Education (ATE)											
Midwest Regional Center for Nanotechnology Education	Dakota County Technical College	MN			X	X		X	X		X
Southwest Center for Microsystems Education	Univ. New Mexico	NM			X						
National Ctr for Nanotechnology Applications and Career Knowledge	Penn. State Univ.	PA			X						
NSF Nanoscale Science and Engineering Centers (NSEC)											
Center for Probing the Nanoscale	Stanford Univ.	CA				X					
Center for Integrated Nanomechanical Systems	UCB	CA			X				X		X
Center for Scalable and Integrated Nanomanufacturing	UCLA	CA						X	X		
Center for Nanoscale Chemical-Electrical-Mechanical Manufacturing Sys	Univ. Illinois-Urbana Champaign	IL		X	X	X		X			X
International Institute for Nanotechnology	Northwestern Univ.	IL	X								
Center for Nanoscale Systems	Harvard Univ.	MA	X								
Center for Hierarchical Manufacturing	Univ. Mass.-Amherst	MA			X			X			X
Center for Directed Assembly of Nanostructures	Rensselaer Polytech. Inst.	NY		X		X					
Center for Nanoscale Systems	Cornell Univ.	NY			X	X					
Center for Electron Transport in Molecular Nanostructures	Columbia Univ.	NY	X								X

Center	Institution	State	RET	Teacher Resources	Teacher Training Workshops	Teacher Summer Program	Other Teacher Program	Student Outreach	Student Summer Program	Student Internship	Other Student Program
Center for Affordable Nanoengineering of Polymeric Biomedical Devices	Ohio State Univ.	OH			X			X			
Nano/Bio Interface Center	Univ. Pennsylvania	PA	X				X		X		X
Center for Biological and Environmental Nanotechnology	Rice Univ.	TX			X	X					X
Nanoscale Science & Engineering Center	Univ. Wisconsin-Madison	WI	X	X	X		X				
Center for Templated Synthesis and Assembly at the Nanoscale	Univ. Wisconsin - Madison	WI	X	X	X				X		
NSF National Nanotechnology Infrastructure Network											
NNIN Education Portal **(Applies to all NNIN Sites. Additional Programs Are Noted Below)**	National Nanotechnology Infrastruture Network		X	X	X	X					
NNIN: Nanotech	UCSB	CA	X		X						
NNIN: Nanofabrication Facility	Stanford Univ.	CA	X	X				X			X
NNIN: Nanotechnology Research Center	Georgia Inst. Tech.	GA	X	X		X			X	X	
NNIN: Center for Nanoscale Systems	Harvard Univ.	MA	X	X			X				
NNIN: National Nanotechnology Infrastructure Network	Cornell Univ.	NY								X	X
NSF Networks and Centers that complement the NSECs											
STC: Center for Energy Efficient Electronics Science	UCB	CA							X		X
MRSEC: The Georgia Tech Laboratory for New Electronic Materials	Georgia Inst. of Technology	GA	X	X		X		X	X		
NCLT: Nanotechnology Center for Learning and Teaching	Northwestern Univ.	IL		X							
MRSEC: Materials Research Science and Engineering Center on Polymers	Univ. Mass.-Amherst	MA	X								X
MRSEC: Nano-Structured and Bio-Molecular Materials	Brandeis Univ.	MA									X
NISE Net: Nanoscale Informal Science Education Network	Boston Museum of Science	MA		X							
Materials Research Science and Engineering Center	Univ. of Maryland	MD			X					X	X
MRSEC: Quantum and Spin Phenomena in Nanomagnetic Structures	Univ. Nebraska	NE	X					X			X
MRSEC: Princeton Center for Complex Materials	Princeton Univ.	NJ				X			X		X

Center	Institution	State	RET	Teacher Resources	Teacher Training Workshops	Teacher Summer Program	Other Teacher Program	Student Outreach	Student Summer Program	Student Internship	Other Student Program
MRSEC: Center For Nanostructured Materials	Columbia Univ.	NY	X					X			X
MRSEC: Center for Nanoscale Science	Penn. State Univ.	PA			X	X			X		
The Laboratory for Research on the Structure of Matter	University of Pennsylvania	PA	X		X		X		X		
MRSEC: Genetically Engineered Materials Science and Engineering Center	Univ. of Washington	WA	X						X		
Nanotechnology Undergraduate Education											
Camp NanoTech	Florida Inst. Of Technology	FL							X		
NanoCORE: Nanotechnology Concepts, Opportunities, Research and Education	Florida State Univ.	FL									X
Nanomanufacturing Center	Univ. of Mass.-Lowell	MA	X								X
NANO@NC State	NC State	NC			X		X				X
Nanoscience at the University of New Mexico	Univ. of New Mexico	NM			X		X	X			
SMALL: nanbioSensors & MicroActuators Learning Lab	SUNY-Buffalo	NY								X	
NSF- Nanosclae Science and Engineering Center for Directed Assembly of Nanostructures	Rensselaer Polytechnic Inst.	NY	X								
Nanotechnology Institute	Drexel Univ.	PA	X				X	X	X		
Miscellaneous											
California NanoSystems Institute	UCLA	CA			X			X			
NSF Engineering Research Center for Extreme Ultraviolet (EUV) Science and Technology	Colorado State Univ.	CO	X	X	X			X			X
Nanotechnology Reseach Center	Georgia Inst. of Technology	GA	X					X			
Center for Nano Science and Technology	Univ. Notre Dame	IN	X								
Nanoscience Center	Indiana Univ.	IN			X						X
Birck Nanotechnology Center	Purdue Univ.	IN									X
Center for Bio-Inspired Nano-Materials	Montana State Univ.	MT									X
Center for Nanotechnology and Molecular Materials	Wake Forest Univ.	NC									X
Center for Materials and Nanoscience	Univ. Nebraska-Lincoln	NE							X	X	X
University of New Hampshire CHN Group	Univ. New Hampshire	NH					X				

Center	Institution	State	RET	Teacher Resources	Teacher Training Workshops	Teacher Summer Program	Other Teacher Program	Student Outreach	Student Summer Program	Student Internship	Other Student Program
Nanotechnology Center	Univ. Nevada	NV		X							
College of Nanoscale Science and Engineering	SUNY Albany	NY					X	X			X
Center for Nanotechnology	Miami Univ. (Ohio)	OH						X			
Oklahoma Nanotechnology Initiative	Oklahoma (3 Univ.)	OK									X
Oregon Nanoscience and Microtechnologies Institute ONAMI	Oregon (3 Univ.)	OR					X	X			X
Center for Advanced Materials and Nanotechnology	Lehigh Univ.	PA									X
Smalley Institute for Nanoscale Science and Technology	Rice Univ.	TX			X				X		X
Nano Tech Center	Texas Tech Univ.	TX									X
Alan G. MacDiarmid NanoTech Institute	Univ. Texas-Dallas	TX									X
NanoSTAR Institute (with Center for Diversity in Engineering)	Univ. Virginia	VA	X	X	X	X	X	X			X
WV Nano Institute	Univ. West Virginia	VA							X		
Seattle's Hub for industry-driven Nanotechnology Education (SHINE)	North Seattle Community College	WA			X						

Appendix C: Websites with K-12 NanoEducation Content

Organization/Institution	URL
Access Nano (Australia)	http://www.accessnano.org/
Am. Chemical Society	http://community.acs.org/nanotation/
European Nanotech. Gateway	http://www.nanoforum.org
Institute of Nanotechnology	http://www.nano.org.uk/CareersEducation/education.htm
Inst of Bioengn & Nanotechnology	http://www.nano-biokit.com/
Intro to Nanotechnology	http://www.nanowerk.com/news/newsid=16048.php
McREL Classroom Resources	http://www.mcrel.org/NanoLeap/
Nanopolis	http://www.nanopolis.net
NanoEd Resource Portal	http://www.nanoed.org
NanoHub	http://nanohub.org/
NISE Net	http://www.nisenet.org
NanoSchool Box (Germany)	http://www.nanobionet.de/index.php?id=139&L=2
Nanotech KIDS	http://www.nanonet.go.jp/english/kids/
NACK Center	http://www.nano4me.org/
Nanotech. News, People, Events	http://www.nano-technology-systems.com/nanotechnologyeducation/
NanoTecNexus	http://www.Nanotecnexus.org
NanoYou (European Union)	http://nanoyou.eu/
Nanozone	http://nanozone.org/
NASA Quest	http://quest.nasa.gov/projects/nanotechnology/resources.html
National S&T Ed.Partnership	http://nationalstep.org/default.asp
NNI Education Center	http://www.nano.gov/education-training/K12
NNIN Education Portal	http://www.nnin.org/nnin_edu.html
NSF Classroom Resources	http://www.nsf.gov/news/classroom/nano.jsp
PBS – DragonflyTV	http://pbskids.org/dragonflytv/nano/
Taiwan NanoEducation	http://www.nano.edu.tw/en_US/
Nanotechnology Group, Inc.	http://www.tntg.org
Time for Nano	http://www.timefornano.eu/
Wikipedia	http://en.wikipedia.org/wiki/Nanotechnology_education
NanoSense	http://www.nanosense.org/activities.html
NSTEP	http://www.nstep-online.org/default.asp
ComPADRE	http://www.compadre.org/Repository/document/ServeFile.cfm?ID=8662&DocID=1069
IN-VISEE	http://invsee.asu.edu/invsee/invsee.htm
Nanoscale Education Group	http://ced.ncsu.edu/nanoscale/

Appendix D: U.S. Community and Technical College Programs Focused on NSE

School	Country	Associates Degree	Minor	BS	Graduate Certificate	MS	PhD
Austin Community College	US				X		
Bucks County Community College	US	X			X		
Chippewa Valley Technical College	US	X					
College of Lake County	US	X					
Dakota County Technical College	US	X					
Danville Community College	US				X		
Foothill College	US	X					
Forsyth Technical Community College	US	X					
Harper College	US	X					
Harrisburg Area Community College	US	X					
Minnesota State Community and Technical College	US	X					
Montgomery County Community College	US	X					
Normandale Community College	US	X					
North Dakota State College of Science	US	X					
North Seattle Community College	US	X			X		
Northwest Vista College	US				X		
Oklahoma City Community College	US	X					
Penn Community Colleges	US	X					
Richland College	US	X					
Schenectady County Community College	US	X					
Texas State Technical College	US	X					

Note: X indicates degree; C indicates certificate or concentration

Appendix E: U.S. Four Year College and University Programs Focused on NSE

School	Country	Associates Degree	Minor	BS	Graduate Certificate	MS	PhD
Appalachian State University	US					X	
Arizona State University	US					X	
Boston University	US			C			
California Institute of Nanotechnology	US				X		
California University of Pennsylvania	US			C			
City University of New York	US						X
Clarion University of Pennsylvania	US		X				
Cornell University	US						C
Drexel University (IGERT)	US			C	X		
George Mason University	US				X		
Georgia Institute of Technology	US				X		
Johns Hopkins University	US					C	
Joint School of Nanoscience & Nanoengineering	US					X	X
Lehigh University	US				X		
Lock Haven University	US	X	X				
Louisiana Tech University	US			X		X	X
Mansfield University of Pennsylvania	US			C			
Maryland Nanocenter	US		X				
Michigan Technological University	US		X		X	X	
North Carolina A&T State University	US					X	
North Carolina State University	US	X		C			
North Dakota State University	US						X
Northeastern University, MA	US						X
Northwestern University	US			C			
Ohio State University Institute of Technology	US	X					
Oklahoma State University	US	X					
Pennsylvania State University	US	X	X		X		
Rice University (IGERT)	US					X	C
Rochester Institute of Technology	US		X				
Rutgers University (IGERT)	US					C	
South Dakota School of Mines & Technology	US						X
Stanford University	US				X		
Stevens Institute of Technology	US					C	C
Texas State University-San Marcos	US			C			
Union College	US		X				

School	Country	Associates Degree	Minor	BS	Graduate Certificate	MS	PhD
University at Albany, SUNY	US	X		X		X	X
University of California-Berkeley	US						C
University of California-Riverside	US			C			
University of California-San Diego	US			X		X	X
University of Central Florida	US			C			
University of Delaware	US		X				
University of Denver	US					X	X
University of Illinois at Urbana-Champaign	US				X		
University of Maryland	US		X				
University of Massachusetts Lowell	US				X		
University of Michigan	US				X		
University of Minnesota	US					C	
University of Nevada-Reno	US		X				
University of New Mexico	US					X	X
University of North Carolina - Charlotte	US						X
University of Pennsylvania (IGERT)	US		X		X	X	
University of Southern California	US			C			
University of Texas at Austin	US				X	C	C
University of Virginia	US			C			
University of Washington	US					X	X
University of Wisconsin-Stout	US			C			
Virginia Commonwealth University	US						X
Wayne State University	US			C			

Note: X indicates degree; C indicates certificate or concentration
Data Acquired 1/17/11

Appendix E: Non-U.S. Four Year College and University Programs Focused on NSE

School	Country	Associates Degree	Minor	BS	MS	PhD
Graz University of Technology	AT				X	
Danube University Krems	AT				X	
University of Technology Vienna	AT				X	
University of Nat. Resources and Life Sciences Vienna	AT				X	
Curtin University	AU			X		
Flinders University	AU			X	X	
Griffith University	AU			X		
La Trobe University	AU			X	X	
Murdoch University	AU			X		
RMIT University	AU			X		
Royal Melbourne Inst. of Tech. Univ.	AU			X		
Univeristy of Technology, Sydney	AU			X	X	X
University of Melbourne	AU				X	
University of New South Wales	AU			X		
University of Queensland	AU			X		
University of South Australia	AU			C	C	
University of Western Australia	AU			X		
University of Western Sydney	AU			X		
University of Wollongong	AU			X		
University of Antwerp	BE				X	
Catholic University of Leuven	BE				X	
Erasmus Mundus	BE				X	
Katholieke Universiteit Leuven	BE				X	
Hasselt University	BE				X	
Centro Universitário Franciscano	BR				X	
Pontifícia Universidade Católica de Rio de Janeiro	BR				X	X
Universidade Federal do ABC	BR				X	X
Universidade Federal do Rio de Janeiro	BR				X	
Carleton University	CA			C		
McMaster University	CA			C		
Northern Alberta Institute of Technology	CA	X				
University of Alberta	CA			C	C	
University of British Columbia	CA			C		
University of Calgary	CA		X	C		
University of Guelph	CA			X		
University of Toronto	CA			C		
University of Waterloo	CA			X	X	X

School	Country	Associates Degree	Minor	BS	MS	PhD
Eidgenössische Technische Hochschule	CH				X	X
Swiss Federal Institute of Technology	CH				X	
Swiss Universities of Applied Science	CH				X	
Universität Basel	CH			X	X	X
University of Neuchâtel	CH				X	
Academia Sinica	CN					X
Hong Kong University of Science and Technology	CN				X	X
Technical University of Ostrava	CZ			X	X	
Chemnitz University of Technology	DE				X	X
Dresden University of Technology	DE				X	
Fachhochschule Gelsenkirchen	DE			X	X	
Fachhochschule Kaiserslautern	DE			X		
Fachhochschule Sudwestfalen	DE			X		
Georg-Simon-Ohm Hochschule Nurnberg	DE				X	
Gottfried Wilhelm Leibniz Universität Hannover	DE			X	X	
Jacobs University Bremen	DE				X	X
Julius-Maximilians-Universitat Wurzburg	DE			X	X	
Leibniz Universitat Hannover	DE			X	X	
Ludwig-Maximilians-Universität	DE					X
Max Planck Inst. of Microstructure Phys.	DE					X
Munich University of Applied Sciences	DE				X	
Technical University of Dresden	DE				X	
Technical University of Munich	DE					X
Universitat Bielefeld	DE			X	X	
Universitat des Saarlandes	DE			X	X	
Universitat Duisburg Essen	DE			X	X	X
Universitat Erlangen-Nuremberg	DE			X		
Universitat Hamburg	DE			X		
Universitat Kassel	DE			X	X	
University of Regensburg	DE			X		
University of Ulm	DE				X	
Westsächsische Hochschule Zwickau	DE				X	
Aalborg University	DK			X	X	
Aarhus University	DK			X	X	X
Technical University of Denmark	DK				X	X
University of Copenhagen	DK			X	X	X
Nile University	EG				X	
University of Alicante	ES				X	
University of Barcelona	ES				X	

School	Country	Associates Degree	Minor	BS	MS	PhD
University of Bercelona, Rovira & Virgili University	ES				X	
University of Valencia	ES				X	
University of Zaragoza	ES				X	
Aalto University	FI				X	
Helsinki University of Technology	FI				X	
University of Jyväskylä	FI			X	X	
Institut National des Sciences Appliquées de Rennes	FR				X	
Université Joseph Fourier- Grenoble	FR				X	
Université Lille Nord de France	FR				X	X
National Technical University of Athens	GR				X	
Hong Kong University of Science and Technology	HK			C	X	X
Dublin Institute of Technology	IE			X		
Trinity College Dublin	IE			X		
University College Dublin	IE				X	
Technion - Israel Institute of Technologt	IL				X	X
Alagappa University	IN				X	X
Amity Institute of Technology	IN			X	X	
Andhra University, Visakhapatnam	IN				X	
Anna University	IN				X	
Indian Institute of Technology	IN		X		C	
Jawaharlal Nehru Technology University	IN				X	X
Karunya University	IN				X	
Noorul Islam University	IN				X	
Panjab University, Chandigarh	IN				X	
Pondicherry University	IN				X	
Sastra University	IN				X	
Sathyabama University	IN				X	
Singhania University	IN	X		X	X	X
SRM University	IN			X	X	
Tezpur University	IN				X	C
University of Madras	IN			X	X	
University of Rajasthan at Jaipur	IN				X	X
Vellore Institute of Technology	IN				X	
CIVEN	IT				X	
Universities of Padua, Venice & Verona	IT				X	
University of Milan	IT					X
University of Torino	IT				X	
University of Trento	IT				X	
University of Venice	IT				X	

School	Country	Associates Degree	Minor	BS	MS	PhD
WASEDA University	JP				X	
Hanyang University	KR					X
Inje University	KR			X		
Korea Adv. Inst. of Science & Technology	KR			X	X	X
Kunsan National University	KR			X		
Seoul National Univ.	KR				X	X
Sungkyun Kwan University	KR				X	X
Universidad de las Américas	MX			X		
Instituto Nacional de Astrofisica	MX				X	X
Malaysia Uni. of Science and Tech.	MY			X		
Eindhoven University of Technology	NL				C	
Leiden University	NL				X	
Radboud University of Nijmegen	NL			C	X	X
University of Groningen	NL				X	
University of Twente	NL				X	X
Utrecht University	NL				X	
Norwegian University of Science and Technology	NO				X	
University of Bergen	NO			X		
University of Oslo	NO			X	X	
Massey University	NZ			X		
University of Silesia	PL				C	
Jagiellonian University	PL			X		
Tambov State Technical University	RU			X	X	
King Saud University	SA				X	
Chalmers University of Technology	SE				X	
Karlstad University	SE				X	
KTH Royal Institute of Technology	SE				X	
Linköping University	SE				X	
Lund University	SE				X	
Nanyang Polytechnic	SG	X				
Nanyang Technological University	SG				C	C
National University of Singapore	SG		X	C	X	X
Republic Polytechnic	SG	X				
Singapore Polytechnic	SG	C				
Jozef Stefan International Postgraduate School	SI				X	X
Asian Institute of Technology	TH				X	X
Chulalongkorn University	TH					X
Mahidol University, Thailand	TH				C	C
Anadolu University	TR				X	

School	Country	Associates Degree	Minor	BS	MS	PhD
Bilkent University	TR				X	
Middle East Technical University	TR				X	
National Cheng Kung University	TW				X	
Southern Taiwan University	TW				X	
Bangor University	UK				X	
Cranfield University	UK				X	
De Montfort University	UK				X	
Heriot-Watt University	UK			X	X	
Imperial College London	UK				X	
Loughborough University	UK				X	
Newcastle University	UK				X	
Queen Mary Univ. of London	UK			X	X	
Queen's University Belfast	UK					X
Royal Holloway University of London	UK				X	C
Swansea University	UK			X	X	X
University College London	UK				X	
University of Birmingham	UK				X	
University of Cambridge	UK				X	X
University of Hull	UK			X	X	
University of Leeds	UK			X	X	X
University of Leicester	UK			X	X	
University of Liverpool	UK				X	
University of Manchester	UK				X	X
University of Nottingham	UK			C	X	
University of Oxford	UK					
University of Sheffield	UK				X	
University of Southampton	UK				X	X
University of Surrey	UK				X	X
University of Sussex	UK			X	X	
University of Ulster	UK				X	
University of York	UK			X	X	
Hanoi University of Technology	VN				C	
Viet Nam National University	VN			X		

Note: X indicates degree; C indicates certificate or concentration

Appendix: G: College Level Textbooks on NSE

Title/Chapters	Author	Year Published	Pages
Fundamentals of Nanotechnology			
Introduction Nanometrology: Standards and Nanomanufacturing Nanoelectronics Nano-Optics Nanomagnetism Nanomechanics Nanostructure and Nanocomposite Thin Films Applications of Thin Films Nanocatalysis Nanocomposites and Fibers Nanobiotechnology Biomimetics Medical Nanotechnology Environmental Nanotechnology	Gabor L. Hornyak	2008	786
Intermolecular and Surface Forces			
Historical Perspective Thermodynamic and Statistical Aspects Strong Intermolecular Forces: Covalent Interactions Involving Polar Molecules Interactions Involving the Polarization of Molecules Van der Waals Forces Repulsive Steric Forces, Total Intermolecular Pair Potentials, and Liquid Structure Special Interactions: Hydrogen-Bonding and Hydrophobic and Hydrophilic Interactions Nonequilibrium and Time-Dependent Interactions Unifying Concepts in Intermolecular and Interparticle Forces Contrasts between Intermolecular, Interparticle, and Intersurface Forces Force-Measuring Techniques Van der Waals Forces between Particles and Surfaces Electrostatic Forces between Surfaces in Liquids Solvation, Structural, and Hydration Forces Steric (Polymer-Mediated) and Thermal Fluctuation Forces Adhesion and Wetting Phenomena Friction and Lubrication Forces Theromynamic Principles of Self-Assembly Soft and Biological Structures Interactions of Biological Membranes and Structures Dynamic Biointeractions	Jacob N. Israelachvili	2010	710

Title/Chapters	Author	Year Published	Pages
Introduction to Nanoscale Science and Technology			
Nanoscale Fabrication and Characterization Nanomaterials and Nanostructures Nanoscale and Molecular Electronics Nanotechnology in Magnetic Systems Nanotechnology in Integrative Systems Nanoscale Optoelectronics Nanobiotechnology	Massimiliano DiVentra	2004	632
Introduction to Nanoscience			
Introduction Societal Implications of Nano Nanotools Characterization Methods Fabrication Methods Materials, Structure and the Nanosurface Energy at the Nanoscale The Material Continuum Nanothermodynamics Chemistry: Synthesis and Modification Carbon-based Nanomaterials Chemical Interactions at the Nanoscale Supramolecular Chemistry Chemical Synthesis and Modification of Nanomaterials Natural and Bionanoscience Natural Nanomaterials Biomolecular Nanoscience	Gabor L. Hornyak	2008	856
An Introduction to Nanosciences and Nanotechnology			
What are Nanos? *Putting Things into Perspective* Some Science to Get You Started: *The Necessary Toolkit* The Revolution in Techniques Used in Observation and Imagery The Marriage of Software and Hardware of Intelligence Engraved in Silicon Mechanics of the Living World: *Convergence on the Molecular Level Bottom-up Example* The Uses of Nanotechnologies: *They are Everywhere!* Nanos are Changing the World	Alain Nouaihat	2008	256

Title/Chapters	Author	Year Published	Pages
Introduction to Nanotechnology			
Introduction Introduction to Physics of the Solid State Methods of Measuring Properties Properties of Individual Nanoparticles Carbon Nanostructures Bulk Nanostructured Materials Nanostructured Ferromagnetism Optical and Vibrational Spectroscopy Quantum Wells, Wires and Dots Self-Assembly and Catalysis Organic Compounds and Polymers Biological Materials Nanomachines and Nanodevices	Charles. P Poole	2003	400
Nanophysics and Nanotechnology: An Introduction to Modern Concepts in Nanoscience			
Introduction Systematics of Making Things Smaller, Pre-quantum What are Limits to Smallness? Quantum Nature of the Nanoworld Quantum Consequences for the Macroworld Self-assembled Nanostructures in Nature and Industry Physics-based Experimental Approaches to Nanofabrication and Nanotechnology Quantum Technologies Based on Magnetism, Electron and Nuclear Spin, and Superconductivity Silicon Nanoelectronics and Beyond Looking into the Future	Edward L. Wolf	2004	187
Nanotechnology 101			
What is Nanotechnology? The Science of Nanotechnology The Nanotechnology Tool Box Carbon Nanotubes, Nanowires, and Nanocrystals Nanotechnology in Medicine and Health The Business of Nanotechnology Nanotechnology for Food, Agriculture, Livestock, Aquaculture, and Forestry Nanotechnology for a Sustainable Environment Nanotechnology Projects and the United States Government Colleges and Schools and Nanotechnology	John F. Mongillo	2007	304

Title/Chapters	Author	Year Published	Pages
Nanotechnology: A Gentle Introduction to the Next Big Idea			
Introducing Nano Size Matters Interlude One: The Fundamental Science Interlude Two: Tools of the Nanosciences Points and Places of Interest: The Grand Tour Smart Materials Sensors Biomedical Applications Optics and Electronics Nanobusiness Nanotechnology and You	Mark A. Ratner	2002	208
Nanotechnology: Understanding Small Systems			
Big Picture and Principles of the Small World Introduction to Miniaturization Introduction to Nanoscale Physics Nanomaterials Nanomechanics Nanoelectronics Nanoscale Heat Transfer Nanophotonics Nanoscale Fluid Mechanics Nanobiotechnology	Ben Rogers	2007	416
Science at the Nanoscale: An Introductory Textbook			
Introduction and Historical Perspective Classical Physics at the Nanoscale Brief Review of Quantum Mechanics From Atoms and Molecules to Nanoscale Materials Surfaces at the Nanoscale Low-Dimensional Nanostructures Formation and Self-Assembly at the Nanoscale Nanotools and Nanofabrication Future Trends	Chin Wee Shong	2009	228

Title/Chapters	Author	Year Published	Pages
Applied Physics of Carbon Nanotubes			
From quantum models to novel effects to new applications: theory of nanotube devices Symmetry based fundamentals of carbon nanotubes Elastic continuum models of phonons in carbon nanotubess Direct growth of single walled carbon nanotubes on flat substrated for nanoscale electronic applications Nano-peapods encapsulating fullerenes The selective chemistry of single walled carbon nanotubes Fluorescence spectroscopy of single-walled carbon nanotubes The Raman response of double wall carbon nanotubes Carbon nanotube electronics and optoelectronics Carbon nanotube-biomolecule interactions: applications in carbon nanotube separation and biosensing Electrical and mechanical properties of nanotubes determined using in-site TEM probes Nanomanipulator measurements of the mechanics of nanostructures and nanocomposites	Slava V. Rotkin	2005	371
Biomimetic Nanoceramics in Clinical Use: From Materials to Applications			
Biological Apatites in Bone and Teeth Synthetic Nanoapatites Biomimetic Nanoapatites on Bioceramics Clinical Applications of Apatite-Derived Nanoceramics	Maria Vallet-Regi	2008	184
Block Copolymers in Nanoscience			
An introduction to Block Copolymer Applications: State-of-the-art and Future Developments Guidelines for Synthesizing Block Copolymers Block Copolymer Vesicles Block Copolymer Micelles for Drug Delivery in Nanoscience Stimuli-responsive Block Copolymer Assemblies Self-assembly of Linear Polypeptide-based Block Copolymers Synthesis, Self-assembly and Applications of Polyferrocenylsilane (PFS) Block Copolymers Supramolecular Block Polymers Containing Metal-Ligand Binding Sites: From Synthesis to Properties Methods for the Alignment and the Large-scale Ordering of Block Copolymer Morphologies Block Copolymer Nanofibers and Nanotubes Nanostructured Carbons from Block Copolymers Block Copolymers at Interfaces Block Copolymers as Templates for the Generation of Mesostrucured Inorganic Materials Mesostructured Polymers-Inorganic Hybrid Materials from Blocked Macromolecular Architectures and Nanoparticles Block Ionomers for Fuel Cell Application Structure, Properties and Applications of Crystallizable ABA and ABC Triblock Copolymers with Hydrogenated Polybutadiene Blocks Basic Understanding of Phase Behavior and Structure of Silicone Block Copolymers and Surfactant-Block Copolymer Mixtures	Massimo Lazzari	2006	447

Title/Chapters	Author	Year Published	Pages
Core Concepts in Supramolecular Chemistry and Nanochemistry			
Introduction Solution host-guest chemistry Self-assembly Solid state supramolecular chemistry Nanochemistry	Jonahan W. Steed	2007	320
Introduction to Nanoelectronics: Science, Nanotechnology, Engineering and Applications			
Toward the nanoscale Particles and waves Wave mechanics Materials for nanoelectronics Growth, fabrication, and measurement techniques for nanostructures Electron transport in semiconductors and nanostructures Electrons in traditional low-dimernsional structures Nanostructure devices	Vladimir V. Mitin	2008	348
Nanocharacterisation			
Characterisation of Nanomaterials Using Transmission Electron Microscopy Scanning Transmission Electron Microscopy Scanning Tunneling Microscopy of Surfaces and Nanostructures Electron Energy-loss Spectroscopy and Energy Dispersive X-Ray Analysis Electron Holography of Nanostructured Materials Electron Tomography In-situ Environmental Transmission Electron Microscopy	J. Hutchison	2007	231
Nanocomputing: Computational Physics for Nanoscience and Nanotechnology			
Little Big Science Tools for Analysis Mesoscopic Systems Analytical Chapter Numerical Chapter Nonlinear Many Body Physics and Transport OOP, MPI, and Parallel Computing Low Dimensionality and Nanostructures Special Topics Applications	James Hsu	2009	384

Title/Chapters	Author	Year Published	Pages
Nanoethics: The Ethical and Social Implications of Nanotechnology			
Nanoscience and Nanoethics: Defining the Disciplines Why the Future Doesn't Need Us On the National Agenda: U.S. Congressional Testimony on the Society Implications of Nanotechnology Nanotech's Promise: Overcoming Humanity's More Pressing Challenges Debating Nanotechnologies In the Beginning: The U.S. National Nanotechnology Initiative The Nanotechnology R(Evolution) Technology Revolutions and the Problem of Prediction Complexity and Uncertainty: A Prudential Approach to Nanotechnology The Precautionary Principle in Nanotechnology Nanotechnology and Risk: What are the Issues? Personal Choice in the Coming Era of Nanomedicine Are We Playing God With Nanoenhancement? Anticipating the Ethical and Political Challenges of Human Nanotechnologies Global Technology Regulation and Potentially Apocalyptic Technological Threats Deliberative Democracy and Nanotechnology Rhetoric of "Stakeholding" Rules of Engagement: Democracy and Dialogue in Creating Nanotechnology Futures	Patrick Lin	2007	416
Nanoscale Devices: Fabrication, Functionalization, and the Accessibility from the Macroscopic World			
Matter on the Nanoscale Top-Down Paradigm to Miniturization Physical Limits to Miniaturization The Crossbar Structure Crossbar Production The Litho-to-Nano link Functional Molecules Grafting Functional Molecules Examples Self-Similar Nanostructures Molecular Motors Nanobiosensing Abstract Technology	Gianfranco Cerofolini	2009	205

Title/Chapters	Author	Year Published	Pages
Nanoscience: Colloidal and Interfacial Aspects			
Forces in Nanosystems Electrokinetic Phenomena on Nanoscale Bio nanosystems Nanoemulsions Self-Organization on Nanoscience Formation of Nanocolloids Capillary Phenomena on Nanoscale Coagulation/Stability in Nanosystems Applications of Nanocolloids	Victor M. Starov	2010	1256
Nanoscience and Nanotechnology: Environmental and Health Impacts			
Nanomaterials and the Environment Assessing the Life Cycle Environmental Implications of Nanomanufacturing: Opportunities and Challenges An Integrated Approach Toward Understanding the Environmental Fate, Transport, Toxicity, and Health Hazards of Nanomaterials Properties of Commercial Nanoparticles that Affect Their Removal During Water Treatment Transport and Retention of Nanomaterials in Porous Media Transport of Nanomaterials in Unsaturated Porous Media Surface Oxide on Carbon Nanotubes (CNTs) Chemical and Photochemical Reactivity of Fullerenes in the Aqueous Phase Bacterial Interactions with CdSe Quantum Dots and Environmental Implications Potential Toxicity of Fullerenes and Molecular Modeling of Their Transport across Lipid Membranes In Vitro Models for Nanoparticle Toxicology	Vicki H. Grassian	2008	470
The Nanoscience and Technology of Renewable Biomaterials			
A Fundamental Review of the Relationships between Nanotechnology and Lignocellulosic Biomass Biogenesis of Cellulose Nanofibrils by a Biological Nanomachine Tools for the Characterization of Biomass at the Nanometer Scale Tools to Probe Nanoscale Surface Phenomena in Cellulose Thin Films: Applications in the Area of Adsorption and Friction Polyelectrolyte Multilayers for Fibre Engineering Hemicelluloses at Interfaces: Some Aspects of the Interactions Lignin: Functional Biomaterials with Potential in Surface Chemistry and Nanoscience Cellulose and Chitin as Nanoscopic Biomaterials Bacterial Cellulose and Its Polymeric Nanocomposites Cellulose Nanocrystals in Polymer Matrices Development and Application of Naturally Renewable Scaffold Materials for Bone Tissue Engineering Template Synthesis of Nanostructured Metals Using Cellulose Nanocrystal	Lucian Lucia	2009	366

Title/Chapters	Author	Year Published	Pages
Nanostructured Materials, Volume 1			
Functional Nanostructured Materials- Microstructure Thermodynamic Stability and Atomic Mobility Reliability of Nanostructured Materials Mechanical Properties of Nanocomposite Materials Nanostructured Supported Catalysts for Low-Temperature Fuel Cells Nanocrystalline Solar Cells Nanoscale Materials for Hydrogen and Energy Storage Materials with Structural Hierarchy and their Optical Applications Interfacial Assembly of Nanoparticles into Higher-order Patterned Structures	Gerhard Wilde	2009	384
Nanostructures- Fabrication and Analysis			
Atomic-Scale Chains: Fabrication and Evaluation Technologies Nanolithography Adsorption Behavior of Single Molecules on Surfaces Formed by Molecular Assemblies Studied by Scanning Tunneling Microscopy Fabricating Nanostructures via Organic Molecular Templates Carbon Nanotubes Calculating Transport Properties of Nanometer-Scale Systems: Nanodevice Applications of Carbon Nanotubes and Organic Molecules Molecular Wires	H. Nejo	2006	304
Nanostructures & Nanomaterials: Synthesis, Properties & Applications			
Introduction Physical Chemistry of Solid Surfaces Zero-Dimensional Nanostructures: Nanoparticles One-Dimensional Nanostructures: Nanowires and Nanorods Two-Dimensional Nanostructures: Thin Films Special Nanomaterials Nanostructures Fabricated by Physical Techniques Characterization and Properties of Nanomaterials Applications of Nanomaterials	Guozhong Cao	2004	448

Title/Chapters	Author	Year Published	Pages
Nanotechnology: Basic Calculations for Engineers and Scientists			
Units, Conversion, Constants, and Dimensional Analysis Atoms, Elements, and the Periodic Table Molecular Rearrangements Concentration Terms Particle, Size, Surface Area, and Volume Materials Science Principles Physical and Chemical Property Estimation Nature of Particulates Particle Size Distribution Particle Sizing and Measurement Methods Fluid Particle Dynamics Particle Collection Mechanisms Particle Collection Efficiency Legal Considerations Size Reduction Prime Materials Production Manufacturing Routes Ventilation Dispersion Considerations Ethics Environmental Regulations Toxicology Noncarcinogens Carcinogens Health Risk Assessment Epidemiology	Louis Theodore	2005	480
Nanotechnology: Health and Environmental Risks			
Introduction: Assessing Nanotechnology Health and Environmental Risks Defining Risk Assessment and How It Is Used for Environmental Protection, and Its Potential Role for Managing Nanotechnology Risks Sustainable Nanotechnology Development Using Risk Assessment and Applying Life Cycle Thinking The State of the Science- Human Health, Toxicology, and Nanotechnological Risk The State of Silence- Environmental Risks NANO LCRA- An adaptive Screening-Level Life Cycle Risk Assessment Framewowrk for Nanotechnology Alternative Approaches for Life Cycle Risk Assessment for Nanotechnology and Comprehensive Environmental Assessment Current and Proposed Approaches for Managing Risks in Occupational Environments Ongoing International Efforts to Address Risk Issues for Nanotechnology	Jo Anne Shatkin	2008	192

Title/Chapters	Author	Year Published	Pages
Nanotherapeutics: Drug Delivery Concepts in Nanoscience			
Nanocarriers in Drug Delivery - Design, Manufacture and Physicochemical Properties Transport Across Biological Barriers Targeting Approaches Nanoscale Cancer Therapeutics Nanotherapeutics for Skin Disease Nanoparticles for Oral Vaccination Nanoparticles: Therapeutic Approaches for Bacterial Diseases Nanoparticle Therapy in Parasites Diseases: Possibility and Reality! Nanocarriers in the Therapy of Inflammatory Disease	Alf Lamprecht	2008	292
Polymer Nanocomposites: Processing, Characterization, and Applications			
Introduction An Overview of Nanoparticles Selecting Resin Matrix and Nanoparticles for Applications Processing of Nanomaterials Characterization of Polymer Nanomaterials Properties of Polymer Nanostructured Materials Polymer Nanostructured Materials for High-Temperature Applications Current Status, Trends Future Directions, and Opportunities	Joseph Koo	2006	272
Principles of Nanotechnology: Molecular Based Study of Condensed Matter in Small Systems			
Advances in atomic and molecular nanotechnology Nanosystems intermolecular forces and potentials Thermodynamics and statistical mechanics of small systems Monte Carlo simulation methods for nanosystems Molecular dynamics simulation methods for nanosystems Computer-based simulations and optimizations for nanosystems Phase transitions in nanosystems Positional assembly of atoms and molecules Molecular self-assembly Dynamic combinatorial chemistry Molecular building blocks- diamondoids	G. Ali Mansoori	2005	341

Title/Chapters	Author	Year Published	Pages
Scanning Electron Microscopy and X-ray Microanalysis			
Introduction The SEM and Its Modes of Operation Electron Beam-Specimen Interactions Image Formation and Interpretation Special Topics in Scanning Electron Microscopy Generation of X-Rays in the SEM Specimen X-Ray Spectral Measurement: EDS and WDS Qualitative X-Ray Analysis Quantitative X-Ray Analysis: The Basics Special Topics in Electron Beam X-Ray Microanalysis Speciment Preparation of Hard Materials: Metals, Ceramics, Rocks, Minerals, Microelectronic and Packaged Devices, Particles, and Fibers Speciment Preparation of Polymer Materials Ambient-Temperature Speciment Preparation of Biological Material Low-Temperature Specimen Preparation Procedures for Elimination of Charging in Nonconducting Specimens	Joseph Goldstein	2003	689
Soft Machines: Nanotechnology and Life			
Fantastic voyages Looking at the nanoworld Nanofabrication The Brownian universe: physics at the nanoscale Making soft machines Machines and mechanisms Wetware: chemical computing from bacteria to brains Single-molecule electronics Our nanotechnological future	Richard A.L. Jones	2004	238

Appendix H: U.S. NSE Centers

NSF Nanoscale Science and Engineering Centers (NSEC)

David Guston	Arizona State Univ.	Center for Nanotechnology in Society
James Yardley	Columbia Univ.	Center for Electron Transport in Molecular Nanostructures
Alexander Gaeta	Cornell Univ.	Center for Nanoscale Systems
Robert Westervelt	Harvard Univ.	Science for Nanoscale Systems and their Device Applications
Richard Freeman	Harvard Univ.	Nanotechnology in Society Network 4
Ahmed Busnaina	Northeastern Univ.	Center for High Rate Nanomanufacturing
Chad Mirkin	Northwestern Univ.	International Institute for Nanotechnology
L. James Lee	Ohio State Univ.	Center for Affordable Nanoengineering of Polymeric Biomedical Devices
Richard Siegel	Rensselaer Polytech. Inst.	Center for Directed Assembly of Nanostructures
Vicki Colvin	Rice Univ.	Center for Biological and Environmental Nanotechnology
Kathryn Moler	Stanford Univ.	Center for Probing the Nanoscale
Placid Ferreira	U Ill. Urbana Champaign	Center for Nanoscale Chemical-Electrical-Mechanical Manufacturing Sys
Alex Zettl	UC Berkeley	Center for Integrated Nanomechanical Systems
Xiang Zhang	UC Los Angeles	Center for Scalable and Integrated Nanomanufacturing
Barbara Harthorn	UC Santa Barbara	Center for Nanotechnology in Society
James Watkins	Univ. Mass.-Amherst	Network for Hierarchical Manufacturing
Dawn Bonnell	Univ. Pennsylvania	Center for Molecular Function at the Nanoscale
Michael Dickson	Univ. So. Carolina	Societal Interactions with Nanotechnology
Paul Nealey	Univ. Wisconsin - Madison	Center for Templated Synthesis and Assembly at the Nanoscale.

NSF NNIN

Sandip Tiwari	Cornell Univ.	National Nanotechnology Infrastructure Network
Roger Howe	Stanford Univ.	Nanofabricaation Facility
Kensall Wise	Univ. Michigan	Lurie Nanofabrication Facility
James Meindl	Georgia Inst. Tech.	Nanotechnology Research Center
Francois Baneyz	Univ. Washington	Center for Nanotechnology
Theresa Mayer	Penn. State Univ.	Penn State Nanofabrication Facility
Mark Rodwell	UCSB	Nanotech
Stephen Campbell	Univ. Minnesota	Nanofabrication Facility
Sanjay Banerjee	UT Austin	Microelectronics Research Center
Jim Reynolds	Harvard Univ.	Center for Nanoscale Systems
Gary Harris	Howard Univ.	Howard Nanoscale Science and Engineering Facility
J.Van Zeghbroeck	Univ. Col	Colorado Nanofabrication Lab
Trevor Thornton	Ariz State Univ.	Nanofab
Dong Qin	Washington Univ. St. Louis	Nano Research Facility

NSF Networks and Centers that complement the NSECs

Robert Meyer	Brandeis Univ.	MRSEC: Nano-Structured and Bio-Molecular Materials
Dennis Hess	Georgia Inst. of Technol.	MRSEC: The Georgia Tech Laboratory for New Electronic Materials
Thomas Mallouk	Penn. State Univ.	MRSEC: Center for Nanoscale Science
Richard Register	Princeton Univ.	MRSEC: Princeton Center for Complex Materials
Thomas Russell	Univ. Mass. - Amherst	MRSEC: Materials Research Science and Engineering Ctr on Polymers
Evgeny Tsymbal	Univ. Nebraska	MRSEC: Quantum and Spin Phenomena in Nanomagnetic Structures
Mehmet Sariakaya	Univ. of Washington	MRSEC: Genetically Engineered Materials Science & Engineering Ctr
Harold Craighead	Cornell Univ.	STC: The Nanobiotechnology Center
Eli Yablonovitch	UCB	STC: Center for Energy Efficient Electronics Science
Lawrence Bell	Boston Museum of	NISE Net: Nanoscale Informal Science Education Network

	Science	
Robert Chang	Northwestern Univ.	NCLT: Nanotechnology Center for Learning and Teaching
Mark Lundstrom	Purdue Univ.	NCN: Network for Computational Nanotechnology
NSF ATE		
Steve Fonash	Penn. State Univ.	National Ctr for Nanotechnology Applications and Career Knowledge
Deb Newberry	Dakota County Technical College	Midwest Regional Center for Nanotechnology Education
Matthias Pleil	Univ. New Mexico	Southwest Center for Microsystems Education
Michael Lesiecki	Maricopa Community College	Maricopa Advanced Technology Education Center
DOE NanoCenters		
Stephen Streiffer	Argonne National Lab	Center for Nanoscale Materials
Carolyn Bertozzi	Berkeley National Lab	Molecular Foundry
Emilio Mendez	Brookhaven National Lab	Center for Functional Nanomaterials
Mike Simonson	Oak Ridge National Lab	Center for Nanophase Material Sciences
Robert Huang	Sandia National Lab	Center for Integrated Nanotechnologies
DOE EFRC		
Chris Marshall	ANL	Institute for Atom-Efficient Chemical Transformations
Michael Thackeray	ANL	Center for Electrical Energy Storage
Victor Klimov	LANL	Center for Advanced Solar Photophysics
Donald DePaolo	LBNL	Center for Nanoscale Control of Geologic CO2
Alex Zunger	NREL	Center for Inverse Design
David Wesolowski	ORNL	Fluid Interface Reactions, Structures and Transport Center
Jerry Simmons	SNL	EFRC for Solid-state Lighting Science
R. Morris Bullock	PNNL	Center for Molecular Electrocatalysis
Harry Atwater	CalTech	Light Matter Interactions in Solar Energy Conversion
Hector Abruna	Cornell	Energy Materials Center
James Spivey	LSU	Center for Atomic-Level Catalyst Design
Peter Green	Michigan	Center for Solar and Thermal Energy Conversion
Donald Morelli	Michigan State	Revolutionary Materials for Solid State Energy Conversion
Gang Chen	MIT	Solid State Solar-Thermal Energy Conversion Center
B. Grzybowski	Northwestern	Non-equilibrium Energy Research Center
Daniel Cosgrove	Penn State Univ.	Center for Lignocellulose Structure and Formation
Stacy Bent	Stanford	Center on Nanostructuring for Efficient Energy Conversion
Clare Grey	SUNY Stony Brook	Northeastern Center for Chemical Energy Storage
Neal Armstrong	Univ. Arizona	Center for Interface Science: Solar Electric Materials
John Bowers	UC, Santa Barbara	Center for Energy Efficient Materials
Vidvuds Ozolins	UC, Los Angeles	Molecularly Engineered Energy Materials
Dion Vlachos	Univ. Delaware	Catalysis Center for Energy Innovation
Peter Green	Univ. Michigan	Cent for Solar and Thermal Energy Conversion
Gary Rubloff	Univ. Md., College Park	Ctr. for Science of Precision Multifunctional NS for Energy Storage
Dan Dapkus	Univ. So. California	Center for Energy Nanoscience
Ken Reifsnider	Univ. So. Carolina	Heterogeneous Functional Materials Center
Gary Pope	UT Austin	Center for Frontiers of Subsurface Energy Security
Paul Barbara	UT Austin	Understand Charge Separation/Transfer at Interfaces in Energy Materials
T. Brent Gunnoe	UVA	Center for Catalytic Hydrocarbon Functionalization
NIH NanoCenters		
Wah Chiu	Baylor College of Medicine	Center for Protein Folding Machinery
Jeffrey Smith	Burnham Institute	Nanotherapy for Vulnerable Plaque
James Heath	Calif. Inst. of Technology	Nanosystems Biology Cancer Center (NSBCC)
Michael Sheetz	Columbia Univ.	Nanotechnology Center for Mechanics in Regenerative Medicine
Gang Bao	Georgia Inst. of Technology	Nanomedicine Center for Nucleoprotein Machines
Gang Bao	Georgia Inst. of Technology	Nanotechnology: Detection & Analysis of Plaque Formation
Shuming Nie	Georgia Inst. of Technology	Nanotechnology Center for Personalized and Predictive Oncology
Ralph Weissleder	Harvard/MGH	Center of Cancer Nanotechnology Excellence
Ralph Weissleder	Mass. General Hospital	Translational Program of Excellence in Nanotechnology
Robert Langer	MIT	Center of Cancer Nanotechnology Excellence

Chad Mirkin	Northwestern Univ.	Nanomaterials for Cancer Diagnostics and Therapeutics
Judith Frydman	Stanford Univ.	Center for Protein Folding Machinery
Sanjiv Gambhir	Stanford Univ.	Ctr. for Cancer NT Excellence Focused on Therapy Response
Ehud Isacoff	UC, Berkeley	NDC for the Optical Control of Biological Function
Chih-Ming Ho	UC, Los Angeles	Center of Cell Control
Sadik Esener	UC, San Diego	Center of NT for Treatment, Understanding, & Monitoring of Cancer
Wendell Lim	UC, San Francisco	Engineering Cellular Control: Synthetic Signaling and Motility Systems
Peixuan Guo	Univ. of Cincinnati	Phi29 DNA-Packaging Motor for Nanomedicine
Eric Jakobsson	U. Ill. Urbana-Champaign	National Center for Design of Biomimetic Nanoconductors
Rudolph Juliano	Univ. of North Carolina	Carolina Center of Cancer Nanotechnology Excellence
Karen Wooley	Washington Univ.	Integrated Nanosystems for Diagnosis and Therapy
Samuel Wickline	Washington Univ.	The Siteman Center of Cancer Nanotechnology Excellence
NIH Other		
Scott McNeil		Nanotechnology Characterization Laboratory
NASA		
Meyya Meyyappan	Ames	Center for Nanotechnology
DOD NanoCenter		
Eric Snow	Naval Research Lab	Institute for Nanoscience
John Joannopoulos	MIT	Institute for Soldier Nanotechnologies
SRC - NRI / FCRP		
Alain Kaloyeros	SUNY Albany	NRI: Institute for Nanoelectronics Discovery and Exploration (INDEX)
Alan Seabaugh	Univ. Notre Dame	NRI: Midwest Institute for Nanoelectronics (MIND)
Sanjay Banerhjee	UT Austin	NRI: Southwest Academy of Nanoelectronics (SWAN)
Kang Wang	UC, Los Angeles	NRI: Western Institute of Nanoelectronics (WIN)
Dimitri Antoniadis	MIT	FCRP: Center for Materials, Structures and Devices
Kang Wang	UC, Los Angeles	FCRP: Functional Engineered Nano Architectonics
Other		
Alain Kaloyeros	SUNY Albany	College of Nanoscale Science and Engineering
Yury Gogotsi	Drexel Univ.	Nanotechnology Inst
Martin Jarrold	Indiana Univ.	Nanoscience Center
Paresh Ray	Jackson State Univ.	Center for Nanoscience and Nanotechnology
Jerzy Leszczynski	Jackson State Univ.	Interdisciplinary Center for Nano Toxicity
Martin Harmer	Lehigh	Center for Advanced Materials and Nanotechnology
Eric Blough	Marshal Univ. (WV)	Center for Diagnostic Nanosystems
Gilbert Pacey	Miami Univ.	Center for Nanotechnology
James Baker	Michigan	Nanotechnology Institute for Medicine and Biological Sciences
Mark Worden	Michigan State	NanoTechnology@Michigan State University
Trevor Douglas	Montana State Univ.	Center for Bio-Inspired Nano-Materials
Greg Parsons	NC State	NANO@NC State
Wolfgang Porod	Notre Dame	Center for Nano Science and Technology
Jim Mason	Oklahoma (3 Univ.)	Oklahoma Nanotechnology Initiative
Robert Rung	Oregon (3 Univ.)	Oregon Nanoscience and Microtechnologies Institute ONAMI
Jun Jiao	Portland State Univ.	Center for Electron Microscopy and Nanofabrication (ONAMI)
James Cooper	Purdue	Birck Nanotechnology Center
Wade Adams	Rice	Smalley Institute for Nanoscale Science and Technology
Shawn Decker	So. Dakota School of Mines	Center for Accelerated Applications at the Nanoscale
Walt Trybula	Texas State – San Marcos	Nanotechnology Advancement Center
Mark Holtz	Texas Tech	Nano Tech Center
Alexandru Biris	Univ Arkansas – Little Rock	Nanotechnology Center
Frank Yaghmaie	UC, Davis	Northern California Nanotechnology Center
Guann-Pyng Li	UC, Irvine	Integrated Nanosystems Research Facility
Paul Weiss	UC, Los Angeles	California NanoSystems Institute
Sudipta Seal	Univ. Central Florida	NanoScience Technology Center
Maciej Kumosa	Univ. Denver	Center for Nanoscale Science and Engineering
Brij Moudgil	Univ. Florida	Center for Nano-Bio Sensors
Vicki Grassian	Univ. Iowa	Nanoscience and Nanotechnology Institute

Yiping Zhao	Univ. Georgia	NanoSEC
Kevin Walsh	Univ. Louisville	Micro/Nano Technology Center
Gary Rubloff	Univ. Md., College Park	NanoCenter
Steve Campbell	Univ. Minnesota	Center for Nanostructure Applications
Fred Hawthorne	Univ. Mo. – Columbia	International Institute of Nano and Molecular Medicine
David Sellmyer	Univ. Nebraska Lincoln	Center for Materials and Nanoscience
Biswajit Das	Univ. Nevada	Nanotechnology Center
Hong Koo Kim	Univ. Pitt	Petersen institute of NanoScience and Engineering
Scott Mao	Univ. Pitt	Swanson Center for Micro and Nano Systems
Tom Vogt	Univ. South Carolina	NanoCenter
Mark Thompson	Univ. Southern California	Biomedical Nanoscience Initiative
Ashok Kumar	Univ. South Florida	Nanotechnology Research and Education Center
Paul Barbara	UT Austin	Center for Nano & Molecular Science and Technology
Ray Baughman	UT Dallas	Alan G. MacDiarmid NanoTech Institute
Marc Porter	Univ. Utah	Nano Institute of Utah
Stuart Wolf	Univ. Virginia	nanoSTAR Institute
David Lederman	Univ. West Virginia	WV Nano Institute
Sandra Rosenthal	Vanderbilt	Initiative for Nanoscale Science and Engineering
David Carroll	Wake Forest	Center for Nanotechnology and Molecular Materials
SM Mukhopadhyay	Wright State Univ.	Center for Nanoscale Mutifunctional Materials

Appendix I: NSE Workforce Oriented Programs and Websites

Title	Partnering Universities/Laboratories	Website
Arizona Nanotechnology Cluster	Arizona State University University of Arizona	http://www.aznano.org/
California NanoSystem Institute (CNSI)	University of California-Los Angeles	http://www.cnsi.ucla.edu/
Colorado Nanotechnology Alliance	Colorado State University University of Colorado-Boulder University of Denver	http://www.coloradonanotechnology.org/home/index.php?option=com_content&task=view&id=60&Itemid=59
Connecticut Nanotechnology Network		http://www.ctnano.org/
Greater Washington Nanotech Alliance	University of Delaware University of Maryland Johns Hopkins University Applied Physics Laboratory U.S. Army Research Laboratory U.S. Naval Research Laboratory	http://www.nanotech-alliance.org/
Micro and Nanotechnology Commercialization Education Foundation (MANCEF)	Karlsruhe Institute of Technology Michigan Tech nano-network of New Mexico New Mexico State University Texas Tech University University of Houston University of New Mexico University of Oklahoma University of South Florida University of Texas-Arlington University of Utah Sandia National Labs	http://www.mancef.org/node
Massachusetts Nanotechnology Initiative		http://masstech.org/mni/index.htm

Title	Partnering Universities/Laboratories	Website
Michigan Small Tech Association	Pennsylvania State University UC, Office of Technology Transfer Argonne National Laboratory Brookhaven National Laboratory Idaho National Laboratory Lawrence Berkeley National Laboratory Los Alamos and Sandia National Labs. Oak Ridge National Laboratory	http://www.nsti.org/Nanotech2007/sponsors.html?id=172
Mid Atlantic Nanotechnology Alliance (MANA)		http://www.midatlanticnano.org/mana.htm
Minnesota Nano		http://www.mnnano.org/
NanoBusiness Alliance		http://nanobusiness.org/index.php
nanoSTAR	University of Virginia	http://www.virginia.edu/nanostar/
The Nanotechnology Institute	Drexel University Harrisburg University of Science and Technology Haverford College Lankenau Institute for Medical Research Lehigh University Millersville University Temple University University of Pennsylvania University of the Sciences in Philadelphia Villanova University Widener University	http://nanotechinstitute.org/
New York Loves Nanotech (NYLN)		http://www.nylovesnano.com/
North Alabama Nanotechnology Organization	Alabama A&M University University of Alabama, Huntsville OakRidge National Laboratory	
Northern California Nontechnology Intiative		http://www.ncnano.org/
North Carolina Nanotechnology		http://www.ncnanoinitiative.org/public/root/home.asp
Oklahoma NanoTechnology Initiative (ONI)		http://www.oknano.com/

Title	Partnering Universities/Laboratories	Website
Oregon Nanoscience and Microtechnologies Institute (ONAMI)	Eastern Oregon University Oregon Health and Science University Oregon Institute of Technology Oregon State University Portland State University Southern Oregon University University of Oregon Western Oregon University Pacific Northwest National Laboratory	http://www.onami.us/
Pennsylvania Initiative for Nanotechnology		http://newpa.com/build-your-business/key-industries/high-technology/nanotechnology
Pennsylvania NanoMaterials Commercialization Center	Carnegie Mellon University Lehigh University Penn State University University of Pittsburgh	http://www.pananocenter.org/
Texas Nanotechnology Workforce Development Initiative	CASPER at Baylor University Del Mar College of Corpus Christi Texas State Technical College-Waco	http://nanotechworkforce.com/
Utah Center for Nanomedicine	The University of Utah	
Washington Nanotechnology Initiative	Pacific Northwest National Laboratory University of Washington Washington State University	
WVNano initiative	West Virginia University	http://wvnano.wvu.edu/initiative/about.html

Appendix J: K-12 International Benchmark Workshop Participants

Name	Institution	Location	E-mail
Fuh-Sheng Shieu	National Chung Hsing University	Taiwan	fsshieu@dragon.nchu.edu.tw
Guo Hao Chia	Dunman High School	Singapore	chia.guohao@dhs.sg
Robert Thomas	Dept of Innovation, Industry, Science and Research	Australia	robert.thomas @innovation.gov.au
Elisabeth Nilsson	Univ Lund	Sweden	elisabeth.nilsson@ftf.lth.se
Lars Montelius	Univ Lund	Sweden	lars.montelius@oresund.org
Lisa Friedersdorf	Univ VA	Charlottesville, VA	lisaf@virginia.edu
Krish Mathur	Dept of Education	Washington, DC	krish.mathur@ed.gov
James Batterson	Advisor to VA State Education	Newport News, VA	jimbatterson@live.com
Robert Chang	Northwestern	Evanston, IL	r-chang@northwestern.edu
Deb Newberry	Dakota County Technical College	Rosemount, MN	deb.newberry@dctc.edu
Barbara Karn	EPA	Washington, DC	Karn.barbara@epa.gov
Elvis Cherry	Consultant	Nashville TN	elvis.cherry@mnps.org
Renee Dewald	Evanston Township High School	Evanston, IL	rdewald@aol.com
Gregory Adragna	Cristorey High School	Houston, TX	gadragna@cristoreyhouston.org
Patricia Simmons	NCSU	Rayleigh, NC	patricia_simmons@ncsu.edu
Sean Murdock	NanoBusiness Alliance	Chicago, IL	sean@nanobusiness.rog
Angela Baber	National Governors Assoc	Washington, DC	ababer@nga.org
Stephen Pruitt	Achieve	Washington, DC	spruitt@achieve.org
Miriam Heller	MHI Tech Systems	Washington, DC	heller@mhitech.com
James Murday	Univ So Calif	Washington, DC	murday@usc.eu

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