NSF Workshop Report

Partnership for Nanotechnology Education

University of Southern California, Los Angeles, CA
26-28 April 2009

Sponsored by the National Science Foundation

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

Partnership for Nanotechnology Education

26-28 April 2008

Organizers
The Partnership for Nanotechnology Education was organized and directed by:

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

Sponsored by the National Science Foundation

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

Copyrights reserved by individual authors or their assignees as noted herein. Reproduction by permission. This work relates to NSF award EEC 0805207.

Table of Contents

I. Executive Summary…….…....1

II. Background…….……7

III. Workshop Breakout Session Reports……13

Standards of Learning: Local, State, and National…….…...15

Teacher Education and Training…….17

Curricula and Teaching Aid Development…….....18

Informal Education……..….22

Public Education – TV, Radio, Press, Books, Magazines, and Web……25

Local Community Outreach and Engagement……...29

University and Community College……..……..32

Industry Needs for Nanotechnology Education……... 34

Cyber and Virtual Innovations……....37

IV. Appendices

Appendix A: Workshop Participants…….……..…..…….42
Appendix B: Workshop Agenda……..43
Appendix C: Centers Addressing Nanoscale Science and Engineering……...47
Appendix D: Representative Listing of Universities and Community Colleges Offering Nanoscale Science, Engineering and Technology Degrees…...49
Appendix E: Textbooks and Reference Book Addressing Nanoscale S&E…….53

References……..54

Executive Summary and Priority Recommendations

The current interest, planning, and activity toward reinvigorating Science, Technology, Engineering, and Mathematics (STEM) education provides programmatic opportunities for innovation. With the disruptive discoveries already realized through nanoscale science and engineering research, it is essential to examine what impact the nanoscale might impose on approaches to revamp STEM education:

- Nanostructures can have new physical, chemical, and biological properties. This new knowledge should be incorporated into the educational corpus.
- Nanoscale science and engineering is largely transdisciplinary. It challenges the traditional science and engineering education taxonomies.
- The nanoscale holds sufficient novelty to attract STEM interest in students.
- As nanostructures become materials building blocks and directed self-assembly becomes a viable manufacturing process, there will be a need for an informed, skilled workforce.
- Workers and members of the general public may be in contact with nanomaterials in various forms during manufacture or in products and should be sufficiently knowledgeable to understand the benefits and risks.
- The National Science Foundation (NSF) and other institutions' attention to education at the nanoscale (NanoEducation) is developing and disseminating a wealth of new instructional materials, some of which are available as cyberinfrastructure resources.

Those interested in NanoEducation believe it is time to: a) broaden the nanoscale education efforts to include the many stakeholder groups and communities; b) establish an enduring infrastructure beyond the NSF-sponsored Nanoscale Science and Engineering Education (NSEE) workshops; and most important, c) develop partnerships toward meeting the challenges and identifying the opportunities provided by the global advances at the nanoscale. This is consistent with the Carnegie Opportunity Equation report that calls for a national mobilization in education exploiting partnerships[1]. A partnership approach is also reflected in the 2009 National Nanotechnology Initiative (NNI) reauthorization bills[2].

To explore the educational challenges and opportunities presented by the nanoscale, the NSF funded a workshop entitled "Partnership for Nanotechnology Education" at the University of Southern California on 26-28 April 2009. The workshop participants, who were selected to represent the stakeholder communities, are listed in Appendix A. The workshop agenda is provided in Appendix B. The workshop goals were to:

- Identify and examine the present status of "nano" education efforts;
- Identify the infrastructure needed to carry out effective "nano" education;
- Lay the groundwork for functional stakeholder partnerships that address the needs and identify the opportunities; and
- Identify mechanisms for the partnerships to provide information for the Nanoscale Science, Engineering, and Technology (NSET) subcommittee member agencies, the National Science and Technology Council (NSTC) interagency Education Working Group proposed in the NNI 2009 reauthorization bills, and other interested parties to use in developing funding goals, strategies, and programs.

On the final afternoon of the workshop the participants discussed the recommendations developed in the prior breakout sessions. They identified the following ten items as warranting immediate action.

1. Creation of a NanoEducation Ecosystem:
Finding: There are numerous groups around the world addressing STEM education, NanoEducation, nanoscale science and engineering research, and nano-enabled technologies. 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.

Recommendation: The NSET, which has representation from about 25 participating Federal agencies, should create a Nanotechnology Education and Workforce working group that will support the agency 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. National Nanotechnology Coordination Office (NNCO) funds (or other contributions from the various Federal agencies) should be used for this effort.

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); the NNI participating Federal agencies listed in Table 2 of this report; National Science Teachers Association (NSTA); professional science and engineering organizations (e.g., American Chemical Society (ACS), American Institute of Physics, Society of Manufacturing Engineers, etc.); NanoBusiness Alliance; and STEM Education Coalition.

2. Standards of Learning (SOL):
Finding: Without incorporating the current understanding of nanoscale science and engineering into science and engineering 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 National Governors Association (NGA) has approached Achieve Inc. with the task of preparing common core learning standards in the physical sciences that might be adapted by each state for its own learning standards.

Recommendation 1: The NSET initiate contact with the NGA, the Council of Chief State School Officers (CCSSO), and Achieve Inc. to foster an effort to appropriately introduce the nanoscale into the common core standards.

Recommendation 2: Participants in the many U.S. NanoCenters (see Appendix C) should begin working with their own State Education Departments toward science learning standard revisions.

Principal Stakeholders include: OSTP/NSTC, NSF, Department of Education (DoEd), 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).

3. 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: 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. The pending NNI reauthorization bills designate funds that might be used to address this need.

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

4. K-12 Curricula and Teaching Aids:

Finding: There are several web sites (such as those listed in Table 1 in this report) with materials that address curricula supplements, teaching aids, and science fair projects. In particular, the NSF-funded Nanoscale Science and Engineering Centers (NSEC) have been very productive at developing innovative approaches to NanoEducation. However, the materials are widely dispersed, are of non-uniform format, and have varying degrees of refinement.

Recommendation: The DoEd, working closely with the NSTA and cyber-oriented curriculum developers (such as those listed in Table 6 in this report), create a central web site. The NSTA should 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. Additional well-designed, highly interactive, media-rich, online learning tools should continue to be developed. The pending NNI reauthorization bills provide funds that might be used to address this need.

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.

Recommendation: The NSF National Nanotechnology Infrastructure Network (NNIN), NSEC, DoE NanoCenters, and the National Institute of Standards Technology (NIST) Center for Nanoscale Science and Technology work with the NSTA and the DoEd toward the preparation of on-site and/or remote access to higher end facilities that might contribute to the K-12 education process. The pending NNI reauthorization bills provide funds that might be used to address this need.

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

Recommendation: 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.

Finding: To regain prominence in science, technology, and engineering the U.S. must stop having a haphazard approach to curriculum development.

Recommendation: Funding is needed to allow for the design, development, testing, and implementation of a coherent curriculum that would allow 7 to 16-year-old students to develop an integrated understanding of core science ideas that underpin nanoscience and engineering. Such a curriculum would focus on helping students develop progressively deeper understanding

of core ideas. Such a process calls for change in the standards that focus on teaching big ideas with a focus on developing a deeper understanding of these ideas.

Principal Stakeholders include: NSF, DoEd, NSTA, and professional science and engineering societies.

5. Informal Education through Museums:
Finding: To date, the Nanoscale Informal Science Education Network (NISE Net) has largely examined how "nano" fits into the size scale of materials. Several studies have suggested that students will respond best to STEM as it addresses societal problems. Now that nano-enabled technologies are beginning to proliferate, it would be timely to develop exhibits and programs associated with the impact of those nano-enabled technologies.

Recommendation: NSF, which is the principal funding source for new nanoscale science and engineering projects, should take the lead in establishing links between museums and the national and international research communities for new exhibit development. Moreover, other Federal funding agencies and industry representatives must also be contributors since they will be engaged in the translational efforts that lead to technology impact.

Principal Stakeholders include: NSF, other relevant mission-oriented Federal funding agencies, Museums, ASTC, and NanoBusiness Alliance.

6. Public Education through Media:
Finding: Nano-enabled technologies will enable us to alter our world and provide advances in standards of living. With the decline in the number of science journalists, there is an opportunity for the NNCO, University and Industrial programs, and other stakeholder groups to develop a continuing stream of information that can inform the public of the benefits and risks emanating from progress at the nanoscale. The rapid growth in information technologies is creating new interaction paradigms that might be exploited using electronic media (e.g., Wikipedia, FaceBook, Second Life, YouTube, and Kindle) that are being adopted by young and IT-literate learners[3].

Recommendation 1: Cyber-education should be included in the suite of learning venues to engage students. NSF, with its interest in cyberlearning, should take the initiative but the DoEd must be engaged to ensure a continuing effort.

Recommendation 2: The Wikipedia entries on nanotechnology should be routinely updated and expanded. This task might be best accomplished by mobilizing the variety of talent and expertise at the various NanoCenters. K-12 science teachers should be involved to ensure the information is structured in ways that can be readily absorbed at the various grade levels.

Principal Stakeholders include: NSF, DoEd and other agencies with relevant missions, NSET/NNCO, NSTA, and ASTC.

7. Local Community Outreach and Engagement:
Finding: The national media plays an important role in informing people. However, local and personal engagement is often more effective.

Recommendation 1: Existing NanoCenters (listed in Appendix C) should expand their outreach activities to local and state communities.

Recommendation 2: A NSEE forum should be established to share best practices wherein all federally funded NanoCenters should participate, not just those funded by NSF.

Principal Stakeholders: NSET/NNCO, ASTC, and NGA.

8. University and Community Colleges:
Finding: While the U.S. research universities are acknowledged as world leaders in science and engineering, there is growing global competition—especially in nanoscale science, engineering, and technology. To meet the national needs in the near future, it will become more important to foster U.S.-born students in STEM. Since 40% of college students get their start in community colleges, the Opportunity Equation report[1] recommends closer interaction between community colleges and the universities.

Recommendation: NSF, DoEd, and other agencies with relevant missions should foster nanotechnology curricula development and evaluation that is appropriate for community colleges and ensure meaningful collaborations between the community colleges and the NanoCenters. The DoEd's Department of College and Career Transitions program addressing articulation should ensure nanotechnology is included in that program.

Principal Stakeholders: NSF, DoEd, Department of Labor (DoL), universities, and National Association of Community College Entrepreneurship (NACCE).

9. Industrial Needs:
Finding: Preparation for employment is an important aspect of the educational process. In our rapidly evolving world, the needs of industry are fluid due to changing technologies and growing global competition. Nanoscale science will be instrumental in technological change. Many countries have followed the U.S. lead and established a nanotechnology initiative. Moreover, those initiatives tend to be more focused on targeted technology development than is the U.S. Consequently, there will likely be strong competition for nano-trained people between the U.S. and those countries.

Recommendation: The DoL needs to work with industry groups and professional science and engineering societies to develop accurate assessments of domestic workforce needs, including the effects of growing overseas education and job opportunities.

Principal Stakeholders include: DoL, Department of Commerce (DoC), professional science and engineering societies, and NanoBusiness Alliance.

10. Cyber and Virtual Innovations:
Finding: NSF's investments in cyber-infrastructure along with those of other agencies have resulted in a range of state-of-the-art, distributed digital resources: some for nanotechnology and science research, some for nanotechnology learning and education, and some for nanotechnology events and news[4]. These cyber-nanotechnology resources vary in terms of their target audiences (education level, country of origin, original purpose), quality, level of integration with other cyber-infrastructure resources, and usage and usage reporting. Most lack such meta-information, which may limit knowledge transfer across user communities in terms of discoverability, searchability, and adaptability. The emerging NanoEducation community must be able to exploit existing cyber-infrastructure resource investments more effectively.

Recommendation 1: NanoHUB, National Center for Learning and Teaching (NCLT), NNIN, and other cyberinfrastructure resources focused on nanotechnology need to be better publicized regarding accessibility, targeted user-levels, customizability both in terms of targeted audiences and user interface, interoperability with other systems, and service and training offerings.

Recommendation 2: Consideration should be given to the research and development of an overall mechanism for efficient search, access, and use of cyber-infrastructure resources focused on nanoscience and technology with potential relevance to education at all levels. Such a mechanism would likely entail providing for the creation of an inventoried, analyzed, tagged registry. Also worth considering are mechanisms for enabling greater interoperability with emerging cyber-nanotechnology resources such as remote access and control to state-of-the-art nanotechnology characterization equipment; databases for properties, applications; environmental, health, and safety implications; and general educational paradigms, such as virtual and immersive environments, simulations, and games. Such integration and knowledge sharing offers greater promise for accelerated discovery and learning of nanoscience and technology.

Principal Stakeholders include: NSF, other Federal agencies with relevant missions, NSET/NNCO, NSTA, Open Education Resources (OER), and NanoTechnology Group Inc.

I. Background

The current interest, planning, and activity toward reinvigorating Science, Technology, Engineering, and Mathematics (STEM) education provides programmatic opportunities for innovation. With the disruptive discoveries already realized through nanoscale science and engineering research, it is essential to examine what impact the explosion of knowledge at the nanoscale might provide for any approaches to revamp STEM education.

To explore the educational challenges and opportunities presented by the nanoscale, the National Science Foundation (NSF) funded a workshop entitled "Partnership for Nanotechnology Education" at the University of Southern California (USC) on 26-28 April 2009. The workshop participants, who were selected to represent the stakeholder communities, are listed in Appendix A. The workshop agenda is provided in Appendix B. The workshop goals were to:

- Identify and examine the present status of "nano" education efforts;
- Identify the infrastructure needed to carry out effective "nano" education;
- Lay the groundwork for functional stakeholder partnerships that address the needs and identify the opportunities; and
- Identify mechanisms for the partnerships to provide information for the Nanoscale Science, Engineering, and Technology (NSET) subcommittee member agencies, the National Science and Technology Council (NSTC) interagency Education Working Group proposed in the NNI 2009 reauthorization bills, and other interested parties to use in developing funding goals, strategies, and programs.

Partnership was emphasized because those interested in NanoEducation believe it is time to: a) broaden the education efforts to include explicitly the many stakeholder communities; b) establish a more enduring infrastructure than just the prior Nanoscale Science and Engineering Education (NSEE) workshops; and c) develop partnerships toward meeting the challenges and identifying the opportunities provided by the global advances at the nanoscale. This is consistent with the Carnegie Opportunity Equation report[1] that calls for a national mobilization in education exploiting partnerships. A partnership approach is also reflected in language of the 2009 National Nanotechnology Initiative (NNI) reauthorization bills[2].

As a recent book "Nanoscale Science and Engineering Education"[5] makes clear, any effective partnership must include a diverse set of potential stakeholders to cope with the extent of the expected nanoscale impact:

- General public
- Federal government agencies
- State and local education, workforce, and economic development authorities
- Industry leadership and workforce
- K-12 teachers and administrators
- Technical and community colleges
- Undergraduate colleges and universities (BS/BA, majors/minors)
- Graduate degree universities (MS/PhD)
- Continuing education institutions, including industrial and individual as well as distance learning
- Professional science and engineering societies
- Professional groups, such as EDUCAUSE and the STEM Education Coalition
- Computer and web-based education groups

- Foundations
- Publishers and media for outreach

The need to improve U.S. student performance in STEM is well documented, with five recent reports as examples:

- The National Academy of Sciences (NAS), "Is American Falling off the Flat Earth" [6];
- The National Science Board (NSB), "National Action Plan for Addressing the Critical Needs of the U.S. Science, Technology, Engineering and Mathematics Education System"[7];
- The NSB, "Moving Forward to Improve Engineering Education"[8];
- The Carnegie Corporation of New York, and the Institute for Advanced Study, "The Opportunity Equation: Transforming Mathematics and Science Education for Citizenship and the Global Economy"[9]; and
- The National Research Council (NRC), "Engineering in K-12 Education: Understanding the Status and Improving the Prospects"[10].

Reflecting this need, the NSB sent a letter to the Obama transition team in January 2009 recommending a number of goals for STEM education[11]. On April 27 2009 President Obama gave a speech at the NAS annual meeting in which he announced a renewed commitment to education in mathematics and science[12]. Mechanisms for actualizing this commitment include: 1) joint work between the Obama administration and the National Governors Association (NGA) to make STEM education a top priority in more states; 2) additional funds for the Department of Education (DoEd) to support States under the *Race to the Top* program; and 3) a joint initiative between the Department of Energy (DoE) and NSF to launch a joint initiative toward inspiring American students to pursue STEM careers, particularly in clean energy. In addition, in the STEM Education Coordination Act of 2009[13] Congress has required a STEM education 5-year strategic plan be formulated by those Federal agencies with programs and activities in support of STEM.

There are several compelling reasons why nanoscale perspectives need to be incorporated into any attempt at improving STEM. The first is the need to incorporate the rapidly evolving new knowledge of nanostructures (see Figure 1) into all aspects of our educational system, as appropriate to the age group, ranging from kindergarten through continuing education[14,15,16,17].

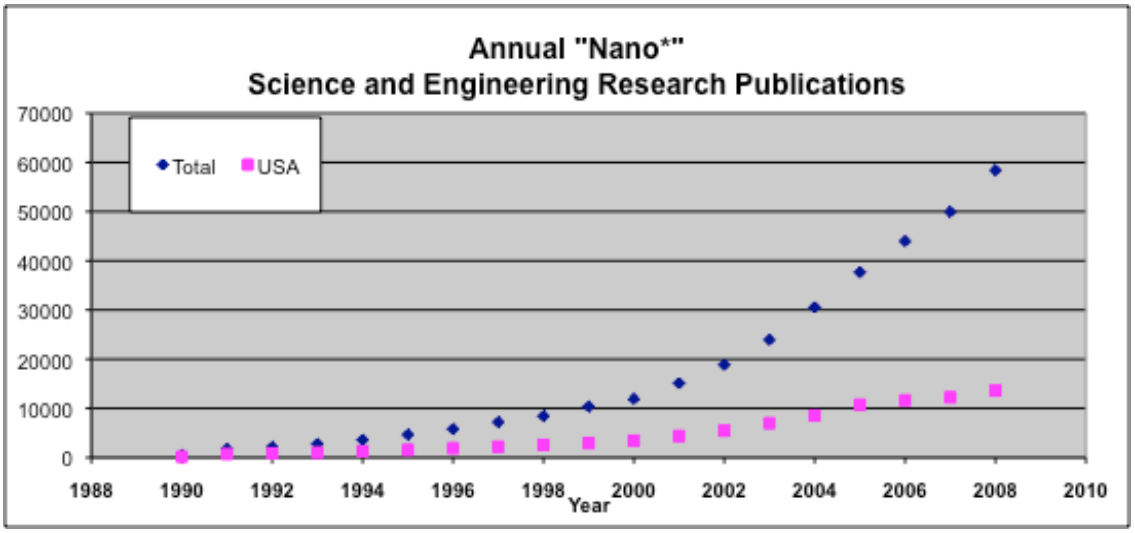


Figure 1: Publication counts derived from the Thompson ISI Web of Science database on 8/15/2009 using "nano*"as the keyword, and with "USA" as a second keyword. The vertical axis is the number of publications. The total represents worldwide publications; the USA count represents those papers with at least one author having a U.S. institution for the address.

The growing interest in the nanoscale impact on education is reflected by many web sites with some focus on NanoEducation (Table 1).

Table 1: Web sites with NanoEducation Content*

American Chemical Society	community.acs.org/nanotation/
European Nanotechnology Gateway	www.nanoforum.org
Institute of Nanotechnology	www.nano.org.uk/CareersEducation/education.htm
McREL Classroom Resources	www.mcrel.org/NanoLeap/
Multimedia Educ. & Courses in Nanotech	www.nanopolis.net
NanoEd Resource Portal	www.nanoed.org
NanoHub	nanohub.org/
Nanotech KIDS	www.nanonet.go.jp/english/kids/
Nanotechnology News, People, Events	www.nano-technology-systems.com/nanotechnologyeducation/
NanoTecNexus	www.Nanotecnexus.org
Nanozone	nanozone.org/
NASA Quest	quest.nasa.gov/projects/nanotechnology/resources.html
National Science & Technology Education Partnership	nationalstep.org/default.asp
Nanoscale Informal Science Education Network Network	www.nisenet.org
National Nanotechnology Initiative Education Center	www.nano.gov/html/edu/home_edu.html
National Nanofabrication Infrastructure Network Education Portal	www.nnin.org/nnin_edu.html
National Science Foundation Nanoscience Classroom Resources	www.nsf.gov/news/classroom/nano.jsp
PBS – Dragonfly TV	pbskids.org/dragonflytv/nano/
Taiwan NanoEducation See also presentation	www.nano.edu.tw/en_US/ www.iat.ac.ae/downloads/NTech/UAE_Workshop_Pamphlet2.pdf
The Nanotechnology Group Inc	www.tntg.org
Wikipedia	en.wikipedia.org/wiki/Nanotechnology_education

**See also Table 3 which lists K-12 educational web sites.*

Second, because traditional academic disciplines are increasingly convergent when working at the nanoscale, the attention to NanoEducation also offers an opportunity to rebuild science education, literally from the bottom up, blurring the traditional disciplinary barriers that are rapidly becoming obsolete in our global research communities.

Third, Sputnik and the challenge to put man on the moon inspired American students in the 1960s. Science and technology at the nanoscale might help us fire the imagination of young people and pique their interest in science and technology. It offers exciting new phenomena, undiscovered mysteries, and a spectrum of revolutionary nano-enabled technological approaches to globally critical problems in medicine and health, renewable energy and energy conservation, and environment and climate change.

Fourth, to enable the projected trillion dollar market in commercial products utilizing nanostructures, there is a need for an informed, skilled workforce with knowledge in forming quality nanostructures, understanding their novel properties, incorporating them into innovative products, and protecting against any adverse environmental, health, and/or safety impact. Historical perspectives on technology transfer (illustrated in Figure 2) suggest nano-enabled technologies are about to explode into the market. There are databases with a listing of hundreds of products presently in the market that are (or claim to be) nano-enabled[18]. As the capability to make, measure, and manipulate individual nanostructures continues to progress, one can expect far more extensive entry of nano-enabled and nano-enhanced products and technologies.

Fifth, the public should be educated about nanotechnology to enable informed marketplace decisions. There has been a shift throughout the last decade, according to researchers from the Center for Nanotechnology and Society, in the main focus of nanotechnology stories in major newspapers. Recent stories are less likely to emphasize progress and more likely to discuss generic risk, regulation, and conflicts. Poor understanding of emerging technologies can lead to consumers either being oversold on the benefits or under-informed on the risks[19].

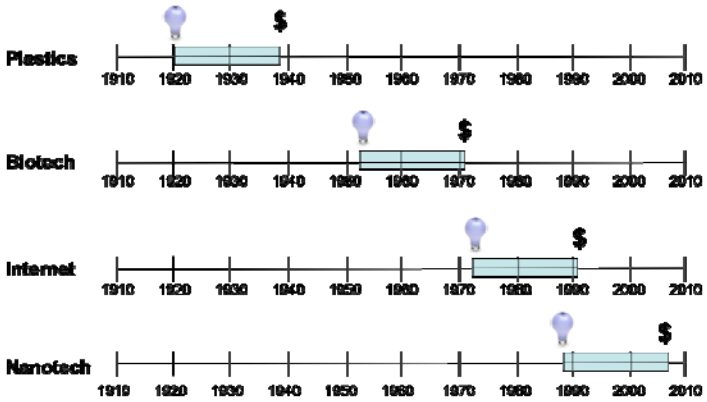


Figure 2. Time required for maturation of science discoveries into commercial products. Courtesy Lux Research Inc. One Liberty Square, Suite 210, Boston MA.

Sixth, the nanoscale is a major factor in the continued miniaturization and functionalization of information technology devices. The augmented capabilities inherent in these new devices offer promise for new approaches to the solution of vexing education problems.

Finally, there are robust nanotechnology programs in many countries around the world[20]. For example, the Taiwan Nanotechnology Initiative has an extensive education component[21]. These can provide resources and expertise toward educational goals.

Presently, NSF supports several major efforts that address the NanoEducation challenges and opportunities. Working with its nanoscale centers and networks (listed in Appendix C) - especially the Nanotechnology Center for Learning and Teaching (NCLT) in Nanoscale Science and Engineering (Northwestern University, lead), Nanoscale Computational Network (NCN) (Purdue University, lead), Nanoscale Informal Science Education Network (NISE Net) (Museum of Science, Boston, lead), and National Nanofabrication Infrastructure Network (NNIN) Education Portal (Cornell University, lead) - NSF has initiated an impressive program to foster education associated with nanoscale science, engineering, and technology. As indicated in Figure 3, the initial focus in the year 2000 addressed graduate degree programs, and has evolved to include undergraduate, high school, K-12, informal, and technical education.

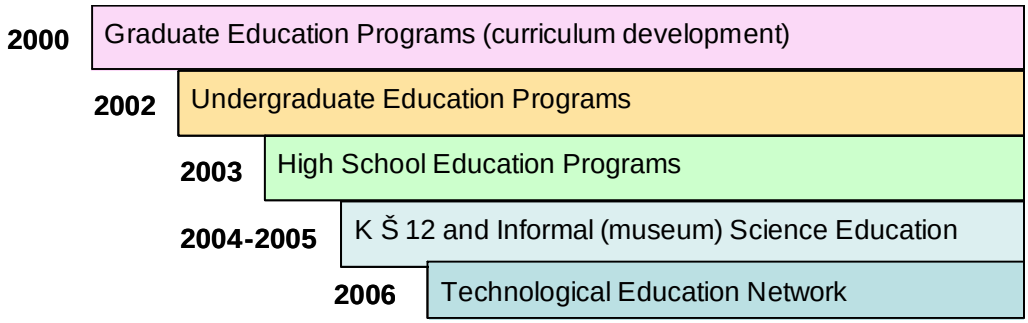


Figure 3: Schematic of NSF Investment in NanoEducation.

Three NSF grantee workshops have been held to strengthen and guide the NSF educational programs. 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[22]. 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[23]. 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[24]. These three NSEE workshops largely focused on work emanating from the various NSF funded activities.

Table 2: Federal Education Programs with Potential for NanoEducation Interest

Agency	Program	
NSF	Education and Human Resources	www.nsf.gov/funding/pgm_list.jsp?org=ehr
DoEd		www.ed.gov/index.jhtml
DoE	Energy Education	www1.eere.energy.gov/education/
	National Labs	www.energy.gov/morekidspages.htm
DoD	National Defense Education Program	www.ndep.us/
USDA	NRCS	soils.usda.gov/education/resources/k_12/
	AFSIC	www.nal.usda.gov/afsic/AFSIC_pubs/k-12.htm
	CSREES	www.agclassroom.org/
NASA	Education Program	www.nasa.gov/offices/education/programs/index.html
NIH	Office of Science Education	science.education.nih.gov/home2.nsf/feature/index.htm
EPA	Teaching Center	www.epa.gov/teachers/

DoEd *Department of Education*
DoE *Department of Energy*
DoD *Department of Defense*
USDA *US Department of Agriculture*
NASA *National Aeronautics and Space Administration*
NIH *National Institutes of Health*
EPA *Environmental Protection Agency*
NRCS *Natural Resources Conservation Service*
AFSIC *Alternative Farming Systems Information Center*
CSREES *Cooperative State Research, Education and Extension Service*

Beyond NSF, there are many other Federal programs that either address NanoEducation or could appropriately do so (Table 2). The 2009 NNI reauthorization bills – H.R. 554 and S. 1482 – provide legislative guidance toward an extended effort at addressing NanoEducation (see text box). In addition, the last NAS Report on the NNI[25] encouraged new approaches to education in its recommendation: "Given that interest in nanotechnology presents a significant opportunity to stimulate renewed involvement in science and technology education and thereby strengthen the nation's workforce, the committee recommends that the NSET Subcommittee create a working group on education and the workforce that engages the Department of Education (DoEd) and the Department of Labor as active participants."

NanoEducation Provisions in 2009 NNI Reauthorization
(H.R. 554 and S. 1482)

- Name an OSTP Associate Director as Coordinator for Societal Dimensions (including for education and societal dimensions)
- NSTC to establish an Interagency Education Working Group under NSET
- All NNI education efforts to include environmental/safety/health (ESH) and other societal aspects
- NNCO develop/maintain database for NNI education projects in: formal settings; informal settings; public outreach; ethical, legal, and other societal issues
- NSF authorized to fund Nanotechnology Education Partnerships to:
    - Enable professional development activities for secondary school teachers;
    - Enrichment programs for students, including access to facilities;
    - Identify secondary school educational materials and their incorporation into curriculum at one or more organizations participating in a Partnership.
- NSF authorized to fund Undergraduate Education Programs for:
    - Interdisciplinary courses or modules to existing courses
    - Faculty professional development
    - Acquire instrumentation / equipment for education and research
    - Provide remote internet access by secondary students / teachers to "nano" facility capabilities for educational purposes

II. Workshop Breakout Session Reports

The workshop agenda (Appendix B) was grouped into three main categories: K-12 education, college and continuing education, and public education. Consideration of each category began with four invited presentations to establish the present state-of-affairs, after which there were three breakout sessions to brainstorm possible recommendations for future action:

- K-12 Education:
  - Standards of Learning: Local, State, and National Involvement
  - Teacher Education and Training
  - Development of Curricula and Teaching Aids
- Post-Secondary Education:
  - University and Community College
  - Industry Workforce Needs
  - Cyber and Virtual Innovation (cross-cutting all categories)
- Public Education:
  - Informal Education: Museums
  - Press, Radio, Television, and Web-based
  - Local Community Outreach and Engagement

In addition, there were presentations that provided a perspective on the extensive approaches to NanoEducation in Europe[26,27,28] and in Asia[29]. A Norwegian project, the Relevance of Science Education (ROSE), surveyed student interest in science, engineering, and mathematics in many countries of the world (not the U.S.) (Figure 4)[30]. One of the interesting points made in the presentation was the prevalence of low student interest in science and technology among the developed nations and the realization that this is not a uniquely U.S. problem. The ROSE study found that all students want to do something meaningful in their careers, something that fits their values and identities. In the more developed countries, students do *not* think that they can find this in science and technology studies and careers. Further, the study reinforced the disparity between the genders toward STEM. While there are similar perceptions about U.S. students, the Carnegie Opportunity Equation Study did report an expectation that U.S. students and parents would be receptive to calls for higher levels of math and science learning. With its expected contributions toward technological solutions to medicine, health, environmental, energy, and water problems, the nanoscale might provide a motivational factor toward engaging student interest.

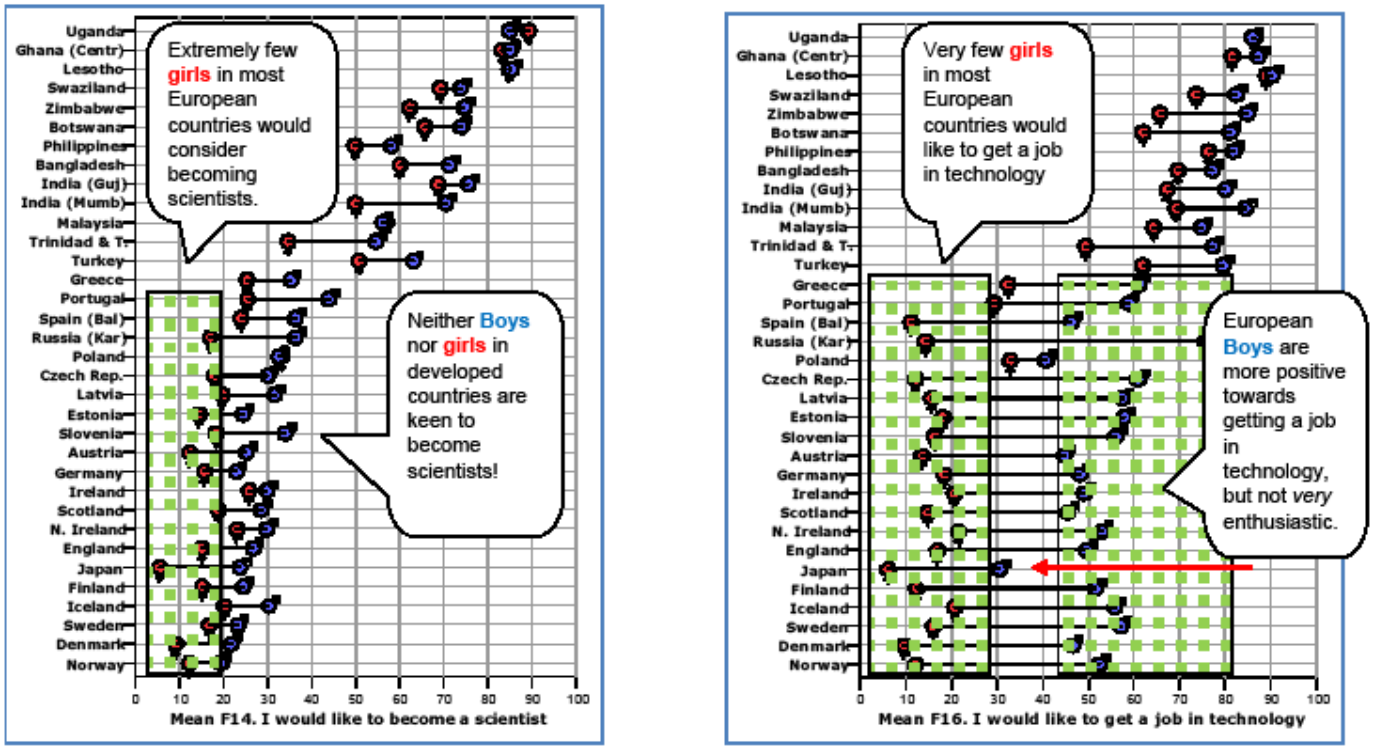


Figure 4: Percentage who "strongly agree" and "agree" for boys (triangles, blue) and girls (squares, red) in answering the questions "I would like to become a scientist" and "I would like to get a job in technology".[30]

1. **Standards of Learning: Local, State, and National Standards and Benchmarks**
   Dr. James Batterson, Senior Advisor to the Commonwealth of Virginia for STEM Initiatives, and Dr. Krish Mathur, DoEd

There was strong agreement that "nano" needs to be in the K-12 education world; it is not advanced science, but rather simply part of 21st century science and is enabling the rapid entry of nano-enabled technologies into the commercial marketplace. In addition to comprehending the science, it is also necessary to get good nano information to students, since there are many examples of misrepresentation.

K-12 education is the responsibility of the states, with most states and/or localities providing in excess of 90% of the funding for the K-12 education in their schools. While being a part of a national standard can be helpful, inclusion of nano in curricula is only guaranteed if it is in the state's learning standards. A state's standards of learning or content standards form the official guide to course content and the basis for end-of-course assessments. Student results on these assessments are often the basis for evaluating progress under the Federal "No Child Left Behind" benchmarking.

Example from a Current High School Physics Standards of Learning

PH.14: The student will investigate and understand that extremely large and **extremely small quantities** are not necessarily described by the same laws as those studied in Newtonian physics. Key concepts include:

- wave and particle duality;
- wave properties of matter;
- matter and energy equivalence;
- quantum mechanics and uncertainty;
- relativity;
- nuclear physics;
- solid state physics;
- superconductivity; and
- radioactivity.

In this standard, the teacher is directed to look at "extremely small quantities" but given no guidance as to what that means. Though this standard was written in 2003, nanostructure is not mentioned. A 2003 survey of middle and high school science teachers in Kentucky found that only 33% of those science teachers were familiar with the concept of nanotechnology and only 60% of the teachers surveyed were even aware of the concept (18% said that they "understood" it). Thus if ALL students are to be introduced to nano, all teachers must know to teach it – something that requires its inclusion in the standards.

All states review their standards periodically and look to national standards such as the American Association for the Advancement of Science (AAAS) Project 2061 Benchmarks[31], the NRC National Science Education Standards[32], and the College Boards for some guidance. Also, there is a national organization that works state-by-state to recognize gaps in their standards - the American Diploma Project [33](ADP) sponsored by National Governors Association (NGA) and run by Achieve, Inc. There are currently 35 states working with Achieve and using the Achieve benchmark guidance in Mathematics and English Language Arts. The NGA and Achieve have begun to develop a "common core" of rigorous academic standards to prepare children for post-secondary education and the 21st century workplace[34]. The NGA and the Council of Chief State School

Officers (CCSSO) are coordinating this new effort. The CCSSO is the national professional organization for state superintendents and commissioners of public instruction – the individual state superintendents normally make recommendations to state boards of education regarding standards. As with the ADP benchmarks, it will be up to each state as to whether to participate; and, if participating, whether to use any or all of the common core standards. The Mathematics and English Language Arts benchmarks were released in the summer of 2009.

The Common Core State Standards Initiative was not known to most of the breakout group. This highlights the need to partner the pertinent stakeholders and the nano content experts. There should be an effort by the NSET subcommittee and the National Nanotechnology Coordination Office (NNCO) to engage the NGA, CCSSO, and Achieve toward including nano in the ADP science benchmarks. Session participants saw an opportunity for the 20 Nanoscale Science and Engineering Centers (NSECs), and other NanoCenters, to get directly involved with their respective state departments of education.

The DoEd has developed a "Career Pathways" instrument to identify essential skills required for careers in various fields or clusters and to guide students in their plans of study. For STEM careers, students are advised to take biology, chemistry, and physics in grades 9 to 11. The specificity of these recommendations is only to the course-level. These courses are guided by learning standards in each state. Thus moving nano into a state's learning standards would directly impact the essential knowledge and skills a student would get for the STEM career cluster.

There was concern that diversity issues be addressed and that Historically Black Colleges and Universities (HBCU) and other institutions primarily serving minorities or women students are specifically included in any plans – particularly any pedagogy issues that might impact these groups.

<u>Items for specific attention:</u>

1. The NNI leadership should contact Mr. Gene Wilhoit, Executive Director of CCSSO, Mr. Michael Cohen, President of Achieve Inc., and Dr. Angela Baber, Senior Policy Analyst for STEM, NGA, regarding the NNI, the concerns that nano be a part of state science standards, and a partnership toward achieving that goal.
2. The NSEC's, or at least a subset of them, should review their respective states' science learning standards; develop some "straw man" nano learning standards at various grade levels (K to 5), (6 to 8), (9 to 12); and contact their state superintendent regarding how to participate in the learning standards review and revision process.
3. A separate working group should be formed to identify and make recommendations regarding specifics issues that may impact women and minorities.

2. **Teacher Education and Training**
   Dr. Robert Chang, Northwestern University, and Dr. Catherine O'Riordan, American Institute of Physics (AIP)

Nanoscience can be an exciting "hook" for both teachers and students because it is new. Students are excited to learn about its relevance and applications. Teachers can use that enthusiasm to lead students to conversations about careers and applications. Students should know that there are many technical careers that are available without getting a PhD and going into research. Nanotechnology will play an important role in many industrial sectors in need of technicians and engineers.

The teachers in the breakout group agreed that one of the biggest challenges to introducing nanoscience in high school (biology, chemistry, and physics) is that many students are not prepared with a basic understanding of measurements and matter. Math skills are often weak as well.

There are teacher needs for additional curriculum and for information on where to find existing nano modules. When building enhancements for courses, feedback should be obtained from students and teachers to pitch material at the right level, recognizing that students don't always have basic knowledge. Teachers need information channels (state and district level) to get word of programs and available materials. State teacher associations, the National Science Teachers Association (NSTA), and perhaps the scientific societies can help.

An opportunity exists in some schools where there is about one month after the Advanced Placement (AP) exams to introduce new material. Modules that fit

The NCLT in Nanoscale Science and Engineering (a Northwestern NSEC) has partnered with **Taft High School** of the Los Angeles Unified School District to launch a Nanotechnology Academy under the U.S. Dept. of Education "Small Learning Community" initiative.

Beginning in fall 2009, the Academy will train several hundred students over a four-year period using an integrated curriculum that links nanotechnology to a wide range of courses, including STEM, social studies, language arts, and fine arts languages arts, and fine arts. NCLT is working closely with Taft teachers and administrators to develop and implement the new curriculum, offer summer research opportunities, and provide professional development for teachers. Members of NCLT's new UCLA hubsite will provide year-round mentoring, together with local industrial researchers.

Inquiry-and-design-based NCLT nano-modules and classroom kits will be enhanced with web-based animations, simulations, and games. A virtual lab space will enable Taft students and teachers to collaborate with each other, and with their peers at other NCLT-network schools nationwide. The four-year program will allow for longitudinal studies and continuous learning interventions with a view to improving student test scores, retention, and college admission rates.

into this time frame as extensions of existing science AP courses would be very useful. The NSF-sponsored Materials World Modules program has found this to be a very effective opportunity for the teachers to introduce nano concepts. Professional development for teachers is also needed to help them understand nanoscale science and engineering as well as the most effective use of the modules.

There is a disconnect between what federal agencies can produce and what actually works at the local and regional level. Pathways must be built to bridge this gap. For example the Discovery Institutes, part of America COMPETES, focus on education and are loosely defined for flexibility. These are centered at National Labs (DoE) and can offer programs to teachers regionally. The various NSECs and NNIN[35] have Research Experience for Teachers (RET) programs and teacher workshops. The EPA currently has a summer program for research that includes nanoscience for high school and undergraduate students. Perhaps this program can be expanded for teachers (as in NSF's RET). In addition the DoD and USDA have programs that might participate.

Engagement with teachers at all levels and institutions should be enhanced by reaching out to national teachers' unions, to research and academic societies (AAAS, NAS, Materials Research Society (MRS), American Physical Society (APS), American Chemical Society (ACS), etc.) and to other similar groups. The university academic communities in particular need to support their colleagues 'in the trenches' instead of just bemoaning the deficiencies of K-12.

<u>Items for specific attention:</u>

1. Share successes at the local level: University/teacher or industry/teacher collaborations. Create regional or state clearinghouses of opportunities and best practices.
2. Share opportunities: RET programs and pay teachers to complete research experience and professional development. Promote existing training programs. Follow teachers post workshop (mentoring).
3. To increase the diversity of the workforce, there is a need to start before high school to spark interest and to reach into community colleges to instill skills.
4. Engage industry to underwrite training programs for teachers (this can be difficult to sustain but may be achievable at local or state levels), and engage the DoE as a partner in operating a distribution network for these materials.
5. The NSF-funded NSEC programs have finite lifetimes. How might their educational component be made sustainable in the longer run? Could it be passed to the DoEd for future funding? Might a state find a mechanism to keep its NSEC educational component going?

3. **Curricula and Teaching Aid Development**
   Dr. Joseph Krajcik, University of Michigan, and Dr. Aldrin Sweeney, University of California, San Francisco

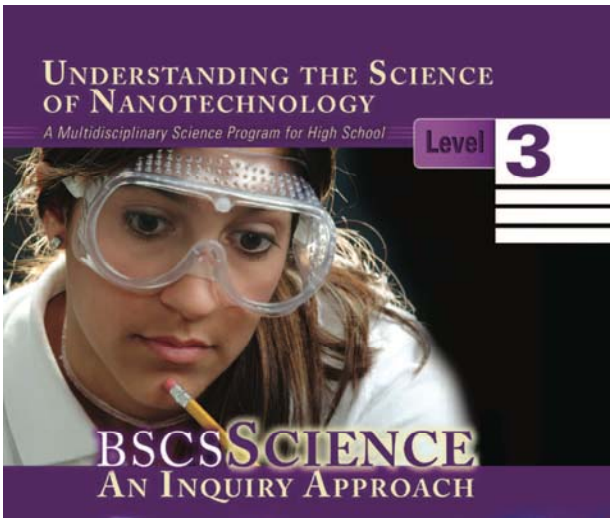
To realize the goal of developing a robust system of K-12 Nanoscale Science and Engineering Education (NSEE) in the U.S., focused attention must be given to the

ongoing development and effective implementation of appropriate curricula materials and teaching aids. To this end, a number of key issues were identified by the working group that require immediate attention from all stakeholders in the K-12, postsecondary, and public education sectors.

One fundamental concern is the typical sequence of science instruction in the middle through high school grades, i.e., biology, chemistry, and physics. In order to develop an appropriately

sequenced and conceptually sound understanding of science and engineering concepts and phenomena, instruction might be restructured to address biology, chemistry, and physics concepts and phenomena on a continual basis and one in which ideas build upon each other. Appropriate ideas from each of the traditional disciplines would be presented each year, with growing sophistication as the needed mathematical skills are developed[36]. This approach would avoid the present stupidity of addressing each one of those traditional disciplines at some depth, and then largely ignoring it in subsequent years. Moreover, it would allow ideas to be linked together in ways that build upon and reinforce each other. While the argument for restructuring science and engineering instruction certainly is not a new (e.g., the *Physics First* movement championed by Nobel Laureate, Leon Lederman[37]), consideration

Biological Sciences Curriculum Study (BSCS) Science: An Inquiry Approach
Nanoscience: The Science Behind Nanotechnology



BSCS has developed a Nanoscience unit that will be a module in the third level of *BSCS Science: An Inquiry Approach*. In developing the unit, the goal was to help students better understand fundamental science principles by exploring concepts in the engaging context of nanoscience. Because the topic of self-assembly in nanotechnology allows for teaching a number of generalized science principles, it was chosen as the overall focus of the unit. Although there are other means of developing nanotechnologies, self-assembly is a primary component of many nanoscience applications and allows presentation of a few basic science ideas in depth.

The first chapter of the unit covers science principles that are important to the understanding of self-assembly, such as intermolecular forces, surface area and volume, and thermodynamics. The second chapter focuses on biological self-assembly and provides a framework for making ethical decisions about the use and development of nanotechnology. Each chapter was developed using the BSCS 5E Instructional Model and provides opportunities for both formative and summative assessment.

The unit was field tested with teachers across the country in a variety of school settings. Revisions were made to the module based on the field test, and it has now been released commercially.

of this issue becomes increasingly relevant when designing science curricula that address physical phenomena of matter at the nanoscale. Efforts will need to be made in concert with mathematics teachers and mathematics education professional organizations to address the mathematical competencies needed to exploit fully this approach.

Worldwide, increasing numbers of NSEE curricula now are being developed and disseminated for use at the K-12 (see Table 3) and university levels (see Appendix D – Listing of Colleges and Universities, and Appendix E – Listing of Nanoscale Science and Engineering Textbooks). These may occur as modules for incorporation into existing science curricula, or as extended, thematic curricula for specialized or elective course offerings. In the United States, such NSEE curriculum development to date usually has occurred as part of NSF funded nanoscale science and engineering (NSE) research projects and centers. NSF requires that each grantee take steps to ensure a "broader impact" of NSF-funded research. NSF should provide assistance to proposers in realizing this impact by offering a number of potential mechanisms and partners. For example, grantees may have an undergraduate or graduate student develop a science fair project in the area of the research in collaboration with an organization such as Science Buddies (www.sciencebuddies.org).

Table 3: Web Sites with K-12 NanoEducation Material

Apopka High School	www.bowlesphysics.com/nano/
Cornell University	www.nbtc.cornell.edu/education/index.htm
NNCO	www.nano.gov/html/edu/eduk12.html
NNIN	www.nnin.org/nnin_k12teachers.html
North Carolina State University	ced.ncsu.edu/nanoscale/materials.htm
Northwestern University	www.nanoed.org/
Purdue University	www.generation-nano.org/educators.php
Rennselaer Polytechnic University	http://www.moleculestothemax.com/Educators.html
Rice University	cnst.rice.edu/
State University of New York, Albany	cnse.albany.edu/Nano_for_Kids/K_12_links.html
Texas Nanotechnology Workforce Development Initiative	nanotechworkforce.com/resources/k_12.php
The Nanotechnology Group	www.tntg.org/documents/46.html
University of Illinois, Urbana-Champaign	www.nano-cemms.uiuc.edu/content/education/index.php
University of Nevada, Los Vegas	nanotechnology.unlv.edu/k12.htm
University of Iowa	research.uiowa.edu/nniui/k12.html
University of Wisconsin, Madison	mrsec.wisc.edu/Edetc/background/nano.html
Washington University, St Louis	www.nano.wustl.edu/NanoResources.aspx
ck-12	about.ck12.org/

Comprehensive information regarding the level and extent of NSEE curriculum materials currently available remains relatively sparse. Although there are noteworthy efforts that

have done much to advance the initial development of NSEE in the U.S. and elsewhere, there is a paucity of reliable data regarding the efficacy of these curriculum materials in the teaching and learning of nanoscale science and engineering. In particular, metadata associated with these and other efforts need to be compiled and reviewed, e.g., relevant teacher and student demographics; assessment approaches; academic prerequisites; required facilities; and instrumentation, etc. One productive manner in which the nation could make progress is to develop coherent curriculum materials around the big ideas of nanoscience[38] so that these ideas become progressively richer as a student advances from one grade to another. What is important is that students develop understanding of the core ideas underlying the phenomena that occurs at the nanoscale. To accomplish this objective, as a nation we need to take a developmental approach to supporting students in learning these complex ideas.[39]

In a related vein, appropriate and more comprehensive dissemination to K-12 teacher and student audiences also needs to be addressed. The annual K-12 Nanotechnology Teacher Conference[40] reaches a very limited audience. While dissemination of NSE research and education initiatives at the postsecondary and university level is accomplished *via* sites such as the NNCO/NNI (nano.gov) and the NNIN, these tend not to be familiar to K-12 teachers and students. Many links to various nano sites may be discovered using general Boolean search terms. But venues, such as the National Science Digital Library, Connexion, and Office of Extramural Research (OER) that have been developed specifically for use by K-12 teacher and student audiences, do not have strong nanoscale education representation. A designated nano portal on an appropriate web site that connects directly to quality NSEE curricula and other instructional resources is suggested. Similarly, more explicit interactions should be undertaken with regional, state, and national science teachers' associations (see, for example, the book recently published by the NSTA, *Extreme Science: From Nano to Galactic*). It was also recommended that expanded collaboration of NSEE proponents with the general educational system should also be pursued. Building relationships with organizations that develop curriculum for the formal sector, including open-source sites for curriculum for nano tech lesson plans with activities could be beneficial.

In terms of disseminating general information specifically to K-12 students, use of social networking utilities regularly frequented by these students (e.g., FaceBook, MySpace, blogging, Twitter, PBS web site, Second Life, etc.) is highly recommended.

Associated with the development of K-12 NSEE curriculum and necessary teaching aids, there is the need to incorporate suitably adapted components of "real" or actual nanoscale science and engineering research into secondary level science education. Given the specialized instrumentation that is required for investigation of matter at the nanoscale, this usually is undertaken at the undergraduate level and above. However, to promote scientific literacy and nurture the future scientific workforce of the country, such efforts must be made as early as possible at the 6-12 grade level. The use of portable, "table-top" atomic force microscopes (AFMs) and scanning tunneling microscopes (STMs) is recommended for 6-12 NSEE. Obviously, necessary funding for the purchase of such instrumentation by school districts must be addressed.

While many K-12 NSEE various universities and research institutes have made outreach efforts (which sometimes include the remote operation of university AFMs and STMs from a K-12 school site), institutional challenges remain that often inhibit the interaction of universities with the K-12 public education system. Such challenges include the relatively low weighting of academic promotion and tenure criteria typically given to K-12 education outreach or to professional service efforts by university science and engineering departments.

Ultimately, a carefully deliberated national strategy (similar to that articulated for the NNI) is needed that explicitly addresses short-term (1-5 years), mid-term (5-10 years) and long-term (10-20 years and beyond) goals for NSEE in the U.S.

Items for specific attention:

1. There is no clearinghouse to identify, validate, and centrally post available NSEE curriculum materials. The site must include such items as prerequisites, material quality and grade level, relationship to learning standards, adjustments for teacher and student demographics, assessment factors, and required facilities.
2. Motivate graduate students in the sciences and engineering to become more involved in K-12 science education by explicit funding toward this goal.
3. Use of social networking utilities such as FaceBook, MySpace, blogging, Twitter, PBS web site, Second Life, etc. The opportunity to interact in the classroom is limited, so we ought to consider using these approaches.
4. Morph high school science courses into science and engineering years 1 to 4 where biology, chemistry, engineering, and physics concepts and phenomena are all covered each year, with growing levels of sophistication.
5. Design, develop, implement, test, and distribute coherent nanoscience materials that take a development prospective and focus on the big ideas of nanoscience. These materials need to build student ideas over time so that by the time a student completes high school they have understanding of those big ideas. We need to resist teaching the final idea in early grades but rather focus on those ideas that build toward the final big idea we want students to understand.

4. **Informal Education**
   Mr. Lawrence Bell, Boston Museum of Science, and Dr. David Bibas, California Science Center, Los Angeles

A recent NAS report highlighted the importance of informal environments in learning.[41] In October of 2005 with NSF funding, the Museum of Science in Boston, in partnership with the Exploratorium in San Francisco and the Science Museum of Minnesota in St. Paul, assembled a group of museums and nanoscale research centers to establish the NISE Net. The focus of NISE Net's work has been to build the capacity of science museums and research centers to raise public awareness, understanding, and engagement with nanoscale science, engineering, and technology. Building on other nanoscale

informal educational efforts that predated NISE Net, many of the initial exhibits and educational activities focused on trying to help the public understand something about the size of things at the nanoscale. It is unclear if anyone, even nano scientists, have a truly visceral understanding of how small 10^{-9} meters is and so it is important to pursue with the public topics that go beyond merely the scale of nano. NISE Net educational products developed to date touch upon about 50 topics that can be categorized as relating to basic awareness of nanoscale science and technology; properties of nature relevant to nanoscale science and technology; tools, techniques, and the pursuit of nanoscale science and engineering; applications of nanoscale science and engineering; and nanotechnology and society.

The NISE Net's initial efforts in exhibit development were not only designed to create new exhibits but also to raise the capacity of a number of lead institutions to conceive and develop exhibits that supported learning about nanoscale science and engineering. The science museum exhibit developers involved in NISE Net initially got together with scientists to generate ideas for exhibits. They then built inexpensive exhibit prototypes to communicate concepts in nano, professionally critiqued them, and tested them with science museum visitors. The prototypes that formative evaluation results showed to be the most promising were then developed into exhibits. Evaluation data shows that NISE Net has been able to develop exhibits to interpret successfully some core concepts in nanoscale science and technology, but nanotechnology still has difficulty competing for visitor attention with dinosaurs, live animals, indoor lightning, and similar must-see science center attractions. Other exhibit prototypes have had high attracting power but visitors may have a hard time related them to nanotechnology. This may be one of the group's challenges for the future: highly attractive exhibits that deliver nano concepts successfully.

Future efforts should focus on applications as way to draw in the imagination of kids with the interesting and very different properties and behavior of materials at the nano scale that make novel applications possible. STMs and AFMs, which are becoming more affordable and easier to operate, as well as haptic interfaces, could be useful to help interpret the nanoscale. It was also suggested that remote access to research facilities such as is made possible through nanoHUB (at Purdue University) be made available to high schools and possibly science museums.

Overall, it seems that educational programs developed by NISE Net participants, were more successful with the public than were exhibits at connecting novel phenomena specifically to nanotechnology. The presence of a human teacher or facilitator also provides the opportunity to answer visitors' questions. To date, there have been about 34 programs developed and shared amongst other institutions; Table 4 provides examples.

Table 4: Examples of NISE Net Programs

Aerogel	Forms of Carbon
Balloon Nanotubes (giant hanging model)	Inkjet Printer
Balloon Nanotubes Tabletop	Intro to Nano – Stage
Biobarcodes: Antibodies and nanosensors	Intro to Nano Cart Demo
Cutting It Down to Nano	Lotus Leaf Effect
DNA Nanotechnology	Magic Sand and Nanosurfaces
Energy & Nanotechnology	Nano Dreams and Nano Nightmares
Exploring Forces - Gravity	Nanoparticle Stained Glass (cart program)
Exploring Materials - Ferrofluid	Nanoparticle Stained Glass (classroom prog.)
Exploring Materials - Liquid Crystals Exploring	Shrinking Robots
Materials - Nano Fabrics	Sizing Things Down
Exploring Measurement - Human Body	Surface Area
Exploring Measurement - Ruler	The Electric Squeeze
Exploring Measurement - Solutions	Theatre School Program
Exploring Properties - Surface Area	Tiny Particles, Big Trouble!
Exploring Structures - Buckyballs	Treating Tumors with Gold
Exploring Tools – SPM	World of Carbon Nanotubes

Some of these programs are made available to the annual NanoDays festival (see sidebar). Summer science workshops may be a good vehicle for nano science and technology outreach. Cornell University has such a workshop for elementary school kids. Some science centers may be using NanoDays activities for this purpose.

NanoDays is an annual nationwide festival of educational programs about nanoscale science and engineering and its potential impact on the future. NanoDays events are organized by participants in the Nanoscale Informal Science Education Network (NISE Net), and take place at over 200 science museums, research centers, and universities across the country from Maine to Hawaii. In 2010, NanoDays will take place from March 27 through April 4.

Part of the session discussion centered on the need to look for opportunities to partner with groups outside the original circle of target audiences. One such potential collaborator is Science Buddies, a non-profit organization that has a web site receiving 10 million visitors this year, and which provides science-learning resources for home schooling, after school activities, science fair projects, and teachers. The web site offers about 900 project outlines developed by staff scientists, but only one of these is on nano science and technology.

NISE Net has produced some content for You Tube, Flikr, and other social networking sites to extend the reach beyond the nisenet.org web site. The use of iPhone apps and other new technologies is recommended.

Another avenue for outreach is local TV stations that are constantly on the lookout for interesting content and activities for programs such as a morning show. The Museum of Science in Boston produces two 5-minute segments every week for New England Cable News.

A question was posed about reaching out to regulators and policy makers. In this context, it was reported that staff from the Public Health Department in Cambridge, Massachusetts, have now participated in three forum programs on nanotechnology at the Museum of Science in Boston. They are interested in continuing this kind of public input to policy and the Museum is collaborating with researchers at Arizona State University and North Carolina State University to study its impact. However, a major issue in Public Engagement in Science (PES) is that truly engaging the public implies the need for policymakers to relinquish some level of control, which is likely to be uncomfortable for some people in authority. In terms of programs such as "Forums" it may be helpful to partner with civic organizations that cater to adult audiences.

Items for specific attention:

1. There is need for the "WOW!" experience that grabs people emotionally, the "Shamu" of nanotechnology. Cancer diagnostics and therapy and renewable energy applications hold promise in that regard.
2. NISE Net should also focus on the unique behavior and properties of materials at the nanoscale and the applications that are made possible as a result. The emphasis on applications can serve as a hook and help move people from products with which they may be familiar to the nanoscience concepts and principles with which they're not.
3. There is a need to develop resources for after school activities, home schoolers, summer camps, science festivals, and local TV talk shows, which are hungry for engaging science content.
4. Make NISE Net a resource for other organizations in the field of informal education, such as Science Buddies.
5. Explore how NISE Net can continue to support its work beyond current funding.
6. There is a need to build connections between the formal and informal educational systems; an arena of possibly productive cooperation is in curriculum development. Hands-on science activities could be developed for use in both settings.

5. **Public Education – TV, Radio, Press, Books, Magazines, and Web**
   Dr. Philip Lippel, NNCO, and Dr. Lisa Regalla, Twin Cities Public Television

A variety of activities should be utilized to engage the public about the benefits nanotechnology offers to society, as well as risks that it may pose. Different forums and modes of engagement are appropriate for different audiences. Some specific examples are discussed below.

Policy makers should receive accurate, balanced summaries of current progress and future prospects for nanotechnology on a regular basis so that they can develop the necessary background to make informed choices when decisions need to be made, rather than just providing information reactively. At the national level, some forums for legislative engagement are already in place. There is a Congressional Nanotechnology Caucus organized by Senator Wyden's (Oregon) office. The ACS organizes congressional briefings on nanotechnology as part of its "ACS & the Congress" project.

Speakers are always needed for these types of events, and the nanotechnology education community should volunteer to participate. It should also reach out to other professional societies (serving both the technical and education communities), to state and local legislators, and to their organizations (NGA, National Conference of State Legislatures). Note that state and regional nanotechnology programs often have strong ties to the relevant local policymakers.

As part of this effort, there should be community activity to craft strong messages conveying general information about nanotechnology that is not crisis-driven, and to establish authoritative sources of information. The messages should be framed with the goal of helping policymakers develop critical-thinking-based strategies for evaluating the risks and benefits of individual nanoscience-enabled products. In order to accomplish this several difficulties must be overcome:

DragonflyTV, a popular PBS Kids science show, recently teamed up with museums and research institutions nationwide to produce six, half hour episodes on nanoscale science and engineering. The episodes follow a scope and sequence and each contains two science investigations and a profile of a nanoscientist. Beyond broadcast, *DragonflyTV Nano* resources include: online videos, games, and activities; print Educator Guides featuring inquiry-based activities for formal or informal use; a kids' nano 'zine; and the NanoBlast board game. These materials are distributed freely to educators through the National Science Teachers Association (NSTA), Association of Science Technology Centers (ASTC), and at NanoDays museum outreach events across the country.

- Risk/benefit discussions are naturally probabilistic, and it is very difficult to communicate about probability to the general public. Qualitative discussions are needed. Nanotechnology is by no means unique in requiring decision-making under uncertainty. A recent NAS report, "Informing Decisions in a Changing Climate[42]," is an example of well-executed work addressing the larger issues.

- Other countries may be less receptive to new technologies than the U.S. For example, the European attitude towards the use of nanotechnology seems to be highly precautionary[43]. Many parties are concerned that a Genetically Modified Organism-like debacle may ensue in which perceived risks are weighted more than potential benefits by a few nations, with international trade agreements used to amplify their influence.

- There are also significant local variations in attitude within the U.S. Some localities have already established nanotechnology-specific regulations. For

example, after extended debate the City of Cambridge (MA) put in a registration requirement for nanotechnology users.

A recent event at the University of California, Los Angeles (UCLA) provides an interesting model for developing the expertise needed to address these kinds of issues. The Center for Environmental Implications of Nanotechnology at UCLA partnered with the UCLA Law School and the California Nanosystems Institute for the Working Conference on Nanotech Regulatory Policy, with scientists and legal scholars both giving presentations. These organizations plan to continue to hold joint symposia in an attempt to learn each other's languages and contribute to an emerging consensus on policy approaches.

While there is a desire to provide nanotechnology educational opportunities for all age levels, "K through Gray," it is important to identify age-appropriate topics and produce suitably targeted materials. Funding to develop these materials may be available from both public and private sources. For example, the NSF has $150K grants available for communicating science to the public[44]; researchers can apply for these grants in coordination with any ongoing NSF-supported research. The Sloan Foundation public understanding of science program supports activities to accurately weave science and scientists into books, films, theatre, radio, and television. The Federal funding agencies could interact more systematically with the nanotech community (rather than ad hoc with individual researchers) to identify and develop suitable topics for public engagement.

Newspapers and magazines retain high prestige among scientists, educators, and the general public. But these may be difficult times to use traditional print media to increase public awareness of nanotechnology. Science journalism positions are being cut from newspaper and magazine staffs across the nation. The changing dynamics of print media might provide some new opportunities, as editors are forced to look for replacement content. The nanotechnology community could work with university press offices, local newspapers, and specialized science magazines to provide alternative nano-focused content. But with signs of dwindling readership compounding the loss of science journalists, non-print outlets must also be vigorously explored.

In video, storytelling and humor are very powerful tools for creating effective narrative to engage audiences. One well-received example of nanotechnology based video resources, funded by the NSF and targeted toward middle school children, is the public television series *DragonflyTV*. Each half hour of *DragonflyTV* cost about $250,000 to produce. Along with video, PBS is committed to providing additional web and print resources for both children and educators.

A complementary approach is to reach out to commercial television shows that have scientific content embedded in their story lines. Programs such as NUMB3RS, CSI, and The Big Bang Theory include references to "real" science and have at least touched on nanotechnology. The writers and producers might well be open to suggestions for ways to incorporate positive images of nanotechnology in their programs while creating exciting new story angles. Wolfram Research (the developer of Mathematica) has a continuing relationship with the producers of NUMB3RS which could be investigated.

John Underkoffler, who has served as science advisor for a number of movies such as Aeon Flux and Minority Report, is another resource for such activities (Underkoffler, as Chief Scientist for Oblong Industries, demonstrated the g-Speak gestural operating environment to workshop participants as part of the Zemeckis Center tour during the USC workshop.). As an example of what might be implemented, the Hollywood, Health & Society project at USC's Norman Lear Center receives funding from the Centers for Disease Control and Prevention (CDC), The Bill and Melinda Gates Foundation, and other sources to provide scriptwriters with accurate and timely health information.

There are many other science television outlets, which might be utilized for a nanotechnology program. For instance, the Howard Hughes Medical Institute spends about $1.5M per year to support *Nova Science Now* on PBS, and gets some editorial input in return. The AIP develops 12 spots per month for its *Discoveries & Breakthroughs Inside Science* program, for sale to local news channels. Numerous partners support this effort; NSF has provided funding to evaluate it. Several universities produce science-based content on their own television stations, for example, the University of California at San Diego is known for science programming using humor as a hook.

Beyond television, an effort should be made to embrace the media savvy nature of today's youth by placing informative videos on YouTube and other selected web sites. One approach could be to recruit undergraduate and graduate research students to create and maintain content. For existing examples of such work, look to "The Nano Song" and the "Large Hadron Rap" on YouTube. The Museum of Science, Boston also has a set of videos about nanotechnology on YouTube that can be accessed by searching Nanonerds. PBS and *DragonflyTV* partnered with students from North Carolina State University to produce two music videos on YouTube: Scale Music Video and Nanotechnology Music Video.

The growing influence of social networking sites such as MySpace and Facebook could be harnessed to increase the popularity of any nano YouTube videos while building an online nanotechnology community. The demographics of social networking sites should be investigated to ensure coverage of diverse segments of the youth population, especially groups currently underrepresented in the STEM workforce.

A consistent challenge, regardless of the age of the intended audience or the media involved, is to identify the hook that catches the attention of the general public and sparks further interest in science.[45] The majority of the population is not interested in basic science research for its own sake, and needs to feel a connection to become invested in the topic at hand. It is relatively easy to generate such connections in areas such as energy, health, and medicine. These are good topics for promoting awareness of nanotechnology and beginning to discuss its benefits and risks. To give one specific example, cancer has touched millions of families worldwide. Many people are interested in new diagnostic methods and treatments that might eliminate the severe, often debilitating side effects of conventional chemo- and radiation-therapies. Nanomedicine's potential to improve outcomes and quality of life for cancer patients through targeted

treatments would provide a viable framework for a discussion on assessing the risks and benefits of nanotechnology in general.

Outreach to all media and television to suggest stories about engineers and scientists, and to provide content for such stories are another important form of community outreach that needs to be pursued much more vigorously. These stories, especially when laced with exciting, innovative technology products and state-of-the-art devices that improve the quality of life, are powerful avenues of communication and outreach.

Items for specific attention:

1. NSF should consider funding an organization with the necessary production expertise to help NSE researchers develop programs addressing public understanding of the nanoscale on a service basis.
2. There should be more programming made available for public television and to encourage promotional use of quality short excerpts.
3. NNI experts should partner with the proprietors of general web-based science education efforts, such as Science Buddies, to develop and distribute more nanoscience projects.
4. The nanotech community should develop strong positive messages regarding the potential of nanotechnology and should establish ongoing communication with civic officials and thought leaders to deliver these messages.

6. **Local Community Outreach and Engagement**
   Dr. Nora Savage, EPA, and Dr. Thomas Vogt, USC

The community outreach breakout group was tasked with identifying challenges and exploring novel approaches for engaging communities with outreach efforts to enhance the visibility for STEM and nano science.

The first topic discussed was approaches to surmount the difficulties often encountered when attempting to broaden outreach activities to groups underrepresented in STEM and nanoscience activities. Suggestions included approaches such as locating outreach activities within the targeted group's schools, community centers, or churches. It was noted that different cultures and sub-populations receive information differently (e.g., some have limited internet access) and therefore approaches that work with one group might not be successful with others. It was seen as absolutely vital for successful outreach to incorporate members of the targeted populations into 'outreach boards' and encourage their assistance in efforts to broaden science education within their community.

The breakout group stressed the need for increased interactions with community colleges. This should be structured such that the programs and efforts facilitate student mobility when transferring from a community college to a university.

Feedback opportunities for established large technology companies (e.g., GE, Boeing) as well as medium and small businesses to voice their needs and interests are important to

develop an adequately educated workforce. Many nanotechnology-focused small businesses need support when growing their workforce. Small businesses can provide detailed information as to what types of careers (in particular non-PhD jobs) are available as well as the level and depth of educational skills required. Educators at both high schools and universities must initiate these contacts as small firms are often personnel- and resource limited. While these types of interactions do currently exist, the questions raised were: Are they accessible? Are they well known? Are they accessible to local school districts? What roles can the various trade organizations and business associations play in increasing awareness of workforce needs?

Community outreach should also consist of educate the general public about potential career opportunities. This can be done within forums such as citizen schools, science cafes, and information forums. By providing details about what an engineer, scientist, and technology developer actually does on a day-to-day basis one can significantly demystify and influence potential career choices. It would also provide parents fact-based career advice that could redirect their focus on long-term benefits in lieu of short-term monetary gains.

Citizens Schools at the University of South Carolina

A public engagement program called the **South Carolina's Citizens' School of Nanotechnology** connects scientists and interested citizens in a face-to-face dialogue with each other so the public acquires knowledge and understanding about various nanotechnologies, while the scientists learn about the values and concerns of their fellow citizens. These small groups meet once a week for 8 weeks to learn about and debate issues regarding different nanotechnologies such as nanomedicine, polymer nanocomposites, and nanoparticles and the environment. Besides Citizen Schools of Nanotechnology, the University South Carolina has also organized similar schools on environment and global warming and on the global energy challenge. Both scientists and citizens are questioned about changes in their knowledge, attitude, and perception before and after the school.

Mobilizing and utilizing organizations such as parent teacher associations and university alumni are good ways to prompt politicians and alert them that public and private disinvestment in education is a highly contested issue. To increase the visibility of STEM and nano professions, a broad use of multiple media forms to educate and entice students and parents about possible careers is called for. This also includes 'secondary triggers' such as those provided by television shows (i.e., "CSI" has promoted the exciting opportunities in forensic science), novels, blogs, Wikipedia, and twittering.

Science cafés and similar events held at restaurants, public libraries, or community centers can facilitate interactions between scientists and their local communities. The Center for Nanoscience in Society Nano-Meeter series, for example, recently brought together several scientists with different perspectives on the role of nanotechnology in the solar energy field. Local events can reach out to various parts of their communities in the

appropriate—utilizing the Spanish language media where appropriate, or perhaps Farsi in parts of Los Angeles where it is the dominant home language.[46]

An important discussion centered on questions regarding age- and culture-specific communication tools: Are we missing the obvious? Why not communicate with the students in their own language and on their turf? Methods should be deployed taking advantage of the media favored by children and young adults: games, texting, internet, and other popular communication venues have largely been ignored by science educators as a means to increase interest in science and nanotechnology. Let the children show the educators how best to reach them.

Whatever the outreach efforts, there is a critical need to coordinate these efforts with the curricula used in the particular state or region. Coordinating will not only ensure a more coherent approach to education efforts, but will result in the development of more sustainable ones. In addition, these efforts will more easily generate support from the existing school administrators and policy developers.

Another idea is to refurbish or reinvent the community playhouses or playgrounds. There are currently a plethora of playhouses and play stations in schools, fast food restaurants, supermarkets, and malls that could be retooled as STEM and nanoscience education sites. Or put nanoscience showcases at 5 to 10 major airports or train stations. This should be done with additional support from local industries and governments and would provide places where science could be communicated to children, teachers, and parents alike. The promotion and tenure criteria of many academic institutions do not encourage or support faculty participation in such activities; changes in these policies may also be needed.

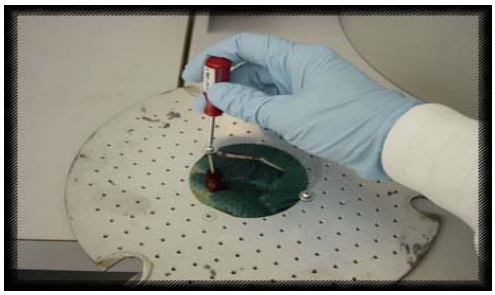
<u>Items for specific attention:</u>

1. There is a need to link community colleges with high schools on the one side, and with undergraduate institutions on the other. A closer and more effective link between these organizations will enable more effective communication techniques. It will also result in more appropriate science educational activities and provide for a well-prepared and diverse work force for the nanotechnology and other emerging STEM fields.
2. Take advantage of the media favored by children and young adults: games, texting, internet, and other popular communication venues have not been fully exploited by science educators as a means to increase interest in science and nanotechnology
3. Engagement with teachers at all levels and institutions should be enhanced by reaching out to national teachers' unions, research and academic societies (AAAS, NAS, MRS, APS, ACS) and other similar groups

7. **University and Community College**
   Dr. Steven Fonash, Pennsylvania State University (PSU), and Dr. Tapas Kar, Utah State University

PSU State-wide Nanotechnology Education Program

The partnership is composed of 27 academic institutions offering a total of 54 two-year and four-year nanotechnology degrees across Pennsylvania. The students in all of these programs must spend one semester at Penn State attending the hands-on nanotechnology fabrication, synthesis, and characterization immersion provided by the Capstone Semester, a 6 course hands-on experience exposing the student to state-of-the art equipment and cleanroom facilities at Penn State.



The 18 credits of coursework can be used toward an associate, or baccalaureate degree, used to earn an NMT Certificate, or both depending on the specific program of the student's "Home Institution ". Refinement of the capstone semester is carried out in close consultation with the industry members of the NMT Program 's Advisory Board.

Nanoscale science and engineering begins with materials behavior at the nanometer size scale where properties can be very different from atomic and molecular and micrometer sized particles. As such, the traditional academic disciplines have been quick to introduce research involving nanostructures that lead to MS and PhD degrees in those disciplines. The rapid growth in nanoscale science and engineering literature is a consequence of this behavior. The criteria for when nano reaches a sufficient critical mass to warrant its own academic discipline is a matter of some debate. Schools with MS degrees focused specifically on nano are relatively common, but only a few schools are experimenting with a PhD in nanoscience, whose value in the marketplace is unknown. (See Appendix D for a listing of schools with some variant on a nano degree. Appendix E has an illustrative listing of textbooks addressing NSET.) At present, industry requirements do not compel a separate nano department, but in the future as larger markets and more sophisticated nano-enabled products are introduced, that may change.

The traditional basic science (biology, chemistry, mathematics, physics) and engineering (electrical, mechanical, chemical) disciplines are now the building blocks for developing a foundation to pursue interdisciplinary work, including nanotechnology education and research. Taking away those regular academic departments at universities is not recommended at this time; rather interdisciplinary courses should be encouraged. The student can assemble programs of study in different areas, such as energy, water, environment, nano, nano-bio, etc., depending on the demands of market. A nano minor in the traditional disciplines is highly recommended and keeps open student options in the job market.

Since community colleges have an important role on developing the future workforce, in particular the technically skilled workforce, they should offer courses addressing the nanoscale. A major bottleneck is infrastructure, which can be expensive. To address the

NanoProfessor

NanoInk's NanoProfessor Project is a public-private partnership seeking to make 21st century education and workforce development in nanotechnology accessible to smaller 2 and 4 year colleges. Three elements define the NanoProfessor Project. The first component is an accessible machine that is simple enough for general students to operate at the nanoscale level - a desktop nanofabrication system.

The second critical element is a worthwhile curriculum grounded in fundamental science and engineering concepts. An interdisciplinary curriculum will engage students in basic science learning through hands-on manufacturing and experiments with cutting-edge technology at the nanoscale level. The curriculum is being developed by a team of teachers, NanoInk professionals, and experts in instructional design. Each unit and the overall course will be evaluated during development and throughout implementation. The third element is the active participation of educational institutions committed to the advancement of science, technology, engineering, and mathematics education. The educational partners will host the project, receive training for faculty members, and cooperate in the evaluation and dissemination of project outcomes.

facilities issue, State governments, working in concert with the DoE and local industries, need to develop mechanisms to enable interactions between the research universities, national laboratory facilities, and community colleges. Some states such as Texas[47] and Pennsylvania[48] are taking steps and making good progress toward that integration. One solution is integrating community college courses with research universities where such facilities are available. Students and faculties from community colleges close to universities can have much easier access to nearby universities for training and workshop. In addition, some mechanism, such as the NanoProfessor project[49] (see insert), is needed to enable hands-on participation for those located far from universities; sending samples and watching characterization through Internet facilities, while helpful, may not be the best training process.

STM and AFM can be effective in air and can be relatively inexpensive. Inexpensive and user-friendly electron microscopes are now available that do not require perfect vacuum and can be used by community colleges for practical classes. Such tools, illustrated in Table 5, may provide local access for initial training and for teaching fundamentals of operation. However, maintenance is an issue and funds are required to keep those instruments operational.

Table 5: Education Oriented NanoProbes[50]

easyScan 2 – SPM	Nanosurf	www.nanoscience.com
Nanoeducator - SPM	NT-MDT	www.ntmdt.com/platform/nanoeducator
Q-Scope - SPM	Ambios Technology	www.ambiostech.com/index.html
NLP 2000	NanoInk	www.nanoink.net/Instrumentation.htm#NanoProfessor
Phenom - SEM	FEI	www.phenom-world.com
5420 - AFM	Agilent	nano.tm.agilent.com

Items for specific attention:

1. Universities should offer minors in nano at the BS level within existing departments. Depending on the evolution of market demand and the experiences of graduates from those schools experimenting with a nano major, the importance of a nano major can be reevaluated.
2. Develop mechanism(s) for potential interaction between community colleges and universities through state government and local industry intervention.
3. To address industrial needs, the NNI should fund development of courses aimed broadly at science and engineering students at the senior undergraduate and graduate (especially MS degree) levels.
4. NSF should facilitate the broader impact of the nanotechnology research by issuing guidance aimed at connecting funded researchers with K-12 education.

8. **Industry Needs for Nanotechnology Education**
   Mr. Russell Maguire, Boeing, and Dr. Celia Merzbacher, Semiconductor Research Center (SRC)

The ability to measure and control matter at the scale of nanometers offers myriad opportunities in every industry that relies on advanced materials, including aerospace, medicine, and electronics. In order to take advantage of the advances that are being made, often in the university research environment, industry needs relevantly educated scientists and engineers. In-house expertise can be established by hiring students who have taken courses and had laboratory experiences that ensure they have the necessary skills and knowledge. Alternatively, existing technical staff may require continuing education or training.

Although it is clear that nanotechnology will have application in many sectors, there are few data on what those industries' needs are today or will be in the near and long term. Collection of better data can aid universities and community colleges to develop programs that better meet those needs. Such data can also be used to inform students in high school and entering college about career opportunities and perhaps inspire students to enter relevant disciplines of study. The Department of Commerce (DoC), in collaboration with professional organizations such as the ACS, AIP, International Electrical and Electronic Engineering, American Society of Mechanical Engineers, and American Institute of Chemical Engineers, are best suited to collect these data.

Despite a lack of quantitative data, industry workforce needs are varied, growing, and expected to change through time. At the outset, an emerging technology such as nanotechnology likely will impact industry at the research level and companies will seek scientists and engineers with advanced degrees to introduce and incorporate new concepts into products and services. Very quickly, as technologies are being developed for a particular application, companies of all sizes need technician-level workers with appropriate skills.

Even among advanced degree holders, the needs of industry are diverse. Small companies in particular may seek employees with a breadth of education, obtained through multidisciplinary degree programs or an emphasis or major in more than one field. Such workers are better able to shift as needed. Large companies with thousands of technology workers may seek employees with specific skills that depend on the sector. Small and large companies may refresh knowledge and skills of current employees through short courses, seminars by outside experts, workshops, etc. Some states offer support for such activities.

Example of Industry Approach to Re-educating Its Workforce In Nanotechnology.

When the Boeing 787 all-composite aircraft was launched, it spurred many engineers with decades of metallurgy experience to seek training in polymeric composites technology. Boeing, in conjunction with the University of Washington, developed a multi-course, multi-layer, university-level curriculum to address this enormous demand. The result was a composite certificate program for professional engineers that won national awards and still is in great demand. In the face of an almost equal hunger among these same engineers for skills and knowledge in nanotechnology Boeing is now planning a similarly styled cross-cutting curriculum, to be kicked off in Fall 2010 and involving several leading universities.

Early applications of nanotechnology are almost all based on novel materials and their properties. As a result, industries need workers with knowledge and skills in materials science. At the upperclass and advanced degree level, universities could help by incorporating coursework in nanomaterials science into almost all physical science and engineering programs. At the technician level, there is a need for 1 and 2 year programs that teach students specific skills for synthesis and/or characterization of nanomaterials. And industrial hygienists need specialized (refresher) training to ensure workplace safety.

The needs of industry for high quality, well-educated scientists and engineers depend heavily on the larger education ecosystem. To ensure a robust supply of workers, the entire ecosystem must be healthy, beginning with K-12 math and science education and continuing through various forms of post-secondary education. Rather than a one-way path from K-12 to undergraduate to graduate school, society

can be better served by interactions and partnerships among industry, academia, government, and the broader formal and informal education system.

Industry can engage the education ecosystem in ways that help to attract and retain students at various ages, such as partnering with local K-12 schools to let young students understand what scientists and engineers do. Support for co-ops and internships help to mentor university and even high school students at a time when career decisions are being made. Industry can also support university education by donating equipment; instruments that are no longer needed by industry may be useful for training students.

Universities tend to be organized along disciplinary lines, in which faculty obtains tenure and students get degrees. This compartmentalization creates barriers to multidisciplinary education. The NNI and other Federal programs include funding for multidisciplinary centers and teams, which has been successful in stimulating the formation of research groups that cross boundaries. However, such multidisciplinary activities must rest on a foundation of strong programs in traditional disciplines to ensure sufficient depth, as well as breadth. University tenure and promotion systems must properly recognize interdisciplinary faculty activities.

The Federal government plays a dominant role in supporting graduate science and engineering education through funding for fellowships and basic university research. Programs that support undergraduate research opportunities and industry-university collaborations are important supplements. Examples include the NSF Research Experience for Undergraduates (REU) and Grant Opportunities for Academic Liaison with Industry (GOALI). Agencies participating in the NNI should adopt similar programs and emphasize their availability to the nanotechnology research community.

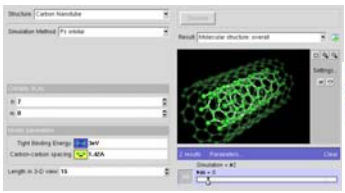
The Federal government also should encourage industry investment in university research, individually or through consortia, by increasing the tax credit for such spending by a factor of three to five or more. Such research is typically basic in nature and of benefit well beyond the individual performing company or consortium. Industry funding also provides university faculty and students with a greater appreciation of “real world” problems. And industrially sponsored research enhances the likelihood of technology transfer from the university to commercial application.

<u>Items for specific attention:</u>

1. The DoC should develop data on trends in needs for workers with skills related to nanotechnology across sectors.
2. Congress should increase the Federal research tax credit for industry investment in university research by a factor of at least three.
3. Industry should forge a greater partnership with State and Federal efforts to revamp STEM education, including funds for local or regional STEM programs and employee involvement in the schools and colleges.

9. **Cyber and Virtual Innovations**
   Dr. Sean Brophy, Purdue University, and Dr. Miriam Heller, Computing Research Association

The nanoscience and nanotechnology centers have spawned several valuable cyberinfrastructure resources, some targeting education. The NanoEducation and STEM education communities need to become more aware of these cyberinfrastructure resources. Also, these cyberinfrastructure resources must become more integrated with each other for easier discovery. For instance, despite nanoHUB's widespread use with over 92,000 annual users, many workshop participants were not familiar with it or its capabilities. NanoHUB capabilities need to be better publicized regarding accessibility, content and updates, targeted user levels, customizability to targeted audiences and individual user interface, interoperability with other systems, and end-user services.



NanoHUB offers a functional and successful cyber-infrastructure geared toward supporting a research communities' access to computational and educational resources for nanotechnology. NanoHUB illustrates how an effective cyber-infrastructure can support virtual access to a variety of remote learning resources: 1) people – instructors, collaborators and any of 92,000 members per year in the nanoHUB virtual community; 2) over one hundred simulations, models, and animations; 3) reference data, publications, course lectures, presentations, workshops, and webinars; 4) learning modules and teaching materials bundled into Sakai and other LMS; and 5) real-time communication and collaboration tools. Cyberinfrastructures like these provide new opportunities for research, collaboration, sharing data, publishing, learning and investigating how an organization learns by observing how they select and contribute resources. As such, nanoHUB offers a natural starting point for the NanoEducation community to examine its assets, needs, and current processes and their effectiveness for disseminating information.

Whether using nanoHUB as the platform or designing a new system to accommodate the various learning resources, the need for a Learning Management System (LMS, also called a Course Management System) versus a Learning Content Management System (LCMS) should be explored. NanoHUB best fits the LMS paradigm; it facilitates planning, delivering, and managing learning events, e.g., online, virtual classroom, and instructor-led courses. An LMS provides structure to manage student, tracking their progress and performance across learning activities.

A LCMS focuses on managing learning content. With LCMS, developers, authors, instructional designers, and subject matter experts can create and reuse e-learning content and reduce redundant development. Some workshop participants voiced a need for LCMS and the focus on learning resources, or digital assets (e.g., simulators, images, movies) that can be used, reused, remixed, and repurposed to construct specific learning objects used in learning activities that meet specific learning objectives. Learning modules can integrate a network of learning objects to address

complex learning objectives associated with problem-based kinds of learning environments[51]. LCMS with learning objects and modules appears to offer greater flexibility in constructing sharable learning resources.

The key to sharing resources is interoperability. Achieving interoperability across different platforms using sharable content and other digital assets suggests the need to reexamine conformance to standards. For example, the Office of the United States Secretary of Defense through its Advanced Distributed Learning Initiative working with experts, specified a collection of existing standards for web-based e-learning, the Sharable Content Object Reference Model (SCORM); there are now over 280 LMS and LCMS items certified to versions of SCORM[52]. NanoHUB conforms to SCORM as well as IMS Global Learning Consortium standards[53] to enable dissemination through similarly compliant LMS such as WebCT-Blackboard (now merged) and Sakai[54]. NSF should evaluate requiring standards conformance in new projects versus future reinvestment needs in large-scale integration projects, such as DataNet, funded at $20 million per project.

Research, collaboration, and development of standards are needed to better integrate and share the wide range of learning resources specific to nanotechnology. Examples of these resources include movies, simulation codes, games, virtual and immersive environments, and instrumentation. For instance, Pennsylvania State's Nanotechnology Applications and Career Knowledge (NACK) National Center provides remote access and control to state-of-the-art nanotechnology characterization equipment such as AFMs and STMs. Cyberinfrastructure offers a means to distribute use and cost of expensive equipment and instrumentation for nanotechnology education.

Cyberinfrastructure promises to narrow the digital divide. Success at narrowing the digital divide requires the input of representatives from schools serving under-represented groups in order to understand the causes and potential remedies. Inequities of access and training may vary according to several factors in addition to socio-economic factors, e.g., educational level, diversity in linguistic abilities, learners with disabilities, age of the school, and general demographics.

Successful projects that helped bridge the divide should be examined for transferability as well. For instance, the Network for Computational Nanotechnology (NCN), which is supported by the nanoHUB, includes two partnering minority-serving institutions: Norfolk University and University of Texas at El Paso. NanoHUB enabled students to access the same level of nanotechnology educational resources and computational tools as students from Purdue University (home of NCN) and Northwestern without leaving their institutions. NanoHUB provides these schools with the opportunity to offer a high quality nanoscience curriculum through the easy access of nanoHUB and its rich set of online resources.

Access to digital resources (see Table 6 for examples) for K-12 audiences may pose greater difficulties due to the larger number of students and schools. Elementary and secondary schools vary widely in terms of the computing facilities and access to

cyberinfrastructure. Moreover, the variability may not wholly align with the socio-economics of the neighbors in which the schools are located. For instance, older schools in affluent neighborhoods may opt to provide limited shared computer resources and rely on individual student computer ownership and home Internet access. The reputations of the schools in affluent areas, regardless of their technology resources, attract students away from their troubled but possibly better equipped, more recently upgraded, neighborhood schools. The students from the disadvantaged neighborhoods are less likely to have individual computers and home Internet access. Computing resources and access limit how cyberinfrastructure learning resources and tools can be used for ongoing inquiry activities, thus overall limiting the kinds of pedagogy that can be used for formal learning experiences. Parents need to be made aware of the resources in their own community schools and what are the opportunities for their children. Mechanisms, perhaps extracurricular, need to be in place that allows students to exploit the technology resources in their own neighborhoods, regardless of whether they attend local schools.

Table 6: Digital Information Resources for STEM

Wikibooks	en.wikibooks.org/wiki/Main_Page
WikiJunior	en.wikibooks.org/wiki/Wikijunior
National Science Digital Lib	nsdl.org
Science Buddies	www.sciencebuddies.org/
Curriki	www.curriki.org/xwiki/bin/view/Main/WebHome
NSTA Learning Center	learningcenter.nsta.org/?lid=lnavhp
Connexions	cnx.org/
Open Education Resources	www.oercommons.org/
Wikiversity	En.wikiversity.org/wiki/
TeachersFirst	www.teachersfirst.com/
NanoHub	nanohub.org/
National Center for Learning and Teaching	www.nanoed.org/lessons/lessons_by_title
Teachers Net	Teachers.net/
Nature Education – Scitable.com	www.nature.com/scitable
eSchool News	www.eschoolnews.com
CK-12 Foundation	about.ck12.org/
Nanotechnology Applications and Career Knowledge (NACK) Center	nano4m3.org

Cyberinfrastucture projects like nanoHUB are powerful environments for learners with skills and literacy to guide their own inquiry with the tools. K-12 learning environments will need a cyber-infrastructure that will provide additional scaffolds to support teachers' use of these tools in their classroom and make them content-age appropriate (i.e., accessible to their language and mathematical literacy level).

Partnering between existing cyber-infrastructures for K-12 and higher education environments could present several interesting opportunities. For example, Science Fair Buddies and Dragonfly provide powerful information learning experiences that could be coupled with sites with computational tools all joined by an advanced LMS/LCMS that supports classroom-based learning environments. The integration of the cyber resources could provide a formal learning environment that supports individual learning, formative

assessments, summative assessments, and initiation into a community of scientists and engineers.

The next generation of learning environments for K-12 NanoEducation will most likely involve a new approach to content conceptualization. New tools will need to be produced to support teachers' education of nanoscience concepts and how to teach these concepts to their students. Coupled with content conceptualization are new problem-solving methods. At NSF, the Directorate for Computer and Information Science and Engineering has staked its claim in educating new learners in Computational Thinking. Clearly, there is opportunity for partnering along these shared objectives.

Continued investigation of the cyber-enabled learning for K-12 learning environments needs to explore such questions as:

- Can we define the network of nanoscience and technology educators who can effectively leverage cyber-infrastructures to support teaching and learning of young learners that results in interest and pursuit of nanoscience as a career?
- What new mechanisms, e.g., "one laptop per child" (OLPC), could be employed to contribute technology resources to those in need (e.g., surplus machines)?
- What are the obstacles to partnerships like the Good Neighbor project?
- How is cyberinfrastructure used for learning in Europe[55]?, Asia[56]?
- What effective instructional models involve cyberinfrastructure? Many K-12 learning environments integrate technology into the learning process well.
- What advances in cyberinfrastructure are necessary to increase the potential for learning nanoscience and nanotechnology concepts?
- How can we better leverage at-home access to the cyberinfrastructure?
- Universities are slow to change. How can we accelerate the adoption of new models of instruction to support the education of the rapidly growing knowledge base associated with the science and engineering of nanoscale devices, materials, and methods for constructing nanoscale objects?

<u>Items for specific attention:</u>

1. NanoHUB and other cyberinfrastructure learning resources need to be better publicized regarding accessibility, targeted user levels, customizability both in terms of targeted audiences and user interface, interoperability with other systems, and responsibility to provide services.
2. Partner digital divide advocates with nanoHUB personnel to identify ways to make tools available and accessible.
3. NanoHUB's learning resources should be examined to determine the feasibility of supporting the wide array of learning resources available on other web sites focused on nanotechnology as well as its ability to incorporate new learning paradigms.
4. Nanoeducation learning resources should be open to the extent possible and content generators should explore integrating their products into the global OER community and other OER projects.
5. The concept of using an ecosystem paradigm for developing content and translating it to usable resources should be evaluated. If pursued, the ecosystem model needs to be vetted and hosted for dissemination.

6. Leverage the development of new cybertools by making them accessible to the nanoeducation communities.
7. Update and make functional the Wikibook entry on nanotechnology.
8. Create an entity to effectively engage the NNI research community with the solution of K-12 teacher needs.

Appendix A: Workshop Participants

Perspective	Name		Institution
Com College	Steve	Fonash	PSU
Com College	Deb	Newberry	Dakota County Technical College
Educ Res	Brooke	Bourdelat-Parks	BSCS
Educ Res	Joe	Krajcik	Michigan
Educ Res	Gisele	Ragusa	USC
Educ Res	Aldrin	Sweeney	UCF
Fed	Scott	Hess	DOEd
Fed	Krish	Mathur	DOEd
Fed	Mihail	Roco	NSF ENG
Fed	Nora	Savage	EPA
Fed	David	Ucko	NSF EHR/DRL
Foundation	William	Galey	Howard Hughes Medical Institute
Industry	John	Ireland	NanoInk
Industry	Tom	Levesque	NanoInk, VP nanofabrication div
Industry	Russell	Maguire	Boeing
Industry	Celia	Merzbacher	Semiconductor Research Corporation
Industry	Jack	Solomon	Praxair; Vision 2020
International	Elisabeth	Nilsson	Univ Lund
International	Maria	Sorensson	Univ Lund
International	Andrew	Wee	National Univ Singapore
Museum	Larry	Bell	Boston Museum of Science
Museum	David	Bibas	Cal Science Ctr, Curator Technology Programs
Fed	Philip	Lippel	NNCO Policy Analyst
Professional	Miguel F.	Aznar	Foresight Nanotech Inst, Dir of Education
Professional	Kristin	Bennett	The Implementation Group / VSA
Professional	Jennifer	Cleary	Workforce Development
Professional	Miriam	Heller	Visiting Fellow, World Resources Inst.
Professional	Alan	McCormack	NSTA, President Elect
Professional	Catherine	O'Riordan	American Institute of Physics
Professional	Lisa	Regalla	Twin Cities Public Television
State/Local	Jim	Batterson	Senior Advisor to the Commonwealth of VA for STEM Initiatives
State/Local	Walt	Trybula	Texas State
Univ	Robert	Chang	Northwestern
Univ	Mamodou	Diallo	CalTech
Univ	Julie	Dillemuth	UCSB
Univ	Tapas	Kar	Utah State University
Univ	James	Murday	USC / NNI
Univ	Susan	Metros	USC
Univ	Tom	Vogt	U South Carolina, NanoCenter
Univ	Hilary	Godwin	UCLA
Unv	Catherine	Nameth	UCLA
Teacher	David	Gaughen	Taft High School LA
Teacher	Maggie	Ku	Taft High School LA
Teacher	Lyda	Lara	Taft High School LA
Teacher	Roald	Roverud	Taft High School LA
Teacher	Sheri	Stephens	Taft High School LA

Appendix B: Workshop Agenda

Agenda for the Workshop
Partnership for Nanotechnology Education
April 26-28, 2009
Davidson Conference Center, Univ. Southern California
Univ Park Campus, Los Angeles, CA

April 26 (Sunday) Evening Kickoff

1900 - 2050	Overview	Krish Mathur session chair
1900 - 1920	Charge to workshop	Jim Murday, USC
1920 - 1950	NSF perspective	Mihail Roco, NSF
1950 - 2020	DoEd perspectives	Scott Hess, U.S. DoEd
2020 - 2050	Challenges/opportunities for K-12 educ.	Aldrin Sweeney, UCF

April 27 (Monday) - Morning

0800	Welcome to USC	Randy Hall, USC VP Res Adv
0800 - 0830	European perspective	Elisabeth Nilsson, Lund Univ., SE
0830 - 1200	K-12 Session	Jim Murday, session chair
0830 - 0845	Secondary education / SOL	Jim Batterson, VA STEM Advisor
0845 - 0900	Effective curricula materials	Joe Krajcik, Univ. Michigan
0900 - 0915	Next generation teachers/teaching	Bob Chang, Northwestern
0915 - 0930	Teacher perspective / training	Alan McCormack, NSTA

0930 - 1000 Break for informal discussions and refreshments

1000 - 1130 Breakout session discussions and prioritization

Challenges to be addressed:

Standards of Learning - State/Local involvement Batterson/Mathur

Should the national standards of learning be modified and, if so, how?

How to best facilitate changes to standards of learning?

How to promote symbiosis amongst the state and Federal efforts?

How might a partnership of stakeholders facilitate the evolution of SOL?

How might diversity issues be addressed?

Teacher education/training Chang/O'Riordan

How might "nano" best be introduced into S&E curricula? –into teacher training?

What might be roles of teachers vice cyber-infrastructure enabled teaching aides?

Are available "nano modules" for K-12 adequate in number and quality?

How might a partnership of stakeholders contribute to teacher "nano" education?

How might diversity issues be addressed?

Curricula and Teaching aide development Krajcik/Sweeney

How create and facilitate symbiosis between teachers and on-line aides?

Is there a role for remote access to laboratory experimental experiences?

Are available "nano modules" for K- 12 adequate in number and quality?

What are the main impediments to more extensive utilization of cyber/virtual?

How might a partnership of stakeholders contribute to "nano" teaching aides?

How might diversity issues be addressed?

1130 - 1200 Joint reporting session and discussions

1200 - 1330 Buffet Lunch

April 28 (Monday) - Afternoon

1330 - 1700	Public education	Catherine O'Riordan, session chair
1330 - 1345	Nanotechnology safety	Walt Trybula, Texas State
1345 - 1400	Informal education (museum)	Larry Bell, Boston Science Museum
1400 - 1415	Perspective on public TV series	Lisa Regalla, Twin Cities Public TV
1415 - 1430	University outreach	Tom Vgt, Univ. South Carolina

1430 - 1500 Break for informal discussions and refreshments

1500 - 1630 Breakout session discussions and prioritization

Challenges to be addressed:

Informal Education Bell/Bibas

Are there sufficient and high quality "nano" exhibits for museums?

Who might fund the efforts?

What might be mechanisms to engage the public with scientists?

How might a partnership of stakeholders facilitate informal education?

How might diversity issues be addressed?

Public Education – Risk/Benefit Decisions Regalla/Lippel

How to inform policy makers? Could a partnership of stakeholders assist?

How to inform general public of benefits/risks associated with "nano"?

How to get more "nano" articles in the press? In documentaries?

What "stories" might be developed to illustrate opportunities/risks?

How might a partnership of stakeholders facilitate public education?

How might diversity issues be addressed?

Community Outreach Vogt/Savage

How to get more "nano" articles in the press?

Might such web-based resources be exploited? chat rooms? other?

How might a partnership of stakeholders facilitate community outreach?

How might diversity issues be addressed?

1630 - 1700 Joint reporting session and discussions

1930 – 2030 After-dinner talk – Interactive Media in Education by Scott Fisher from the USC School of Cinematic Arts, Interactive Media Division

April 28 (Tuesday) - Morning

0800 - 0830	Asian Perspective	Andrew Wee, National Univ. Singapore
0830 - 1200	Post secondary Education	Jim Murday, session chair
0830 - 0845	Advanced technology education	Steve Fonash, PSU
0845 - 0900	Nano-Hub evolved (cyberinfrastructure)	Sean Brophy, Purdue
0900 - 0915	Information industry perspective	Celia Merzbacher, SRC
0915 - 0930	Materials-user industry perspective	Russ Maguire, Boeing
0930 - 1000	Break for informal discussions and refreshment	
1000 - 1130	Breakout session discussions and prioritization	

Challenges to be addressed:

University / Community College Fonash/Kar

Does nano necessitate breaking down traditional academic stovepipes?

Should there be a minor in nano at the BS level?

What might be criteria to determine when a BS major in nano is warranted?

What is the technical/community college role; how integrate with universities?

Is there a "University of Phoenix" on-line degree imperative for nanoeducation?

Are there adequate mechanisms to share experiences, especially on a global scale?

How might a partnership of stakeholders contribute to post secondary education?

How might diversity issues be addressed?

Cyber/Virtual Innovations Heller/Brophy

How to best exploit the growing cyber infrastructure?

How to exploit and coordinate the growing cyber infrastructure – NanoHub, Nanopedia, Nanopolis as examples?

Can cyber infrastructure provide access to real-time remote experimentation?

Is there adequate bandwidth access?

How to integrate the evolving cyber communities with the evolving nano-ed efforts?

How might a partnership of stakeholders facilitate that integration?

Are recommendations of the "Fostering Learning in a Networked World" report to NSF in June 2008 pertinent to "nano"

How might diversity issues be addressed?

Industrial Needs Merzbacher/Maguire

Is there a job market for nano trained students? What should that training entail?

What are the continued education requirements and how fulfill them?

What role(s) of university research in long range industrial product development?

How might a partnership of stakeholders contribute toward industry / government / academic collaboration toward work force training?

How might diversity issues be addressed?

1130 -1200 Joint reporting session and discussions

1200 – 1430 Box Lunch and local sites to visit for demonstrations/exhibits:

Integrated Media Systems Center

GameDesk Program — Dr. Victor Lacour

Interactive Media Division of the School of Cinematic Arts

Co-Design Lab — Dr. Anne Balsamo

Game Innovation Lab — Mr. Kurosh ValaNejad

California Science Center. — Dr. David Bibas

April 28 (Tuesday) - Afternoon

1430 – 1700 Integration and Wrap up Session

Prioritization of recommendations itemized in three prior sessions.

What structures/organizations could carry a partnership forward?

Which stakeholders need to be involved?

Identify teams and team leads for follow-up action

Initiate section report drafts

Participant evaluation of workshop

Appendix C: Centers Addressing Nanoscale Science and Engineering

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
Ahmed Busnaina	Northeastern Univ.	Center for High Rate nanomanufacturing
Chad Mirkin	Northwestern Univ.	International Institute for Nanotechnology
Ly 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	Center for Templated Synthesis and Assembly at the Nanoscale.

NSF Networks and Centers that complement the NSECs (NNIN, NCN, MRSEC, STC)

Robert Meyer	Brandeis Univ.	MRSEC: Nano-Structured and Bio-Molecular Materials
Sandip Tiwari	Cornell Univ.	NNIN: National Nanotechnology Infrastructure Network
Harold Craighead	Cornell Univ.	STC: The Nanobiotechnology Center
Mel Cossette	Edmonds Comm. College	Materials Education Resource Center
Dennis Hess	Georgia Inst. of Technology	MRSEC: The Georgia Tech Laboratory for New Electronic Materials
Lawrence Bell	Museum of Science	Nanoscale Informal Science Education Network (NISE Net)
Robert Chang	Northwestern Univ.	Nanotechnology Center for Learning and Teaching (NCLT)
Thomas Mallouk	Penn. State Univ.	MRSEC: Center for Nanoscale Science
Richard Register	Princeton Univ.	MRSEC: Princeton Center for Complex Materials
Mark Lundstrom	Purdue Univ.	NCN: Network for Computational Nanotechnology
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 and Engineering Ctr

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

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.	Center for Cancer Nanotechnology 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 Nanotechnology 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	Univ. 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
DOD NanoCenter		
Eric Snow	Naval Research Lab	Institute for Nanoscience
Other		
Gilbert Pacey	Miami University	Center for Nanotechnology
Shawn Decker	So. Dakota School of Mines	Center for Accelerated Applications at the Nanoscale
Alain Kaloyeros	Univ Albany, SUNY	College of Nanoscale Science and Engineering
Debra Reinhart	Univ Central Florida	NanoScience Technology Center
Gary Rubloff	Univ Maryland	Nanocenter
Tom Vogt	Univ South Carolina	NanoCenter
Francois Baneyx	Univ Washington	Center for Nanotechnology, NNIN
David Carroll	Wake Forest	Center for Nanotechnology and Molecular Materials

Appendix D: Representative Listing of Universities and Community Colleges Offering Nanoscale Science, Engineering and Technology Degrees

Schools with Nanoscale Assoc, BS, MS and/or PhD							
School		**Minor**	**Assoc**	**BS**	**Grad. Cert.**	**MS**	**PhD**
Arizona State University	US					X	
Bucks County Community College	US		X				
Chippewa Valley Technical College	US		X				
City University of New York	US						X
Clarion University of Pennsylvania	US	X					
Cornell University	US						C
Dakota County Technical College	US		X				
Drexel University (IGERT)	US				X		
George Mason University	US				X		
Georgia Institute of Technology	US				X		
Howard University	US					C	C
John Hopkins University	US					C	X
Lehigh University	US				X		
Lock Haven University	US	X	X				
Louisiana Tech University	US			X		X	X
Mansfield Univ. of Pennsylvania	US			C			
Michigan Technological University	US				X		
Normandale Community College	US		X				
North Carolina State University	US			C			
N. Dakota State College of Science	US		X				
N. Dakota State University	US						X
N. Seattle Community College	US		X				
Northeastern University, MA	US						X
Northwestern University	US			C			
Oklahoma State University	US		X				
Penn Community Colleges	US		X				
Penn State University	US	X	X				
Purdue University	US				X		
Rice University (IGERT)	US					X	X
Richland College	US		X				
Rochester Institute of Technology	US	X					
Rutgers University (IGERT)	US					C	C
Schenectady County CC	US		X				
S. Dakota School of Mines & Tech.	US						X
Stanford University	US				X		
Stevens Institute of Technology	US					X	X
Union College	US	X					
Univ. of North Carolina – Charlotte	US						X
University at Albany, SUNY	US			X		X	X
UC, Berkeley	US						C
UC, San Diego	US						X
University of Central Florida	US			X			
University of Delaware	US	X					
University of Denver	US					X	X
University of Maryland	US	X					
University of Massachusetts Amherst (IGERT)	US						C
University of Massachusetts Lowell	US				X		
University of Michigan	US				X		
University of Minnesota	US					M	
University of New Mexico	US					X	X
University of Pennsylvania (IGERT)	US				X		
University of Southern California	US			C			

University of Texas at Austin	US				X		
University of Washington	US						X
University of Wisconsin-Stout	US			C			
Wayne State University	US			C			
Graz University of Technology	AT					X	
Flinders University	AU			X	X	X	
Griffith University	AU			X			
Royal Melbourne Inst. of Tech. Univ.	AU			X			
Univ. 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	C	
University of Wollongong	AU			X			
Catholic University of Leuven	BE					X	
Interuniversity Microelectronics Ctr	BE						X
University of Antwerp	BE					X	
University of Alberta	CA			C		C	
University of Toronto	CA			C			
University of Waterloo	CA			X			
Swiss Federal Institute of Technology	CH					X	
Universität Basel	CH			X		X	
Academia Sinica	CN						X
Hong Kong Univ. of Sci. and Technol.	CN					X	X
Chemnitz University of Technology	DE					X	X
Dresden University of Technology	DE					X	
Fachhochschule Gelsenkirchen	DE			X		X	
Fachhochschule Kaiserslauter	DE			X			
Fachhochschule Sudwestfalen	DE			X			
Georg-Simon-Ohm Hochschule Nurnberg	DE					X	
Jacobs University Bremen	DE					X	X
Julius-Maximilians-Universitat Wurzburg	DE			X		X	
Leibniz Universitat Hannover	DE			X			
Ludwig-Maximilians-Universität	DE						X
Max Planck Inst. of Microstructure Phys.	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	
Aalborg University	DK			X		X	
Technical University of Denmark	DK					X	X
University of Copenhagen	DK			X		X	X
University of Valencia	ES					X	
Helsinki University of Technology	FI					X	
University of Jyväskylä	FI			X		X	
European School on Nano-Science/Technology	FR						
University College Dublin	IE					X	
Technion - Israel Institute of Technol.	IL					X	X
Weizmann Institute of Science	IL					X	
Amity Institute of Technology	IN					X	
Indian Institute of Science	IN						X
Indian Institute of Technology	IN	X				C	
Singhania University	IN		X	X		X	X
Tezpur University	IN					X	
Vellore Institute of Technology	IN					X	

CIVEN	IT					X	
University of Milan	IT						X
University of Trento	IT					X	
WASEDA University	JP					X	
Hanyang University	KR						X
Korea Adv. Inst. of Science & Technology	KR			X		X	X
Seoul National Univ.	KR					X	X
Sungkyun Kwan University	KR					X	X
Malaysia Uni. of Science and Tech.	MY			X			
Delft University of Technology	ND					X	
Hasselt University	ND					X	
Leiden University	ND					X	
University of Groningen	ND					X	
University of Twente	ND					X	
Utrecht University	ND					X	
Massey University	NZ			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 (Conc)	TH					C	C
Walailak University, Thailand (Conc)	TH					C	C
Cranfield University	UK					X	
De Montfort University	UK					X	
Heriot-Watt University	UK					X	
Imperial College London	UK					X	
Kings College London	UK					X	
Lancaster University	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	X
University of Leicester	UK			X		X	
University of Liverpool	UK					X	
University of Manchester	UK					X	
University of Nottingham	UK			C		X	
University of Oxford	UK				X		
University of Sheffield	UK					X	
University of Southampton	UK					X	X
University of Surrey	UK					X	X
University of Teesside	UK					X	
University of York	UK			X		X	
Hanoi University of Technology	VN					C	

Viet Nam National University	VN			X			

M minor
C concentration

Appendix E:

Text Books Addressing Nanoscale Science, Engineering and Technology		
An Introduction to Nanotechnology	Poole	2003
Introduction to Nanoscale Science and Technology	DiVentra	2004
Applied Physics of Carbon Nanotubes	Rotkin	2005
Nanotechnology: Basic Calculations for Engineers and Scientists	Theodore	2005
Principles of Nanotechnology	Mansoori	2005
Block Copolymers in Nanoscience	Lazzari	2006
Nanophysics and Nanotechnology: An Introduction to Modern Concepts in Nanoscience	Wolk	2006
Nanostructures – Fabrication and Analysis	Nejo	2006
Polymer Nanocomposites: Processing, Characterization, and Applic	Koo	2006
Core Concepts in Supramolecular Chemistry and Nanochemistry	Pitcher	2007
Fullerenes: Principles and Applications	Langa	2007
MEMS and Nanotechnology for Kids	Bourne	2007
Nanocharacterization	Hutchison	2007
Nanostructured Soft Matter	Zvelindovsky	2007
Nanotechnology 101	Mongillo	2007
Nanotechnology in Biology and Medicine	Vo-Dinh	2007
Nanotechnology: Understanding Small Systems	Rogers	2007
An Introduction to Nanoscience	Hornyak	2008
An Introduction to Nanosciences and Nanotechnology	Nouailhat	2008
Applied Scanning Probe Methods VIII	Bhushan	2008
Biomimetic Nanoceramics in Clinical Use	Vallet-Regi	2008
Fundamentals in Nanotechnology	Hornyak	2008
Introduction to Nanoelectronics: Science, Nanotechnology, Engineering Applications	Mitin	2008
Nanoscience and Nanotechnology: Environmental and Health Impacts	Grassian	2008
Nanotechnology: Health and Environmental Risks	Shatkin	2008
Nanotherapeutics: Drug Delivery Concepts in Nanoscience	Lamptrecht	2008
Semiconductor Nanostructures	Bimberg	2008
Soft Machines: Nanotechnology and Life	Jones	2008
What is What in the Nanoworld: A Handbook on Nanoscience and Nanotechnology	Borisenko	2008
Nanocomputing: Computational Physics for Nanoscience and Nanotechnology	Hsu	2009
Nanoscale Devices: Fabrication, Functionalization and Accessibility for the Macroscopic World	Cerofolini	2009
Nanoscale Phenomena: Fundamentals and Applications	Hahn	2009
Nanoscience and Nanotechnology in Engineering	Varadan	2009
Nanoscience and Technology of Renewable Biomaterials	Lucia	2009
Nanoscience: Colloidal and Interfacial Aspects	Starov	2009
Nanoscience: Nanobiotechnology and Nanobiology	Boisseau	2009
Nanostructured Materials, Vol 1	Wilde	2009
Polymer-Based Nanostructures: Medical Applications	Broz	2009
Single Semiconductor Quantum Dots	Michler	2009
Science at the Nanoscale: An Introductory Textbook	Wee	2009
Reference Books		
Springer Handbook of Nanotechnology	Bhushan	2006
Handbook of Nanoscience, Engineering, and Technology	Goddard	2007
Dekker Encyclopedia of Nanoscience and Nanotechnology	Contescu	2008
Oxford Handbook of Nanoscience and Technology	Narlikar	2010

References

[1] The Opportunity Equation: Transforming Mathematics and Science Education for Citizenship and the Global Economy, Carnegie Corporation of New York and Institute for Advanced Study, 2009, www.OpportunityEquation.org .

[2] H.R. 554 www.opencongress.org/bill/111-h554/show
S.1482 www.opencongress.org/bill/111-s1482/show

[3] Grown up Digital, Donald Tapscott, McGraw Hill 2009 ISBN 978-0-07-159863-6

[4] NSF's Cyberinfrastructure Vision for 21st Century Discover, http://www.nsf.gov/pubs/2007/nsf0728/index.jsp

[5] Nanoscale Science and Engineering Education, Sweeney, A.E., and Seal, S., Eds., American Scientific Publishers, ISBN 978-1-58883-085-3, 2008.

[6] Is America Falling Off the Flat Earth, The National Academies, Norman Augustine, Chair, Rising Above the Gathering Storm Committee. ISBN 0-309-11224-9, 2007

[7] A National Action Plan for Addressing the Critical Needs of the U.S. Science, Technology, Engineering, and Mathematics Education System. National Science Board, NSB-07-114, Oct 30 2007. http://www.nsf.gov/nsb/documents/2007/stem_action.pdf

[8] Moving Forward to Improve Engineering Education, National Science Board, Nov 19 2007, NSB-07-122

[9] The Opportunity Equation: Transforming Mathematics and Science Education for Citizenship and the Global Economy, Carnegie Corporation of New York and Institute for Advanced Study, 2009, www.OpportunityEquation.org .

[10] Engineering in K-12 Education: Understanding the Status and Improving the Prospects, Katehi, L., Pearson, G., and Feder, M., eds., National Research Council, ISBN 978-0-309-13778-2 (2009).

[11] National Science Board STEM Education Recommendations for the President-Elect Obama Administration, NSB 09-01 January 11, 2009.

[12] http://www.sciencedebate2008.com/www/index/php?id=65

[13] http://thomas.loc.gov/home/gpoxmlc111/h1709_ih.xml

[14] "Converging Science and Technology at the Nanoscale: Opportunities for Education and Training," Roco, M.C., Nature Biotechnology **21**(10), 1-3 (2003).

[15] Nanotechnology: Societal Implications, Roco, M.C., and Brainbridge, W.S., eds., Springer 2007, ISBN 10 1-4020-4658-8 (HB).

[16] "Assessing the need for nanotechnology education reform in the United States," Foley, E.T., and Hersam, M.C., Nanotechnology Law & Business **3**(4), 467-484 (2006).

[17] "Integrating Nanoscience into the Classroom: Perspectives on Nanoscience Education Projects," Greenberg, A., ACS Nano **3**(4), 762-769 (2009).

[18] Woodrow Wilson International Center for Scholars: Project on Emerging Nanotechnologies. www.nanotechproject.org/inventories/consumer/

[19] Nanotechnology: the Social and Ethical Issues. Ronald Sandler. Woodrow Wilson International Center for Scholars, Project on Emerging Nanotechnologies, PEN 16, January 2009.

[20] "An International Perspective on Government Nanotechnology Funding in 2005," Roco, M.C., Journal of Nanoparticle Research **7**(6), 707-712 (2005).

[21] www.nano.edu.tw/en_US/

[22] www.nclt.us/workshop/ws-faculty-aug06.shtml

[23] www.nclt.us/workshop/ws-faculty-mar08.shtml

[24] www.nclt.us/gnseews2008/

[25] A Matter of Size: Triennial Review of the National Nanotechnology Initiative, ISBN: 0-309-66138-2, 2006.

[26] Abicht, L; Freikamp, H.; Schumann, U. Identification of skill needs in nanotechnology. Luxembourg: EUR-OP, 2006 (Cadefop Panorama series, 120).

[27] "Nano-education from a European Perspective," Malsch I., Journal of Physics: Conference Series **100**, 032001 (2008).

[28] 06 July 2009, The Swiss Federal Institute for Vocational Education (SFIVET) and the Innovation Society just launched the Nano-cube project for vocational training in nanotechnology at secondary and tertiary levels. The project will be implemented over the next 2.5 years. It is modularly structured with a web-

based educational platform, practice oriented modules for education and advanced training, and quality assurance.
http://www.nanoforum.org/nf06~modul~showmore~folder~99999~scc~news~scid~3910~.html?action=longview

[29] Lee, C-K, Wu, T-T, Liu, P_L, and Hsu, S., Establishing a K-12 Nanotechnology Program for Teacher Professional Development, IEEE Transactions on Education **49**(1), 141-146 (2006).

[30] "The Next Generation of Citizens: Attitudes to Science Among Youngsters", Sjoberg S., and Schreiner C., in The Culture of Science – how does the Public relate to Science across the Globe?, Bauer, M. and Shukla, R., (Eds) Routledge (New York, 2010); http://www.ils.uio.no/english/rose/

[31] http://www.project2061.org/

[32] http://www.nsta.org/publications/nses.aspx

[33] http://www.achieve.org/

[34] http://www.ccsso.org/federal_programs/13286.cfm

[35] http://www.nnin.org/nnin_ret_programs.html
http://www.nnin.org/nnin_teacher_workshops.html

[36] "Guest Comment: Is physics difficult?," Ford, K.W., Am J. Phys. **57**(10), 871-872 (1989).

[37] http://en.wikipedia.org/wiki/Physics_First

[38] Stevens, S., Sutherland, L., and Krajcik, J.S., (in press). The Big Ideas of Nanoscale Science and Engineering. Arlington, VA: National Science Teachers Association Press.

[39] "The Development of an Empirically Derived Multi-Dimensional Learning Progression for Atomic Structure and Inter-Atomic Interactions," Stevens, S. Y., Delgado, C. and Krajcik, J.S., *Journal of Research in Science Teaching*, (in press).

[40] www.nano.unh.edu/images/conference5-4-8-09.pdf

[41] Learning Science in Informal Environments: People, Places, and Pursuits, Bell, P, Lewenstein, B., Shouse, A.W., and Feder, M.A., eds., ISBN 978-0-309-11955-9, 2009.

[42] Informing Decisions in a Changing Climate, NAS ISBN-10: 0-309-13737-3
http://www.nap.edu/catalog.php?record_id=12626

[43] But note that one discussant also suggested that we need to err on the side of caution given the uncertainty about how perturbations in structure or composition of nanomaterials affect their safety profile.

[44] NSF 09-553, Informal Science Education

[45] For example, Professor Mike Dennin at UC Irvine has used student's interest in comic book characters as the basis for a popular freshman-level "Science of Superheroes" course.

[46] Local event organizers can try to build consensus for activities that rely on regional strengths—taking advantage of the local spikes that Richard Florida and others say may actually dominate Thomas Friedman's flat world.

[47] Texas Nanotechnology Workforce Development Initiative, http://nanotechworkforce.com/resources/workforce.php

[48] Center for Nanotechnology Education and Utilization, http://www.cneu.psu.edu/abHomeOf.html

[49] http://www.nanoink.net/Instrumentation.htm#NanoProfessor

[50] Nanotech Toolkit, AM Thayer, ACS C&E News, August 10, page 14 (2009).

[51] "Constructing Shareable Learning Materials in Bioengineering Education." Brophy, S. P., IEEE Engineering in Medicine & Biology Magazine. **22**(4), 66-70 (2003).

[52] http://www.adlnet.gov/Technologies/scorm/default.aspx

[53] http://www.imsglobal.org/specifications.html

[54] "The nanoHUB: A Science Gateway for the Computational Nanotechnology Community," Goasguen, S., Madhavan, K., McLennan, M, Lundstrom, M.S., and Klimeck, G., www.teragrid.org/programs/sci_gateways/docs/nanoHUB-GGF-SGW.pdf

[55] "Glow Lights Up Scottish Classrooms," Clery, D., Science **323**, 60-61 (2009).

[56] "Korea Tries to Level the Field," Normile, D., Science **323**, 62-63 (2009).