Creating Nanotechnicians for the 21st Century Workplace

Michael Burke[1], Kristi Jean[1], Cheryl Brown[2], Rick Barrett[1], and Carrie Leopold[1]

[1] North Dakota State College of Science, Department of Applied Science and Technologies, 1305 19th Ave North, Fargo, ND, 58102, USA
[2] Department of Mathematics and Science, 800 N 6th Street, Wahpeton, ND 58076

Abstract. The North Dakota State College of Science (NDSCS) Nanoscience Technology Training Program was designed and implemented to meet the growing demand for technicians skilled in nanofabrication, surface analysis and production of various micro and nano-scale products. The program emphasizes hands-on training and utilizes a state-of–the–art Applied Science and Advanced Manufacturing Training Laboratory to develop the KSA's (knowledge, skills, attitudes) needed by industry. Two-year Associate in Applied Science degree, diploma and certificate tracks are offered in four industry focus areas; nanotechnology, microelectronics technology, bio-fuels technology and biotechnology. Students learn to work in multidisciplinary teams on design, prototyping, analysis and manufacturing processes of products. The program also hosts an extensive hands-on outreach program which interacted with over 8000 secondary school science students and 500 teachers in the first 12 months of operation.

Keywords: nanotechnician training, two-year college program, secondary school outreach, training laboratory.

1 Potential for Workforce Shortages in the Near Future

Estimates published in 2005 by the US National Nanotechnology Infrastructure Network (NNIN) regarding the need for a highly skilled and nano-savvy workforce, identify that meeting the workforce needs of the future represents a major challenge to the industry. Approximately two million nanotechnologists will be needed to meet the growing expansion of industries utilizing nanotechnologies in their manufacturing processes by the year 2015. An NNIN study predicts that 0.8-0.9 million jobs will be created in the USA; 0.5-0.6 million in Japan; 0.3-0.4 million in Europe; 0.2 million in Asia Pacific (not including Japan); and 0.1 million in all other areas combined [1], [2].

The breadth of industries affected by advances in nanotechnology is very diverse due to the ubiquitous and distributed nature of nanotechnology and its applications. To date, current applications of nanotechnology have been seen in electronics/semiconductor industry, materials science and coatings, auto and aerospace industry, sports equipment manufacturing, pharmaceutical industry, energy production,

A. Schmid et al. (Eds.): Nano-Net 2009, LNICST 20, pp. 116–127, 2009.

biotechnology and bioscience fields, medicine, optoelectronics, environmental monitoring and control, food science, forensics, national security/defense, as well as others [3].

2 Problems Associated with the Current Educational Model

Nanoscience is a disseminated, multidisciplinary field with broad reaching and diverse impacts. A wide potential of career options exist for current and future nanotechnologists as a result. Training programs designed to educate and develop the necessary skills sets to meet a single industry focus are too limiting and result in an inflexible workforce. A nanotechnology workforce that is science-grounded and skill-based is needed to ensure a flexible workforce. A generalist approach to nanotechnician training is required. Which instills multidisciplinary KSA's that easily cross disciplines. The very nature of the nanoscience field demands a broad educational foundation in physics, biology, chemistry, mathematics, process flow and control, quality assurance and control as well as societal and environmental issues (see Table 1) [2], [4].

Table 1. Core Science Discipline Justification

Discipline	Justification
Physics	Wave functions, quantum mechanics and tunneling, intra and intermolecular forces of attraction/repulsion
Biology	Molecular self-assembly, increasing trend towards bio-mimicry, increasing bio-medical applications and uses.
Chemistry	Atomic structure, electron orbitals, functionalization of molecules, molecular self –assembly, molecular interactions
Ethics and Social Impacts	Environmental and societal impacts of nanotechnology as they become more pervasive in our world (single and multi-walled carbon nanotubes are listed as "same as graphite" in the MSDS).

The current nature of most of the US post-secondary education systems is one which delays any significant hands-on experiences with equipment/ instrumentation and the unified themes of the science disciplines to the fourth year of a Bachelors program or graduate school. Additionally, the US education system continues for the most part, falls short in its attempts to teach a unified approach to the Science, Technology, Engineering and Mathematics (STEM) disciplines. Secondary school science disciplines are still taught as separate, compartmentalized subjects with little or no time paid to the unifying and interdisciplinary aspects of the science [2], [4].

In order to better meet the workforce needs of the emerging nanotechnology fields a paradigm shift in educational methodology is required. An inversion of certain aspects of the educational pyramid of learning is needed [2]. Presenting more unified concepts of the nature of matter, its properties and biological systems earlier in the educational experience accompanied by significant laboratory skill development and guided investigation using as much equipment and instrumentation as possible. The science discipline has been since its infancy, a dynamic and hands-on activity of exploration and learning which gets lost beginning in elementary school. Expecting students to reach the necessary levels of retention and understanding by simply reading or listening to a lecture on theory is unrealistic and has been proven ineffective. The hands-on aspect of true science investigation offers opportunities for the demonstration, learning and reinforcement of critical concepts. Essential skill development with guided investigation using instrumentation and equipment as well as a hands-on approach to learning greatly improves critical thinking skills, observational and communication skills and leads to increases in the levels of enthusiasm and appreciation of and for the STEM areas.

3 Our Training Model

In 2005, NDSCS established a Center for Nanoscience Technology Training (CNTT) in Fargo, ND to address the lack of a highly skilled and educated work force from which industry can obtain needed entry level workers. This initiative was in response to the establishment of the Red River Valley Research Corridor (RRVRC) by Senator Byron Dorgan and the rest of the congressional delegation of North Dakota [5]. Since the establishment of the RRVRC, numerous spin-off and start-up companies have been established and other well established companies have migrated into the area due to the expertise available, a favorable tax environment and the excellent work ethic of the residents of this area.

The NDSCS-CNTT approach was to create a program which delivers a strong foundation in the sciences while maximizing hands-on training with industry standard equipment and instrumentation. Our initiative offers education and training opportunities currently in four areas; nanotechnology, micro-electronics technology, bio-fuels technology and biotechnology with a fifth area (micro-manufacturing technology) to be added in the near future. In each of these fours areas, three different credentials are offered: Associates in Applied Science Degree (AAS, 2-year); Diploma (1-year); and Certificate (1 semester). Each AAS program is designed to span five semesters or two calendar years (fall, spring, summer, fall, and spring). The first year of course work is designed to lay the foundations in basic sciences, mathematics and communication. Two introductory-level, three credit courses (*Fundamentals of Nanoscience I and II*) are offered on-line and can either be taken asynchronously or synchronously depending on the needs of the student. The first year of instruction also includes a one semester credit, virtual industry experience which tries to expose students to the very superficial aspects of manufacturing in the nanotechnology arena, clean rooms, testimonials from technicians in industry, introduction to GLP and GMP (Good Laboratory Practices, Good Manufacturing Practices), etc. The design of the first year is such to allow maximum flexibility as to the location of taking first year courses, students can take the general sciences, mathematics and communication courses from any college while accessing our *Fundamentals of Nanoscience I and II* on-line. During the first year, the program also attempts to integrate the basic science concepts into a unifying network, which can be related to nanoscience concepts and applications and to give students a sense of what possibly is to come in their future with regards to workplace environments.

During the third semester of the program (summer, end of year one) the students come to the CNTT-Applied Science and Advanced Manufacturing Training Laboratory (ASAMTL) in Fargo, ND. The summer semester is devoted to a 6 credit *Laboratory Instrumentation* course consisting of six modules which develop the knowledge, skills and attitudes (KSA's) required to operate or work with the following: 1) Bio-separation Methods; 2) Spectroscopy Methods; 3) Cell & Tissue Methods; 4) Electron and Scanning Probe Microscopy Methods; 5) Molecular Biology Methods; 6) Clean Room Protocols. Each of these six modules stress the foundational concepts related to the operation of the equipment, data collection, interpretation and report writing, daily maintenance/repair and sample preparation. By the end of this course it is expected that the students are capable of independently operating the equipment, working in class 10,000 and class 100 environments, sample preparation requirements, and record keeping.

During the final year of the program the students are required to take the following courses which further expand the KSA's of specific nanofabrication and analysis procedures in a variety of areas. Each of theses courses is three semester credits (1credit lecture, ~ 1-2 hours/week; 2 credits lab, ~ 4-6 hours/week). Second year, fall semester courses include: *Nanobiotechnology, Nanomaterials/ Nanocoatings, Thin Films/MEMS Case Study, Semiconductor Fabrication, Industry Shadow/Internship Experience.* The second year, spring semester courses include: *Quality Control and Quality Assurance, Surface and Thin Film Analysis Techniques, and Industry Internship* (see Table 2).

A few examples of hands-on activities associated with specific courses include:

- Nanobiotechnology course-
    - Fabricate simple microfulidic devices using soft lithography to demonstrate flow characteristics and rapid prototyping.
    - Wet fabrication of metallic nanoparticles for use in cell culture ablation experiments.
    - Gold nanoparticle synthesis and control of particle size, optical properties.
- Semiconductor Fabrication course-
    - Fabricate simple resistors using photolithography, analyze surface characteristics, electrical behavior, etc.
    - Fabrication of PMOS circuit photolithography, analyze surface characteristics, electrical behavior, etc.

This strategy of building a curriculum around a fabrication process, equipment suite etc. allows for development of the skill sets as well as a deeper understanding and appreciation of the underlying science associated with the topic. Failures, from the instructors view point, are looked upon very favorably as they offer an excellent learning opportunity for critical thinking and process/procedure review and induce the need for multiple reiterations of the procedure.

Table 2. Program Curricular Content

Course	***Credits (Lec/Lab)***	***Content***
Nanobiotechnology	1 / 2	Designed to explore bottom–up methods of nanofabrication, molecular mimicry, self assembly, nanotechnology developments in following areas: nanodrugs, nanocosmetics and delivery methodologies; prostheses and implants; diagnostics and screening technologies; Q-dots, smart dust, labs-on-a-chip, functionalized CNT's, nanomedicine, toxicity & regulation, tissue engineering; Gene therapy; nanoparticles and nanocapsules; biology as nanoscaled machines; construction of a nanoparticle; environmental issues in nanotech; future of nanotechnology in medicine. Lab focus is on nanoparticle synthesis, Quantum dot synthesis, microfluidics fabrication and characterization, soft lithography.
Nanomaterials/ NanoCoatings	1 / 2	Designed to explore property changes that occur as a result of going from bulk to nano-sized; organic & inorganic thin films & particles; methods of fabrication & characterization; crystalline structure of nanoparticles; thin films; swcnt's & mwcnt's; Fullerenes; sol-gels. Lab focus is on Fabrication and characterization of nanomaterials- wet chem.. synthesis of nanoparticles/ tube furnace fabrication of nanostructures, CVD of various materials.
Thin Film Technology- MEMS Case Study	1 / 2	Designed to cover vacuum technology, vacuum troubleshooting; vacuum deposition, etching & analysis techniques; MEMS design, fabrication, packaging & characterization techniques; Sandia Summit Technology; MEMS failure analysis; MEMS applications; Bio- MEMS; NEMS. Lab focus is on simple cantilever and pressure sensor fabrication and characterization.
Semiconductor Fabrication	1 / 2	Designed to cover semi-conductor design & fabrication methods; photolithography, deposition, etching, cleaning, packaging, electrical characterization; environmental or Ongoing Reliability Testing (ORT); characterization & failure analysis. Lab focus is on design, fabrication & characterization of simple resistors & PMOS devices.
Manufacturing Quality Assurance	1 / 2	Designed to cover Ongoing Reliability Testing (ORT); Accelerated age testing; quality control plans; sampling plans gauge reliability & reproducibility; SPC;SQC; unit cost, yield, incoming raw materials inspection; charting techniques; trouble shooting; documentation. Lab focus is on design, prototyping, set up, operation & analysis associated with functional production line.
Surface and Thin Film Analysis Techniques	1 / 2	Designed to cover theory, application, operational procedures & data acquisition/ interpretation/ reporting of variety of surface analysis techniques; FTIR (transmission, reflectance, attenuated total reflectance modes); microscopy (SEM-EDX, AFM/STM); ellipsometry; profilometry. Lab focus is on surface characterization associated with functional production line.
Shadow Experience	2	4 hrs/week for 14 weeks; rotate thru 3 different industries (biotech, electrical, materials).
Industry Internship	5	20 hrs/week for 14 weeks in industry of choice.

Fig. 1. Nanotechnology student working in class 100 clean room trouble shooting an ion gauge

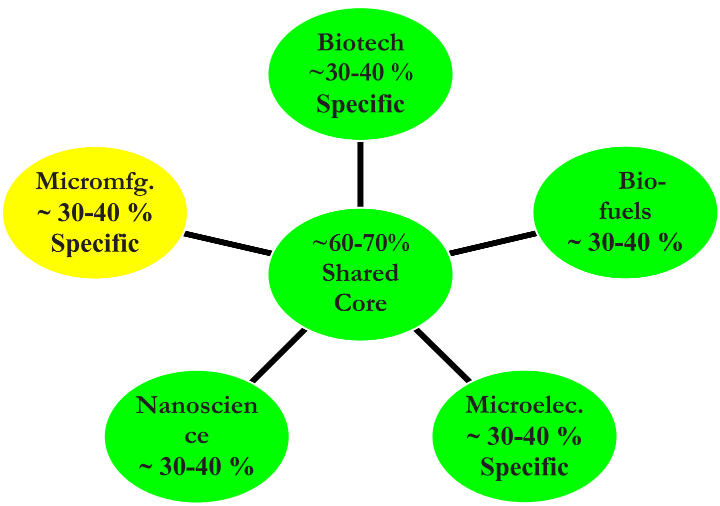

Fig. 2. Curriculum model of CNTT programs currently offered (green) and planned (yellow)

Table 3. Equipment Suite

Industry Area	**Equipment Description**	
Nanotechnology	Clean Room	• Class 10,000 clean room • Particle counts • ESD Training
	Fabrication	• Photolithography Hood • Spin coater • Mask Aligner • Chemical-Vapor Deposition • Tube Furnace Thermal Chemical Vapor Deposition • Reactive Ion Etching (RIE) • Vacuum Training
	Characterization	• SEM-EDX • AFM/STM • Ellipsometer • FTIR Spectrophotometer • Optical light microscopes • Profilometer
Micro-electronics	MEMS	• SandiaNationalLabs Summit V Design Software • Tegam-MEMS Driver/Analysis System • Microfluidic 4 point probe station
	IC Design & Characterization	• Resistor&PMOS fabrication • 4 point probe station • Resistivity Meter • RFIDdesign& charac./testing
Biotechnology	Bioseparations	• GC & GC/MS • HPLC/DAD • FPLC/UV
	Electrophoresis	• Vertical & Horizontal Methods • Western & Immunoblotting
	Molecular Biology	• Nucleic Acid Sequencing • Nucleic Acid Hybridization • Real-Time and standard PCR • Microarrays • Electroporation System
Bio-fuels	Cell Culture	• Laminar Flow Hoods • Bench top Bioreactors/ fermentors • 24L Pilot Plant fermentor • PLC control systems • 50 Gallon Bio-diesel Production System • Photo-bioreactors

4 Core Curriculum

Analysis of skill sets and competencies required by the indicated industry areas, (nanotechnology, biotechnology, bio-fuels technology, microelectronics technology and micromanufacturing technology) indicated the existence of and significant overlap of a core set of KSA's common to all areas. In an effort to create efficiencies of scale, reduce staffing needs, and maximize cross disciplinary use of equipment suites, we designed our program curricula's to share significant amounts of core courses and training modules (see Figure 2).

The core curriculum covers foundational concepts in physics, general chemistry, organic chemistry, biochemistry, cell biology, algebra, statistics, technical writing and ethics/societal impacts. Each specific program area's unique curricula involves on-line introductory level courses available to secondary school students as dual-credit courses and methods/techniques courses (see Table 2).

The first step in the pedagogy of appropriate KSA development involves establishing a good foundation of basic science knowledge and understanding of the common unifying concepts during the first two semesters of study (see Figure 3). Observational, critical thinking and basic laboratory skills are developed in the traditional science lab courses with a strong emphasis on record keeping skills. The second step involves the students transitioning to the CNTT-Applied Science and Advanced Manufacturing Training Laboratory in Fargo, ND, where advanced laboratory skills are developed around specific equipment/instrumentation suites that parallel industry manufacturing process and procedures as closely as possible (see Table 3). The final step in the development of appropriate KSA involves.

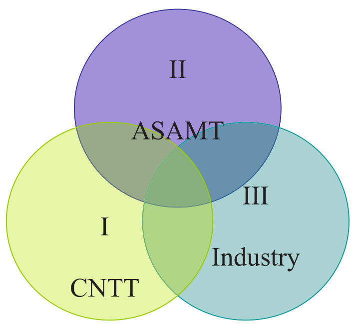

Fig. 3. Ven diagram of the three foundational aspects of program structure. I- CNTT I creates and delivers industry based curriculum. II-ASAMTL, Applied Sciences & Advanced Manufacturing Training Lab develop industry based skill sets/competencies on industry standard equipment. III Industry Internships used to enhance specific skill sets and competencies.

industry internships which are used to develop those specific aspects of manufacturing unique to each companies manufacturing process. At the end of this process, it is hoped that the students will transition directly into a fulltime position at the location where they carried out their internship experience. Feedback form these industry partners are utilized to adjust course content and training to better meet their needs for workforce development.

5 Primary and Secondary School Outreach

A well informed public is essential for society to be able to make informed decisions at a personal level and at a national policy level. A well informed public also allows for the existence of a more technology savvy workforce pool from which potential employees can be obtained. One of the primary aspects of its mission is to promote STEM related issues, education and career opportunities to the primary and secondary school levels as well as the general public. The importance of outreach activities and the incorporation of nanoscience topics into existing science curriculum at all levels cannot be underscored enough [2]. According to the National Science Board (NSB), governing body of the National Science Foundation (NSF), “the US is failing to meet the STEM education needs of U.S. students, with serious implications for our scientific and engineering workforce in the 21st century. Addressing this issue is absolutely essential for the continued economic success of the Nation and its national security. All American citizens must have the basic scientific, technological, and mathematical knowledge to make informed personal choices, to be educated voters, and to thrive in the increasingly technological global market” [6].

The recommendations put forth by the NSB include the following goals for NSF:“(1) Support research on learning and educational practices and the development of instructional materials; (2) develop human capital; and (3) increase public appreciation for and understanding of science, technology, engineering, and mathematics”. As well as “better links between high school and higher education, and creating or strengthening state councils on STEM education that would align and rationalize content at all educational levels” [6].

In response to these recommendations, the CNTT has establish and initiated delivery of an outreach program designed to increase awareness levels of primary and secondary school students and their instructors to critical STEM issues, the career options available in the STEM fields, the education paths required to achieve their career goals and bridges to higher degree programs in the emerging technology fields. This model involves a three-tiered approach to outreach experiences:

- Tier One- involves face to face outreach session with NDSCS/MSCTC staff. Sessions are from 50 minutes up to 3+ hours depending on the needs and capabilities of the middle and high schools. Sessions revolve around hands-on demonstrations of critical concepts in the areas of nanotechnology, biotechnology, alternative energy technologies, and microelectronics coupled with underlying theory discussions of relevant STEM concepts and potential career opportunities.

- Tier Two- involves primary and secondary school teacher training with regards to kits and modules in the above mentioned focus areas to facilitate their ability to incorporate the modules into their curriculum. Instructors once familiar and trained on a specific kit/module will be able to check the kit out from an Outreach Lending Library (an archived assortment of emerging technology kits and modules for use by primary and secondary school instructors) an use it in their classroom. Also part of Tier-two will be on-line, remote access to specific instrumentation for classroom operation. This remote operation of industry standard equipment and instrumentation will be accompanied by more in-depth modules and educational materials to build a deeper understanding of relevant alternative energy and STEM concepts and potential career opportunities. Examples of equipment targeted for remote access module development includes: SEM-EDX, SPM, bio-fermentor for ethanol production, photo-bioreactors for algae propagation, HPLC and GC for bio-fuels analysis.

- Tier Three- involves day trips to our training laboratory for mini-camps on alternative and renewable energy production, nanotechnology, bio-fuels production and analysis, biotechnology methods, etc and/or tours of regional industry facilities.

During the initial year of operation of the outreach program instructors were able to interacted with over 8000 secondary school science students and 500 teachers in the first 12 months of operation. By having the three-tiered structure for the outreach activities, deeper learning and understanding is achieved through reinforcement of critical concepts and potential career opportunities and by allowing hands-on access to equipment and instrumentation. This flexible design also allows for the participating schools to only go as far in the tiered structure as deemed appropriate for the grade level.

Educational outreach materials will be created in a modular format with all materials digitally enhanced through still pictures, videos and voice-over power point. All developed materials are vetted through our industry partners who are members of our Industry Advisory Boards. All materials will be archived on the programs web site (www.NDSCSnano.com) and available 24/7 to high school instructors, students and the general public in order to facilitate asynchronous distance education and awareness building to occur at remote sites. The benefit of the modular format is it imparts a great deal of flexibility for customization of course materials, customized training modules and short courses for incumbent worker training (see Figure 4). Each programmatic course and short courses consists of multiple modules which are packaged for delivery of the lecture content in a variety of formats. Remote access of instrumentation in conjunction with mini-camp based lab experiences are also planned to facilitate educational and awareness building.

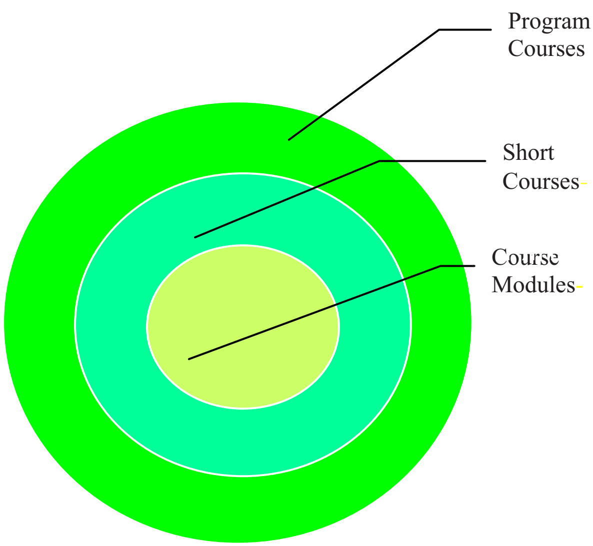

Fig. 4. Individual Course Structure

6 NANO-Link Project

In 2008, NDSCS in a collaborative project with five other two-year institutions (Dakota County Technical College-Minnesota, Harper College-Illinois, Chippewa Valley Technical College-Wisconsin, Minnesota State Community and Technical College-Minnesota, Lansing Community College-Michigan) which offer nanotechnology programs or courses, was awarded a NSF sponsored 4-year, $3 million dollar grant for the establishment of a Midwest Regional Center for Nanotechnology Education, NANO-Link [7]. As part of this group, NDSCS is tasked with the creation of a standardized, best-practices curriculum for training two-year nanotechnologists. Curriculum and training materials from partner colleges, Penn State Nanotechnology Applications and Career Knowledge, NACK [8] and the University of Minnesota Nanofabrication Center [9] will be collated and distilled down to produce a curriculum which will be digitally enhanced, complete with hands-on training modules, assessment tools, etc and will be made available for adoption, review by other institutions. By establishing a standardized educational and training database of nanotechnology materials, outcomes and competencies, NANO-Link hopes to positively impact the availability of a nano-educated and skilled workforce. As industry standards for KSA's for nanotechnologists become more formalized, NANO-Link will modify and update its materials as necessary to align with the recommendations of engineering and manufacturing associations as well as industry leaders.

7 Conclusion

Predictions indicate that as early as next year, 2010, the world will experience a dramatic increase in the need for well trained nanotechnologists [10]. Current numbers of training programs are insufficient at present levels to meet such a potential and future need. Those programs that are in existence vary considerably in the content and KSA's produced in their graduates [11]. If the predictions hold true, the workforce needs and the long-term success of industries utilizing nanotechnology in their manufacturing processes will only be helped by a consistent supply of uniformly well trained and educated employees who are generalists in terms of the nanotechnology background have a broad educational foundation and an interdisciplinary set of skills.

Acknowledgements. We wish to thank the US Department of Education, US Department of Labor, US Small Business Administration, the States of North Dakota and Minnesota and the National Science Foundation for their support.

References

1. National Nanotechnology Infrastructure Network, `http://www.nnin.org/nnin_careers.html`
2. Roco, M.C.: Converging science and technology at the nanoscale: opportunities for education and training. Nature Biotechnology 21(10), 1–3 (2003)
3. Uldrich, J., Newberry, D.: The Next Big Thing is Really Small. Crown Business Publishers (2002)

4. Fonash, S.W.J.: Education and training of the nanotechnology workforce. Journal of Nanoparticle Research 3, 79–82 (2001)
5. Red River Valley Research Corridor, http://www.theresearchcorridor.com/index.html
6. A National Action Plan for Addressing the Critical Needs of the U.S. Science, Technology, Engineering, and Mathematics Education System, National Science Board (2007), http://www.nsf.gov/nsb/documents/2007/stem_action.pdf
7. Midwest Regional Center for Nanotechnology Education, http://www.nano-link.org
8. Nanotechnology Applications and Career Knowledge, http://www.nano4me.org/nack.html
9. University of Minnesota, Nanofabrication Center, http://www.nfc.umn.edu
10. Angela Hullman (EC): The economic development of nanotechnology - An indicators based analysis (November 28, 2006), ftp://ftp.cordis.europa.eu/pub/nanotechnology/docs/nanoarticle_hullmann_nov2006.pdf
11. Wansom, S., et al.: A Rubric for Post-Secondary Degree Programs in Nanoscience and Nanotechnology. International Journal of Engineering Education (2008), http://www.umassk12.net/nanodev/Documents/NCLT/Rubric%20Manuscript-March08.pdf