

McMillan, 2004

NANOSCALE SCIENCE AND ENGINEERING EDUCATION

M.C. Roco

National Science and Foundation and
National Nanotechnology Initiative

- **Long view of nanotechnology**
- **Changing focus and priorities**
- **Educational programs**

November 13, 2008

Benchmark with experts in over 20 countries

“Nanotechnology Science and Technology”

Book Springer, 1999



Nanotechnology

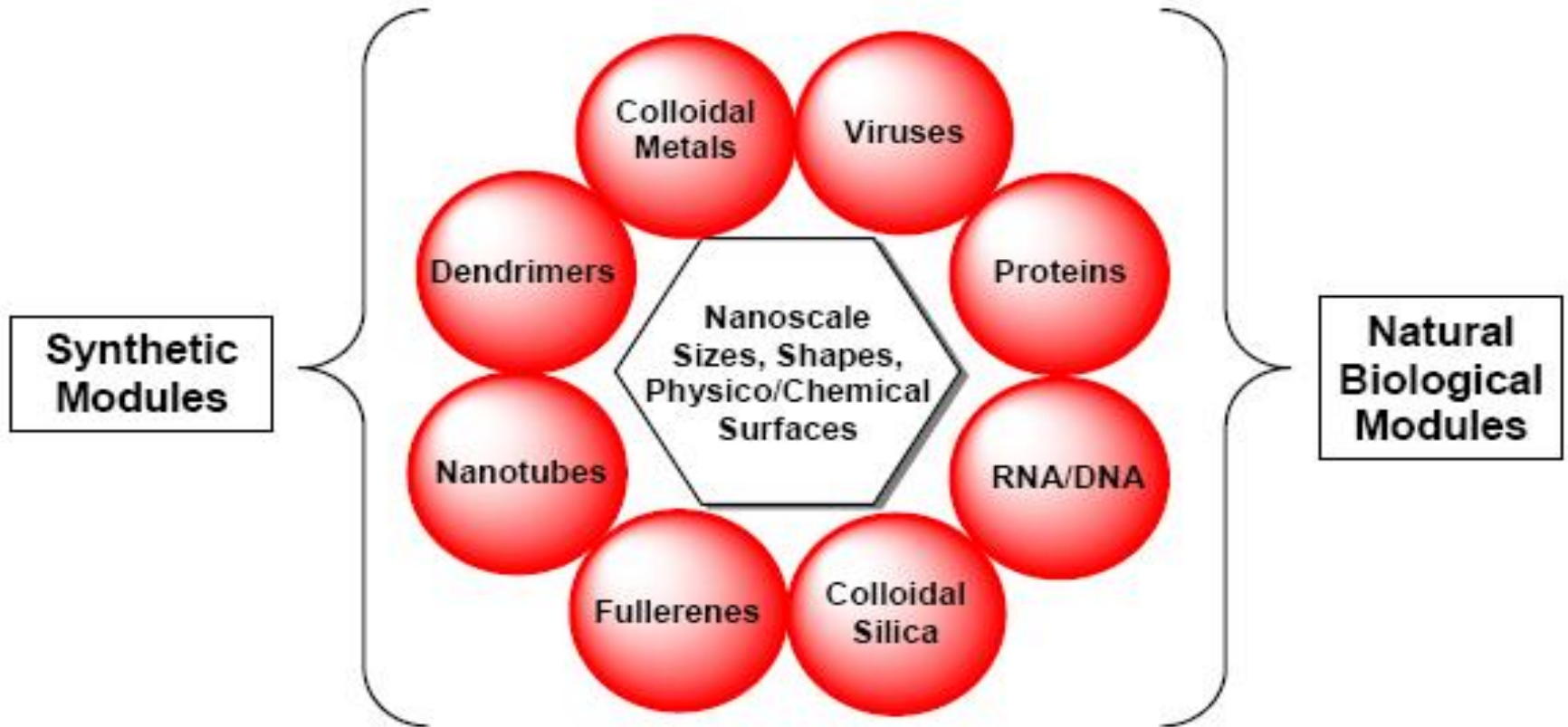
is creation of materials, devices and systems
by ***control and restructuring of matter*** at
dimensions of roughly 1 to 100 nanometers,

- ⇒ at the transition from individual to collective behavior of atoms and molecules
- ⇒ where new phenomena
- ⇒ enable new applications

NANOSCALE IS A NATURAL THRESHOLD OF TRANSITION

from individual to collective behavior of atoms & molecules,

where nanoscale modules are established
dominated by quantum, selfassembling, etc. effects



Nanotechnology Research Directions

Vision for Nanotechnology in the Next Decade

Edited by
M.C. Roco, R.S. Williams and P. Alivisatos

Book, Springer, 2000

“Vision for nanotechnology in the next decade” (2001-2010)

Systematic control of matter on the nanoscale will lead to a revolution in technology and industry

Change the foundations from micro to nano

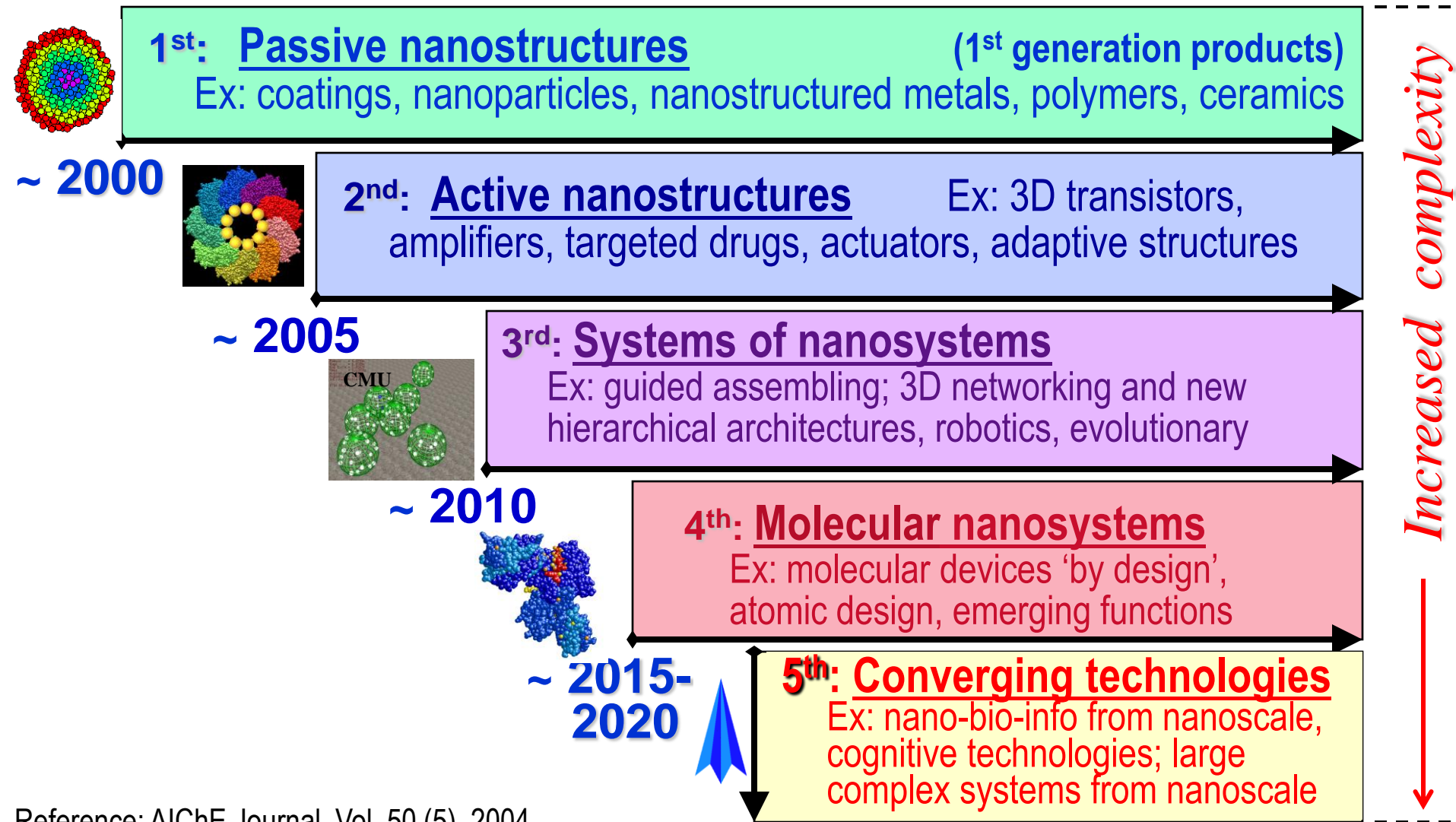
Create a general purpose technology (similar IT)

More important than miniaturization itself:

- **Novel properties/ phenomena/ processes**
- **Unity and generality of principles**
- **Most efficient length scale for manufacturing**
- **Show transition from basic phenomena and components to system applications in 10 areas and 10 scientific targets**

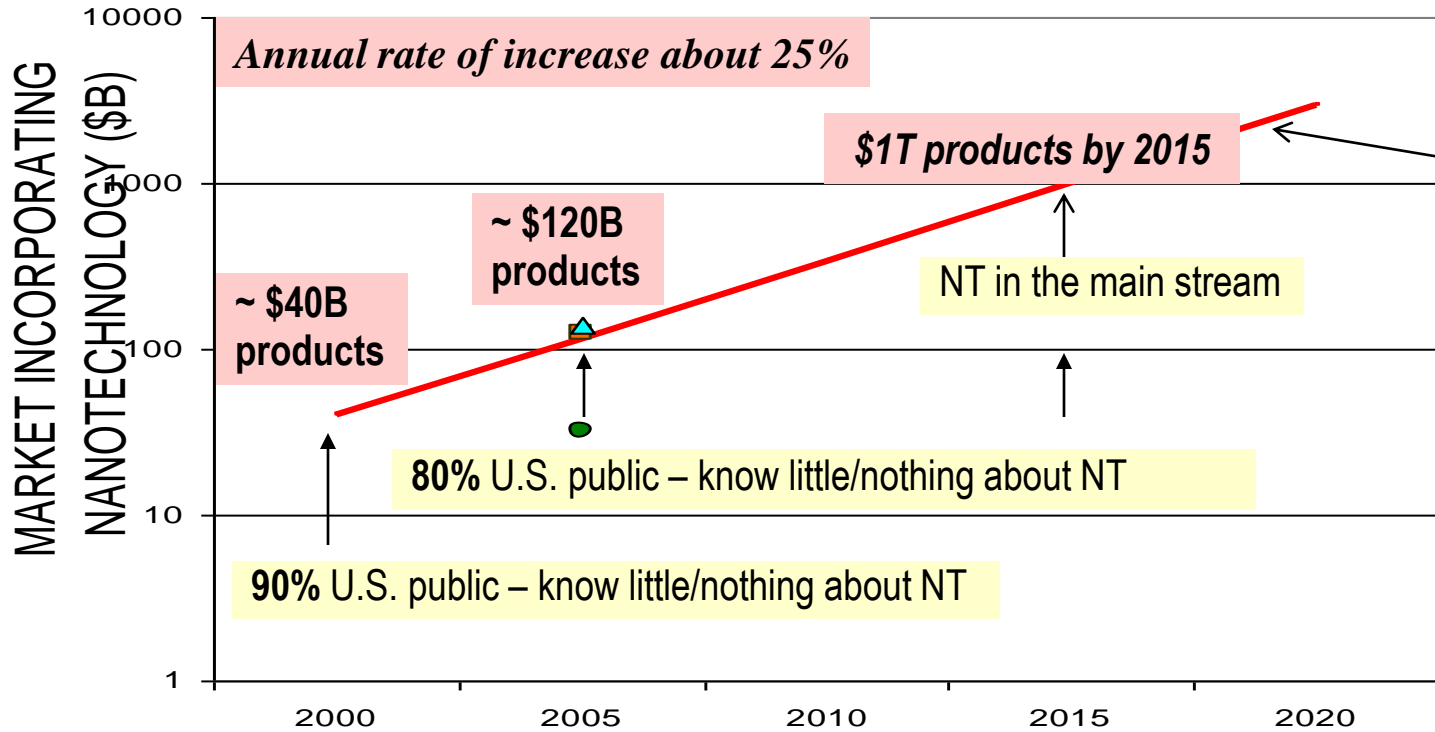
Generations of Products and Productive Processes

Timeline for beginning of industrial prototyping and nanotechnology commercialization (2000-2020)



WORLDWIDE MARKET INCORPORATING NANOTECHNOLOGY (2000-2015)

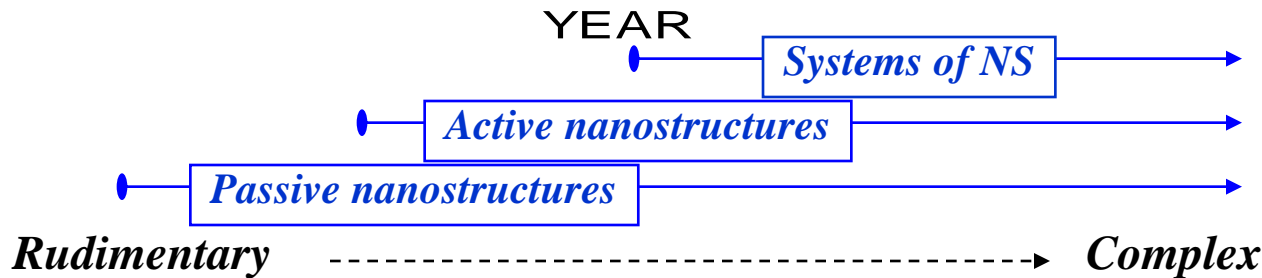
(Estimation made in 2000 after international study in > 20 countries; data standing in 2008)



Final products incorporating nano (2000)

- Total \$B
- Deutsche Bank
- Lux Research
- ▲ Mith. Res. Inst.

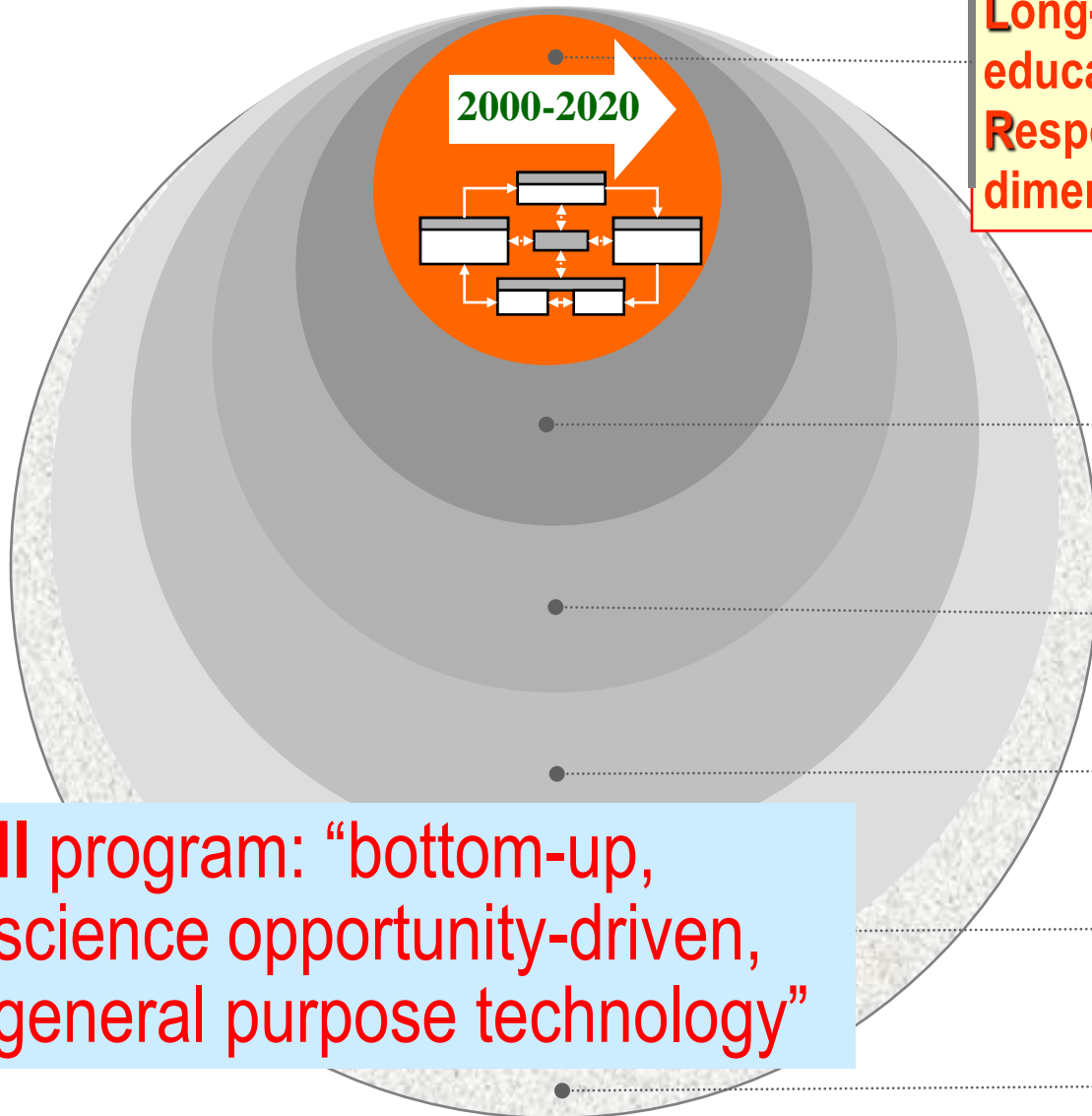
Correlates to surveys by Lux Res. (after 2003)



Reference: MC Roco and WS Bainbridge, Springer, 2001

NANOTECHNOLOGY GOVERNANCE OVERVIEW

Core Governance Process:
Long-term view; Transforming (incl. education, innovation); Inclusive; Responsible (addressing societal dimensions, nano risk governance)



Main Actors:

R&D Organizations
(Academe, industry, gov.)

Implementation Network
(Regulators, business, NGOs, media, public)

Social Climate
(Perceived authority of science, civil involvement)

National Political Context

International Interactions

NNI program: “bottom-up, science opportunity-driven, general purpose technology”

The long-term view drives NNI

2000-2020

- **NNI was designed as a science project** after two years of planning without dedicated funding in 1997-1999:
 - Long-term view (“Nanotechnology Research Directions”)
 - Definitions and international benchmarking (“Nanostructure S&T”)
 - Science and Engineering Priorities and Grand Challenges (“NNI”)
 - Societal implications (“NSF Report”, 2000)
 - Plan for government agencies (“National plans and budgets”)
 - Public engagement brochure (“Reshaping the word”, 1999)
- **Combine four time scales in planning (2001-2005):**
 - Vision - 10-20yrs; Strategic plan - 3-5yrs; Annual budget - 1yr;

NNI Vision (2000 -)

Systematic control matter on the nanoscale will lead to a revolution in technology and industry that benefits society

Two concepts (reference for research education):

- **Changing the foundation of understanding, control, manufacturing and medicine from the macro and micro domains to the nanoscale, where all fundamental material structures, properties and functions can be efficiently established and changed**
- **Create general purpose technology that will affect almost all sectors of the society. It will disrupt – produce structural changes - markets, industrial organizations and business models (ex: 50% of new products in advanced industrial areas will use NS&E by 2015)**

NNI as part of the U.S. Federal R&D ~ 0.25% (2000) to 1% (2005-2008)

U.S. NNI as part of world nanotech investment ~ 1/4 (2005-2008)

Nanotechnology in 2008, still in an earlier formative phase of development

- **Characterization** of nanomodules is using micro parameters and not internal structure
- **Measurements and simulations** of a domain of biological or engineering relevance cannot be done with atomic precision and time resolution of chemical reactions
- **Manufacturing Processes** – empirical, synthesis by trial and error, some control only for one chemical component and in steady state
- **Nanotechnology products** are using only rudimentary nanostructures (dispersions in catalysts, layers in electronics) incorporated in existing products or systems
- **Knowledge for risk governance** – in formation

Expanding nanotechnology domains since 2000

- 2000-2001:** nano expanding in almost all disciplines
- 2002-2003:** industry moves behind nano development
- 2003-2004:** medical field sets up new goals
- 2004-2005:** media, NGOs, public, international organizations get involved
- 2006-2007:** new focus on common Earth resources - water, food, environment, energy, materials
- 2007-2008:** increased relevance to economic-politic-sustainability

Changing research frontier focus

2000-2002

Nanoparticles, nanotubes, quantum dots, coatings

2003-2005

Self- and guided molecular assembling Expands
nanobio technology and medicine

2006-2008

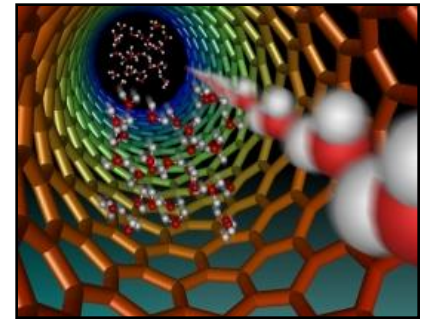
Focus on nanodevices and components of nanosystems

> 2008 from COMPONENT to SYSTEM NANOTECHNOLOGY



FY 2008 NS&E Priorities Research Areas (1)

The long-term objective is building a foundation of fundamental research to understand and restructure matter at nanoscale in all areas of S&E



A. Scientific challenges

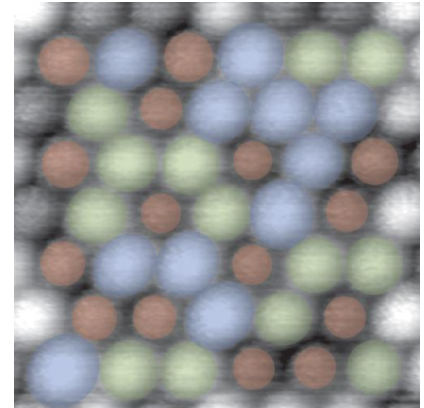
- **New theories at nanoscale**
Ex: transition from quantum to classical physics, collective behavior, for simultaneous phenomena
- **Non-equilibrium processes**
- **Designing new molecules with engineered functions**
- **New architectures for assemblies of nanocomponents**
- **The emergent behavior of nanosystems**



FY 2008 NS&E Priorities Research Areas (2)

B. Development of nanotechnology

- Tools for measuring and restructuring with atomic precision and time resolution of chemical reactions
- Understanding and use of quantum phenomena
- Understanding and use of multi-scale selfassembling
- Nanobiotechnology – sub-cellular and systems approach
- Nanomanufacturing hybrid, on site
- Systems nanotechnology

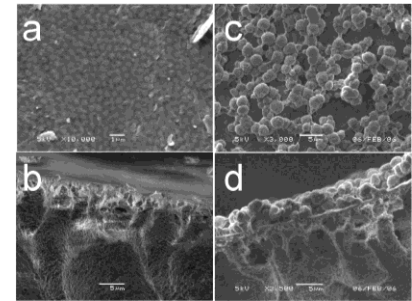




FY 2008 NS&E Priorities Research Areas (3)

C. Integration of nanotechnology in application areas

- Replacing electron charge as the information carrier in electronics
- Energy conversion, water filtration / desalinization using new principles



SEM micrographs of membranes (UIUC)

- Efficient nanomanufacturing and sustainable environment
- Nano-bio interfaces between the human body and manmade devices
- Nano-informatics for better communication and nanosystem design



From FY 2008 NSF priority research areas (4)

Societal dimensions of nanotechnology

- Understanding & sustainable ENV, including research for natural/ incidental/ manufactured nanomaterials

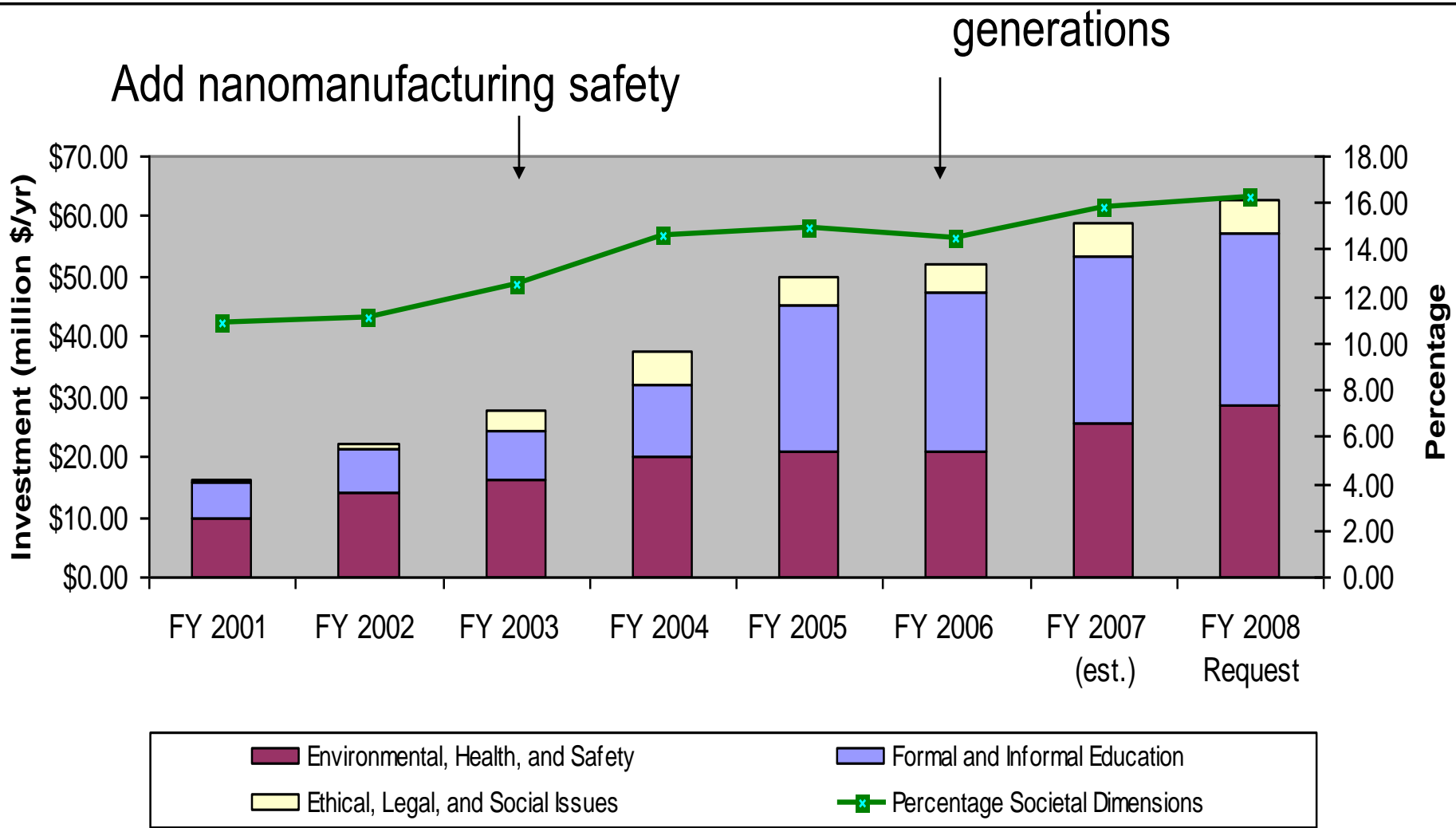
Key nano- EHS priorities at NSF

- New instrumentation for nanoparticle characterization and nanotoxicity
 - Transport phenomena and physico- chem.- biological processes
 - Nano-bio interface: ecological and human health implications
 - Predictive models for interaction of nanomat. with cells/living tissues
 - Separation of nanoparticles from fluids
 - Safety of manufacturing nanoparticles
- Earlier formal (earlier K-12 and public education integrated in K – Gray) and informal education
 - Social issues and public engagement



NSF Investment in Societal Dimensions of NT

Of FY 2008 NNI / NSF request of \$390 M,
 \$63 M or 16.1% is for SI, and \$28.8 M (7.4%) for nano ENV/EHS
 Add focus on future nano generations



Industry-academe-government R&D partnerships – increased relevance

- Increased role of industry in funding nanotechnology R&D ; changes in gov. funding because other oblig.
- Special role of local governments (state, county) for infrastructure, education and small business
- Global partnerships for nanotechnology knowledge, markets and organizations
- **Cross-industry R&D consortia for nano-platforms**

NNI-Industry Consultative Boards for Advancing Nanotech

Key for development of nanotechnology, Reciprocal gains

❑ NNI-Electronic Industry (SRC lead), 10/2003 -

Collaborative activities in key R&D areas with 2 solicitations
5 working groups, Periodical joint actions and reports
NSF-SRC agreement for joint funding; other joint



funding

❑ NNI-Chemical Industry (CCR lead)

Joint road map for nanomaterials R&D; Report in 2004
2 working groups, including on EHS
Use of NNI R&D results, and identify R&D opportunities



❑ NNI – Organizations and business (IRI lead)

Joint activities in R&D technology management
2 working groups (nanotech in industry, EHS)
Exchange information, use NNI results, support new topics



❑ NNI – Forestry and paper products (AF&PA lead, 4/2007), 10/2004- Workshop / roadmap for R&D Exchange information



American Forest & Paper Association

Ten high promising products incorporating nanotechnology in 2008

- Catalysts
- Transistors and memory devices
- Structural applications
- Biomedical applications and cosmetics
- Treat cancer and chronic diseases
- Batteries
- Alternative energy conversion and utilization
- Displays
- Optical lithography
- Environmental applications

Education Challenges in the governance of nanotechnology

TRANSFORMATIVE

Earlier transdisciplinary, global education for NT; “breath and depth”; “T- shape”; “trans-discip.”, “platform” innovation; incl. system complexity

VISIONARY

Reverse pyramid of learning; Virtual reality; Networking; Cognitive technologies (sensors, brain-machine interface, brain to learning, ..)

INCLUSIVE and COLLABORATIVE

For diverse cultural and knowledge backgrounds; Interdisciplinary teams & projects; Increased role engineering; International & ind. collaboration

RESPONSIBLE DEVELOPMENT

*Equitable access to public education; R&D ethics; Risk governance
Approaches for sustainable development*

M.C. Roco, 11/13/08

Key objectives for nanotechnology education

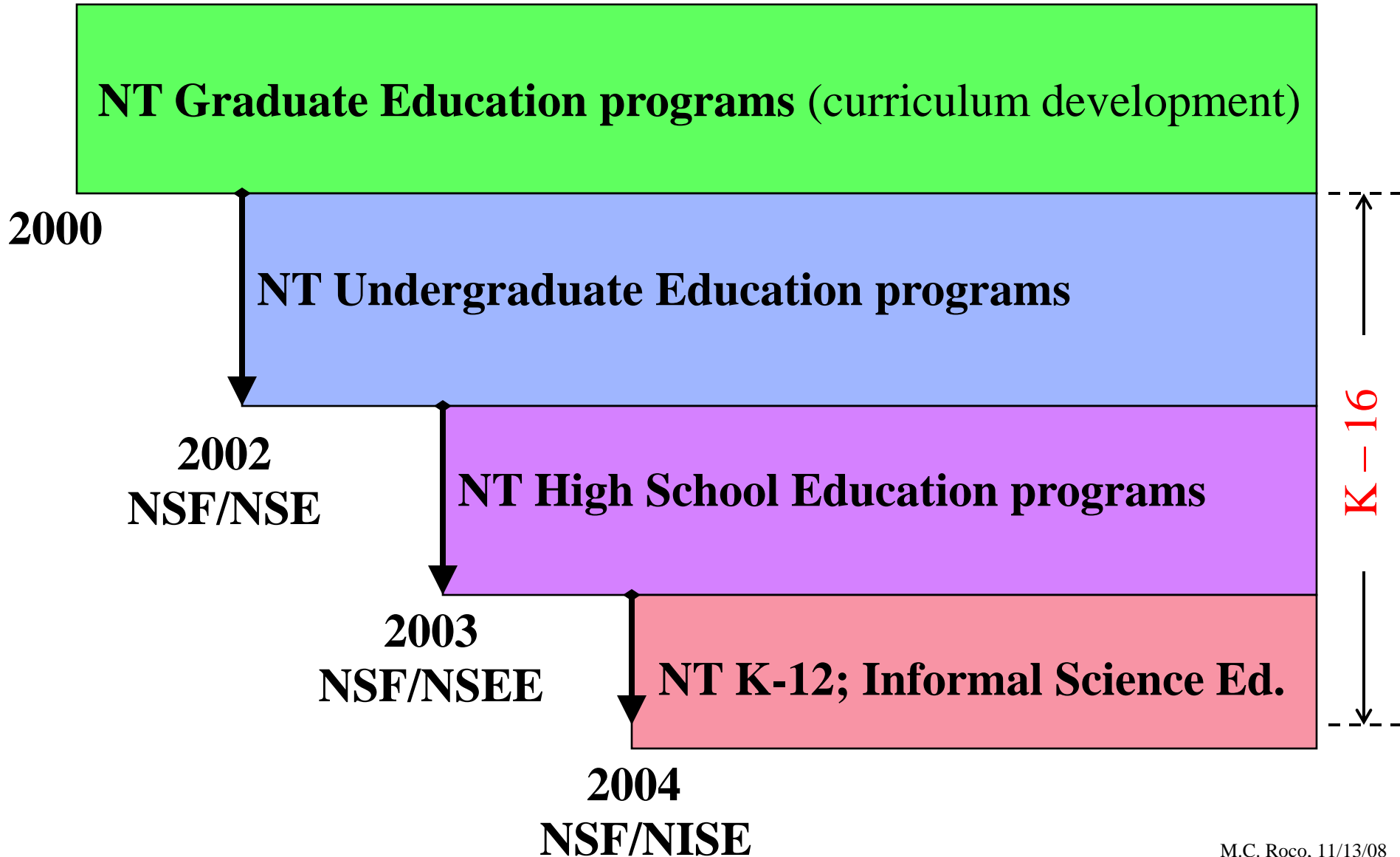
- Fundamental understanding from the nanoscale:
moving the foundation of learning from “microscale” to “nanoscale”
- Sharing similar concepts in various disciplines and relevance areas:
unifying concepts earlier in education
- **“Reversing the pyramid of learning”**: learning first unifying concepts of matter/ biology/ information systems, and then averaging techniques specific to each discipline
- **Combine “depth” with “breadth”**
- **Broader accessibility and motivation to S&T**
- **Engineering has an increased role** because of its interdisciplinary, integrative, system approach and transforming characteristics. Nanotechnology deals with systems



Needs for nanotechnology education

- **Developing coherent, longitudinal program** with proper bridges between K-12, UG, G, continuing and informal education
- **Unifying S&E and broad relevance courses**
- **Informing and engaging the public and civil society actors**
- **Partnering** for cross-disciplinarity, cross-relevance, and sharing resources (such as facilities and expertise, remote access)
- **Enabling the teachers** (Training; Educational materials; Access to experimental facilities and specialized museums)
- **International education opportunities** (ex: Young researchers to Japan and EU; PASI - Latin America, NSF-E.C.)

Introducing earlier nanotechnology education (NSF: Nanoscale Science and Engineering Education)



Nanotechnology university education

- examples of activities supported by NSF-

- Nanotechnology curriculum development (G, UG)
- Integration of research and education
(ex: IGERT, CRCD, REU, RET)
- Local and long-distance outreach education (G, UG, 12)
- Technological education
- Education and training in centers and networks
- Modules for individual training
- Informal science education,
including public education (non-technical audiences)
- Courses and tutorials offered by professional societies
- International activities

FY 2008 NSF investment in NSE (incl. fellowships) ~ \$389 M

FY 2008 NSF investment specific in nano education ~ \$28.3 M
(three networks: NCLT, NISE, and NIS)

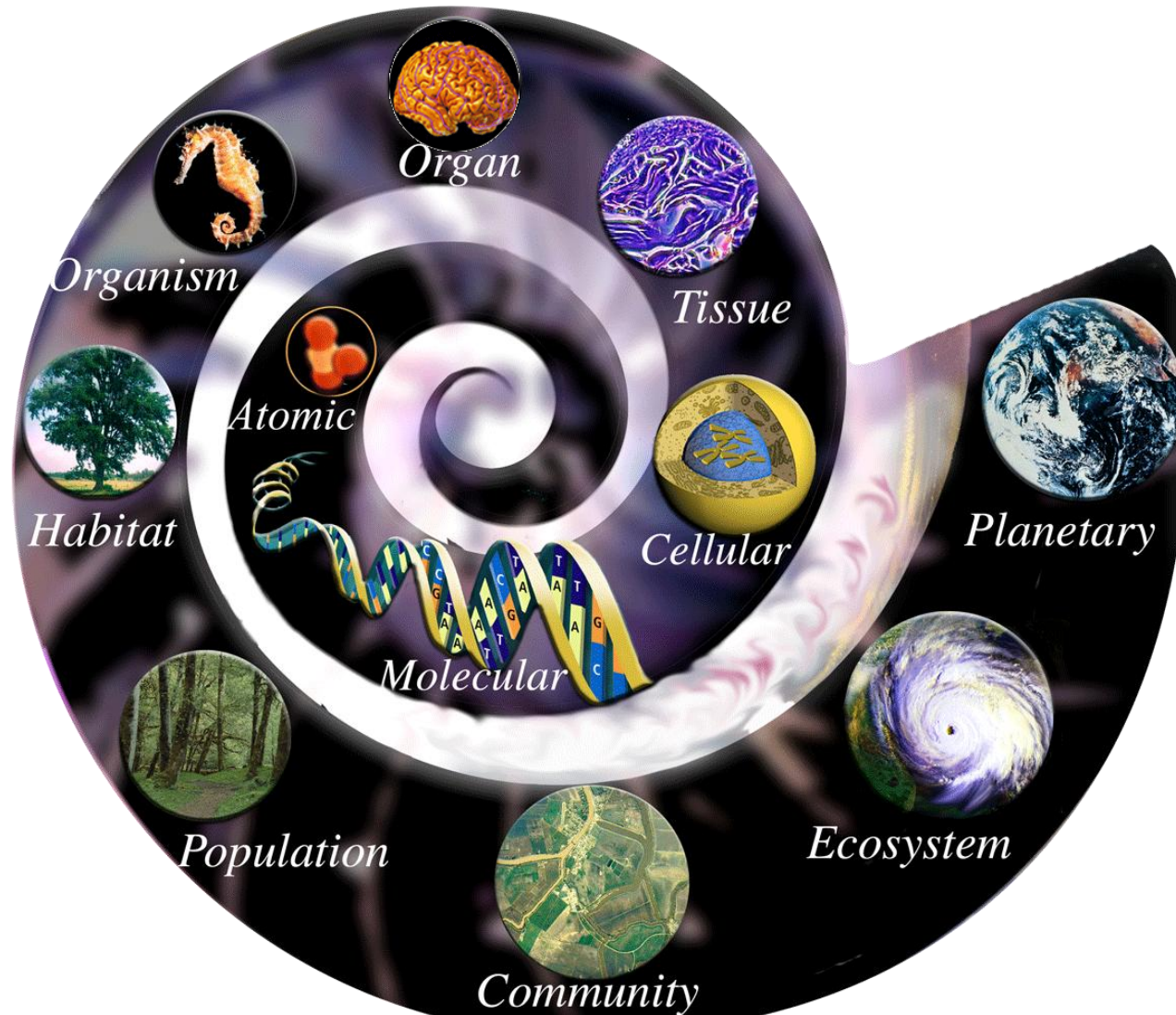
Nanotechnology education to an ecology of innovation

Connecting

- **Creativity:** new ideas by NT "multidisciplinary" education and motivation
- **Invention:** novel results by using the NT tools
- **Innovation:** better commercialization when multiple opportunities via "NT platforms"

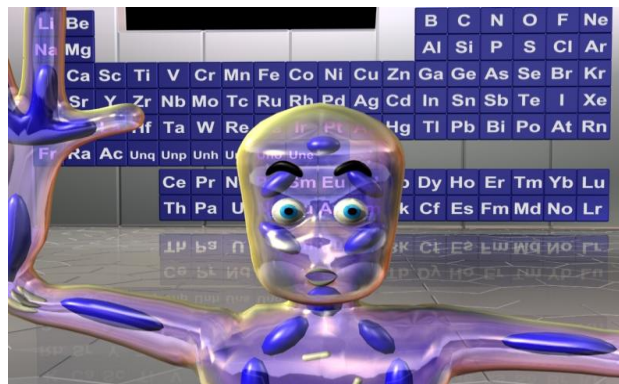
Illustrations: IGERT program at NSF
secondary NT degrees in universities
multi-domain research & industry internships

Nanotechnology education to include system complexity



“Reverse pyramid” of learning

- Learning first unifying concepts of matter / biology/ information systems, and then averaging techniques specific to each discipline
- Sharing similar concepts in various disciplines and relevance areas: unifying concepts earlier in education



Use of Virtual Reality

Portable virtual reality for education and training

- Learning tool
- Working environment
- Virtual laboratory experiments
- Social and economic observatory
- Computer and information tool



Role of Networking and Virtual Communities

- Networking made possible by IT and nano
- Implications on research, education, and culture
- Remote work, collaboration and education
– a fast growing approach
- The language barrier; more undergraduate and graduate schools in a foreign language
- Increased creativity and education exchanges
(mixing the waters)

Five possibilities for enhancing global education for nanoscale science and engineering

1. Earlier education from nanoscale
2. Establish global – transdisciplinary communication system
(using cyber IT, informatics, virtual reality, etc.)
3. Create and leverage international education institutes, courses, networks, etc.
4. Leverage education for common resources and soc. impl.
5. Commitment to long-term, priority driven, global view
using scenarios and anticipatory measures