Development and Implementation of a Comprehensive Nano-education Program

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Abstract - The National Science Foundation (NSF) estimates that by 2015 there will be a need for two million workers worldwide in the fields of nanoscience and nanotechnology. To meet the need of an educated populace that can work in the field as well as support its safe development, it is critical that universities, governments, and industries support nano-education efforts. The National Nanotechnology Infrastructure Network (NNIN) is a NSF-funded program of thirteen universities which assist nanoscience researchers by providing state-of-the-art nanotechnology facilities, support, and resources. In addition to researcher support, the NNIN has a large and integrated education and outreach program. Its focus is to develop a workforce ready for the demands of nanotechnology as well as develop a nano-literate public. Our programs span the K-gray continuum by offering a variety of programs which include: summer camps for middle and high school students; on-site and off-site school visits which include laboratory tours, hands-on activities, demonstrations, and presentations; summer research experiences for undergraduates and teachers; workshops for teachers; K-12 instructional materials; community college programs; symposia at national meetings; workshops for faculty, industry, and government personnel; and a web site for accessing information on our resources and programs.

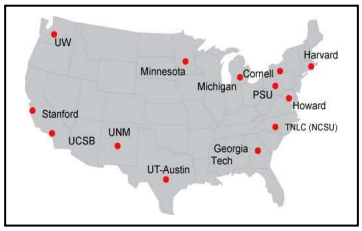
Index Terms – Nanoscale science and engineering, nanotechnology, nanotechnology education, workforce development

Introduction - Nanotechnology is viewed by many as the next great technical revolution. Evidence for this belief in the U.S. is in the establishment of the National Nanotechnology Initiative (NNI) and the nearly tripling of its budget since its inception in 2001 from $464 million to nearly $1.4 billion in 2007. A substantial portion of the funding increase to several U.S. agencies has been due to the *American Competitiveness Initiative* authorized by the U.S. Congress.

The National Science Foundation (NSF) estimates that by the year 2015 there will be a need for two million workers worldwide in the fields of nanoscience and nanotechnology [1]. An additional 5 million workers will be needed in support areas. Of these two million workers, it is estimated that the workforce needs will be 0.8-0.9 million for the U.S., 0.5-0.6 million for Japan, and 0.3-0.4 million for the E.U. The need for a skilled workforce to meet this challenge has been highlighted in two recent reports: *Innovate America* [2] and *Engineering Research and America's Future: Meeting the Challenges of a Global Economy* [3] which stress the critical importance of technological innovation in U.S. competitiveness, productivity, and economic growth. Nanotechnology is seen as one of these technologically important fields and as noted in *Innovate America,* "nanotechnology could impact the production of virtually every human-made object."

The economic importance of nanoscience and nanotechnology has not yet been fully realized. However, it is rapidly expanding with more than 40 countries having national activities in nanoscale science and engineering. To meet the need of an educated populace that can work in nanotechnology as well as support its safe development, it is critical that universities/colleges, governments, and industries support nano-education efforts.

The National Nanotechnology Infrastructure Network – Education and Outreach Programs



The National Nanotechnology Infrastructure Network (NNIN) is a U.S. NSF-funded program which supports nanoscience researchers by providing state-of-the-art nanotechnology facilities, support, and resources. The NNIN is a consortium of thirteen universities across the United States (http://www.nnin.org). In addition to researcher support, the NNIN has a large and integrated education and outreach program. The focus of our program is to develop a workforce ready for the demands of the rapidly developing field of nanotechnology as well as develop a nano-literate public. This outreach must begin in the elementary grades and expand up to professional adults in need of retraining and skill enhancement. The NNIN has termed this need as K-gray education and is implementing programs to reach all facets of our society in order to educate them. An important component of this outreach is to excite secondary and post-secondary students to enter the fields of science, technology, and engineering and in particular nanotechnology.

The NNIN has four overarching goals which drives its education efforts: 1) Expose young people to advanced

and exciting research in nanotechnology and motivate them to educate themselves for careers in the sciences or engineering; 2) Train teachers about the discipline of experimental sciences, provide additional teaching tools, and enhance their enthusiasm for having students pursue careers in science; 3) Create and distribute educational materials for children, college students, technical professionals, teachers and the general population; 4) Focus these efforts on population segments having disproportionately low employment and education in sciences, including women, disadvantaged minorities, and the economically disadvantaged.

From these overarching goals, specific programmatic objectives have been established that have an impact at the national or local scale. These include:

- develop and distribute activities to encourage K-12 students to enter science and engineering fields;
- develop resources to inform the public about nanotechnology;
- develop activities and information for undergraduates; develop programs to ensure inclusion of underrepresented groups;
- develop programs for workforce development; and
- develop programs and resources for K-12 teachers.

NNIN has both local and national educational programs. Some local activities have been sufficiently strong or had sufficiently broad support among sites that they have expanded to national or network-wide activities that take advantage of synergy between sites and the increased visibility possible with a networked program. Examples of local programs are community days, tours, open house while those with a national focus include Research Experience for Undergraduates/Teachers, technical workshops, and national conferences. This paper provides an overview of who we are reaching, how we are reaching them, and what impact our endeavors are having on the participants.

The NNIN education programs reach a wide variety of individuals which include: K-12 students and teachers, undergraduate students, graduate students, post-docs, faculty, other professionals, and the general public. Our efforts have reached a growing number of individuals with the program **directly** reaching approximately 500 in the first year of the program (2003) to reaching over 10,000 in 2006.

Reaching K-12 Students – Seven of the NNIN sites provide summer "nanocamps" for high school and middle school students. These camps have one, three, and five day formats and offer hands-on activities for the participants. During 2006, we reached over 500 students. For example, Pennsylvania State University and University of California Santa Barbara offer camps where the participants learn about basic nanofabrication processes and applications, and have the opportunity to observe or actually use these nanofabrication processes in the cleanroom. Camps at other sites offer students the opportunity to do hands-on activities either developed by the NNIN or other nano-education centers, visit cleanroom facilities, visit research labs, and explore education and career opportunities. Pre and post survey results indicate that there is an increased understanding of nanoscale science and engineering and the opportunities in education and careers. Some survey results from participants at a 2006 high school camp at Georgia Institute of Technology are shown below (scale of 1-5 with 5 the highest):

- The course helped me understand the science behind nanotechnology **3.7**
- The course help me to understand how nanotechnology relates to the real world **4.1**
- The course helped me to understand how nanoscience applies to my life **4.0**
- The course helped me to understand career opportunities **3.5**
- The course helped me consider the possible societal and ethical issues of nanotechnology **4.0**
- The course encouraged me to want to learn more about nanotechnology **3.5**
- Familiarity with nanotechnology prior to camp **2.4**
- Familiarity with nanotechnology post-camp **4.0**

Because these camps represent informal science education efforts it is difficult to determine the long-term impact of the events on student learning and education/career choices. However, the camp survey results indicate a positive impact on participant awareness and comprehension of nanoscale science and engineering.

The NNIN is currently developing camp models which will have formats of 1-5 days camps with a comprehensive list of resources that can be used to provide a rewarding experience for participants. It is our goal that these models will allow other universities, science centers, and community programs to provide such fun experiences without having to search for materials and formats.

All of the NNIN sites provide on-site and off-site activities for K-12 students through a variety of venues. At Georgia Institute of Technology, a program called *NanoInfusion* is offered. School groups participate in a series of hands-on activities/demonstrations, tour the cleanroom, visit research labs, and work with graduate student mentors during their visit. A full description of this program was recently presented for Northwestern University's National Center for Learning and Teaching in Nanoscale Science and Engineering's monthly webcast seminar series [4] and can be viewed along with other nano-education presentations. To provide engaging activities for visiting students we use units developed by the NNIN [5,6], as well as those published such as *NanoSense* [7] and *NanoScale Science: Exploring the World at the Smallest of Scales* [8], among others. Off site programs occur at

schools or community centers where presentations and demonstrations concerning the nano-world are provided. Typically, the visits revolve around career days, family science nights, or school festivals.

Reaching K-12 Teachers – The NNIN has three primary approaches for reaching K-12 teachers which in turn reaches their students. We develop instructional materials that can be used in classrooms, typically for grades 5-12. These are posted on the NNIN education portal [5] for downloading. In addition, we provide a teacher resource guide [5, 6] which directs teachers to other instructional materials developed by universities, research centers, industry, etc. This resource guide is updated regularly and also through quarterly teacher newsletters. Several sites are active in providing and developing teacher workshops on nanotechnology. These workshops are offered both locally and nationally and range from half day to three day programs. The intent of these activities is to give teachers the background and tools necessary to increase student awareness and interest in science and technology in general and nanotechnology in particular. Pennsylvania State University provides two different workshops: *Hands-On Nanofabrication Workshop for Educators* which introduces nanotechnology and the nanofabricaton process and *Nanotechnology in the Secondary Classroom* where teachers create and test instructional units to use in their classrooms. The University of Michigan has developed a workshop for educators and administrators while UC Santa Barbara offers a "chip" camp for educators. All of these programs indicate that teachers develop an understanding of nano-concepts and how nanoscale science and engineering can be included in the science classroom. The next step in our program's development is to determine how these teachers are incorporating the information that have learned into their classrooms and what impact this has on student learning.

The NNIN has also provided workshops at national and local meetings using the materials developed by the sites. During the 2006 National Science Teachers Association Annual Meeting (NSTA) we conducted a survey of workshop participants (n=46) to assist us in developing resources and programs for teachers. The results were similar to an informal survey we conducted at the 2005 meeting of visitors to our exhibit and include:

- 65% had little to no knowledge of nanotechnology
- 49% learned about nanotechnology through the news/media
- 46% prefer education materials that were short (1 class period) while 25% indicated they wanted 2-3 week long units tied to required science concepts
- 30% wanted on-line units to implement in the classroom and 30% indicated they wanted workshops before using these materials in the classroom
- 96% were interested in remote access to tools and cleanrooms

Teachers, as with the general public [9], have very little knowledge about nanotechnology and thus need professional development to convey correct information about the field to their students. Our analyses indicate that the students are driving the interest in the field by asking teachers about nanotechnology. Survey results from teacher workshops indicate that teachers develop some understanding of how nanotechnology can fit into the science classroom but that additional training and support is required to ensure effective implementation of units into classes.

Our results also indicate that teachers are concerned that "nano" is one more topic to be taught in an overly crowded curriculum. The NNIN philosophy has been to demonstrate to teachers how nanoscale science is based on currently taught concepts and our units are tied to science concepts typically taught such as polarity, hydrophobic-hydrophilic properties, phase transformations, chemical reactions, forces, among others. All of our instructional units are tied to the National Science Education Standards to demonstrate how the materials fit into the K-12 science content standards. The next step in our program's development is to evaluate the use of nano-instructional units in the classrooms of teachers who have completed our workshops. We have just developed a field testing evaluation instrument which will allow teachers to provide feedback to the NNIN on units we have developed. This instrument is posted on our website and distributed at all teacher workshops.

The NNIN also offers a Research Experience for Teachers (RET) program funded by the NSF during which teachers conduct research for six weeks at one of the NNIN sites. In 2006, 19 teachers participated at five sites (Georgia Institute of Technology, Harvard University, Howard University, Pennsylvania State University, and University of California Santa Barbara). During the summer, the teachers also begin to develop instructional units for their classrooms which are refined during the school year through follow-up activities. Our goal is to create a cadre of teachers who will support nanotechnology education in their classroom and schools as well as continue to support our education efforts by participating in NNIN education outreach events. At Georgia Institute of Technology, participants have been active in providing such outreach including workshops at state meetings, summer enrichment workshops for teachers, assisting in summer camps, and assisting with the 2007 RET program. The program culminates with a week at the NSTA annual meeting during which lessons are presented to meeting attendees in a NNIN RET session as well all RETs presenting their lessons to each other during the NNIN RET "share-a-thon." NSTA meeting attendees indicated that they liked the units presented because they had been "developed by teachers for teachers" and thus met the needs of classroom teachers. These units have been or will be posted on our education portal.

Reaching Undergraduates – The NNIN's primary program for undergraduates is our Research Experience of Undergraduates (REU). The NNIN has developed, operated, and managed a highly successful REU Program in Nanotechnology for over ten years (begun under the former National Nanotechnology Users Network; NNUN).

This ten-week summer research program supports approximately 70 students across the network. At least five students participate at each site to provide a critical mass of peers to work and interact with at the site. Participants work with faculty advisors and graduate student mentors to conduct an independent research project. Our program draws participants from a diverse applicant pool, with an emphasis on women and minorities, and by students from non-research (non Ph.D-granting) institutions. We have been committed to providing research opportunities to students who have the most to gain from the NNIN REU experience—67% of the 2005 and 53% of 2006 participants had not participated in a prior summer research experience. The quality of the research projects is very high and often results in presentations at national conferences and publication in refereed journals. During 2006, several of our NNIN interns had their results published in the *Journal of Young Investigators*. Below is the demographic make-up of applicants and participants and their type of home institution for 2005 and 2006 which indicate that women and minorities are well represented in the applicant pool but more importantly at a higher participation rate.

NNIN REU Demographics

	Applicants		Applicant Pool (%)		Participants	
Year	'05	'06	'05	'06	'05	'06
Overall	500	354			81	64
Gender						
Women	148	97	30%	27%	33	28
Men	352	257	70%	73%	48	36
Race/Ethnicity						
Minorities	74	68	15%	19%	19	15
Non-Minorities	426	259	85%	73%	62	45
Institution Type						
Ph.D. Level	343	231	69%	65%	49	39
Master's Level	82	71	16%	20%	28	12
Bacc. Level	63	40	13%	12%	13	11
Assoc. Level	12	12	2%	3%	1	2

NNIN REU Demographics (cont'd.)

	Applicant Success Rate		Participation (%)	
Year	'05	'06	'05	'06
Overall	16%	18%		
Gender				
Women	22%	29%	41%	44%
Men	14%	14%	59%	56%
Race/Ethnicity				
Minorities	26%	22%	23%	23%
Non-Minorities	15%	17%	77%	77%
Institution Type				
Ph.D. Level	14%	17%	60%	61%
Master's Level	21%	17%	21%	19%
Bacc. Level	21%	28%	16%	17%
Assoc. Level	8%	17%	2%	3%

All participants complete an annual evaluation of the program and have consistently rated the program very highly. Below are some 2006 results on a scale from 1-5 (5 is the highest):

- Was the program a positive influence on your educational/career choices? **4.5**
- Did the program offered a substantial research project? **4.5**
- Did the program provide an understanding of the breadth of nanotechnology? **4.2**
- Did the program assist in learning to use advanced equipment and processes in nanotechnology? **4.2**
- Do you plan to share information on your experience with faculty/students at your home institution? **4.6**
- Do you consider participation in this program a positive experience? **4.5**
- Overall rating of the quality of the program? **4.5**

The NNIN REU program culminates with the NNIN REU Convocation which is a "mini" scientific conference of the participants. At the convocation, each student presents his/her research results in oral and poster format. The presentations are also simultaneously webcast so that each site and interested others may view the presentations. All students write a research report which we publish in the *NNIN REU Research Accomplishments* which are also available at our website.

Each year we also contract with an external evaluator to asses the impact of the REU Convocation and provide feedback on the overall program. Each year, the NNIN

REU program receives a highly positive evaluation. The 2006 evaluation concluded the program meets or exceeds its goals and is a highly ambitious programs that runs smoothly despite its size. The convocation was noted in helping student in developing many writing and presentation skills necessary for the modern scientist.

Since its inception in 1997, the NNIN REU program has had over 500 participants. We are now conducting a longitudinal study to determine the educational and career path of our participants who attended the program in the first six years (1997- 2002). We have chosen this time period because participants will have graduated from their home institutions and will have entered or completed additional education and/or entered into the workforce. This is a labor intensive analysis as participants have moved, changed names, and even home addresses are no longer valid due to family moves. However, of the 250 participants we have contacted ~90 with the results in the table. Eighty-nine percent of the respondents indicated that the program significantly or very significantly influenced their career path. We are continuing this study and believe the highly positive results are not only of importance for the NNIN program but also for other undergraduate research programs in general.

Degree/Career	**1997-2001**
Ph.D.	44%
Terminal Master's	32%
Terminal B.S.	10%
J.D.	5%
M.D.	7%
Science Career	92%

Cornell University has developed with Clarkson University a one-week laboratory course for graduate students enrolled in a nanotechnology course at Clarkson. The workshop provides the students with a laboratory component not available at their home institution due to the lack of a cleanroom facility. The students fabricate a functioning silicon nitride cantilever which can be measured at the home institution thereby extending the laboratory experience. Of the 22 students who have participated in the workshop, 19 reported that the workshop will have an impact on the choice of their future career, 16 rated the workshop and the hands-on laboratory sessions extremely valuable and the remaining six students rated the workshop as valuable to them. This program can be a supplement to nanofabrication courses taught at any university that lacks access to cleanroom facilities.

Technical Workshops and Training – To assist adult professionals in mastering new skills and methods of nanoscale science and engineering, the NNIN offers numerous technical workshops. These are attended by undergraduates, graduate students, faculty, post-docs, and government and industry personnel. The workshops are one to three days in duration and cover a variety of topics such as BioMEMs and Microfluidics, Imprint Lithography, Fabrication and Characterization, and Building Nanostructures – Bit by Bit (computation), among other topics. The technical workshops are designed to introduce the novice to nanofabrication techniques to more advanced workshops for the experienced nano-researcher. Participants are from the U.S. and abroad. These are advertised on the NNIN web site and are open to anyone who is interested. In addition, we provide online training videos which allow our more than 4,300 annual users to prepare in advance for use of equipment at our facilities. This, along with staff training and support, allows new users to quickly and efficiently begin and complete research projects.

In addition to workshops for nano-researchers, the NNIN offers technical workshops on additional topics. In June 2006, Cornell University offered *The Importance of Nanotechnology for Science and Social Policy* as part of our social and ethical programs. In a continuing series to educate the media, Cornell University also offered *Nanotechnology Workshop for Journalists*.

Evaluation – As with any multi-pronged educational program, the type and quality of evaluation varies by the program component. As noted above, we conduct annual surveys of our REU participants which have shown highly positive results. We also survey the RET participants with similar positive results:

- RET program was responsive to professional development needs **3.9/4.0**
- The program provided opportunities to engage in inquiry/research **3.8/4.0**
- As a professional development program, rate NNIN RET **4.6/5.0**

A challenge for any large program such as the NNIN is to keep accurate records of our activities and resources. Such record keeping is important in developing an understanding of the scope of the programs and their impact on participants. Because of the wide variety of activities across the sites, it is important to know the types of activities, the duration, and the impact in terms of numbers served, etc., both at individual sites and across the network. To achieve this, we developed in 2006 the Education Events Manager which is an online tracking system for entering and tracking educational activities. This allows the NNIN management team to review events in real time, to comment, and to suggest synergies with the network. It also allows the assemblage of reports on type of events, content, audience, and participant demographics. The next step in the development of this management system will be the inclusion of survey results from camps, workshops, and field testing of instructional units.

With a defined program such as a workshop or summer camp, we can obtain evaluation of the program and some possible impact on the participants' learning. However, for programs such as visiting school groups and the public, evaluation of the impact of such programs becomes problematic. We can determine if a group "enjoyed" an event or that they "learned something" from attending.

But often we are unable to determine long term impact of such programs. We continue to strive to offer exciting and interesting programs with the hope that students and the public will begin to develop an understanding of what nanotechnology is and how it will influence our future. As more teachers implement instructional units in the classroom, we will be able to evaluate the learning of their students with evaluation instruments under development.

Conclusion – Nano-education is a new and rapidly growing field. The U.S. is investing over a billion dollars annually to ensure that the U.S. maintains a competitive economic edge. The NNIN provides a wide array of programs with the purpose of educating young children through adult professionals concerning nanotechnology. The network has just completed its third year of operation and has developed numerous programs at all levels of education. Our initial results indicate that these programs are having a positive impact on K-12 students and teachers, undergraduates, and other professionals. Our future direction is to continue to offer support for teachers to implement nanotechnology lessons in their classrooms so that we continue to excite children about science and engineering in hope that we have a nano-ready workforce and a nano-literate population. Now that the NNIN education and outreach programs have reached the stage where we have moved from program develop to implementation of education activities and programs, we will be able to obtain information on the impact of these programs on participant learning. We hope that our evaluation efforts will assist in developing an understanding of how people learn about nanotechnology and if they develop an positive belief in its future development.

References

[1] Roco, M.C., *Converging science and technology at the nanoscale: opportunities for education and training*, 2003, Nature Biotechnology, 21 (3) pp.1-3.

[2] Principals Committee, *Innovate America: Thriving in a World of Challenge and Change*, 2004, Council on Competitiveness, pp. 98.

[3] Committee to Assess the Capacity of the U.S. Engineering Research Enterprise, *Engineering Research and America's Future: Meeting the Challenges of a Global Economy*, 2005, National Academy of Engineering, pp 50.

[4] Palma, D., K-*12 Nanotechnology Education Outreach for Workforce Development: The Georgia Institute of Technology Model*, 12/2006, Available: http://www.nclt.us/ conferencing_archive2005.htm

[5] NNIN education portal, Available: http://education.nnin.org

[6] Microelectronics Research Center Education Site, Available: http://www.mirc.gatech. edu/education.php

[7] *Nanosense – the basic science behind nanoscience*, 2005, Available: http://nanosense.org

[8] Jones, G.M., Falvo, M.R., Taylor, A.R., & Broadwell, B.P., *NanoScale Science: Exploring the World at the Smallest of Scales*, 2007, NSTA Press, pp. 221

[9] Macoubrie, J. *Informed Public Perception of Nanotechnology and Trust in Government*, 2005, Woodrow Wilson Center for Scholars, pp.31.

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