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COMPILATION OF NANOSCALE COMMUNICATION PROJECTS

Part IIB of Front-End Analysis in Support of Nanoscale Informal Science Education Network Programming, Media, School-based Projects

Report for
Nanoscale Informal Science Education Network

by
Barbara N. Flagg, Ed.D.
Director, Multimedia Research

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INTRODUCTION

The Nanoscale Informal Science Education Network (NISE Network) is a national infrastructure that links science museums and other informal science education organizations with nanoscale science and engineering research organizations. The Network's overall goal is to foster public awareness, engagement, and understanding of nanoscale science, engineering, and technology. The Museum of Science in Boston is the lead institution working in partnership with the Exploratorium in San Francisco and the Science Museum of Minnesota in St. Paul to form the core leadership team for the project. An additional 10 organizational partners, 22+ "thinking partners", 12 advisors, and 2 evaluation firms form the initial fabric of the network.

A front-end analysis to support the NISE Network entails three parts:

I. A review of secondary research materials on the adult public's awareness, interest, knowledge and attitudes relating to nanotechnology;
II. A compilation of past and current projects that attempt to communicate nanoscale issues to the general public, including children;
III. A review of secondary research materials on communicating atomic theory and behavior to a general audience.

Part II, presented here, documents work that has been done and is being done to communicate nanoscale science, engineering and technology to the public and the results of those communications. This report compiles past and current nanoscale communication projects, answering the following questions:

- What is the project?
- Who are the target audiences?
- What are the communication goals?
- What are the evaluation findings?
- Who is the contact?
- What are references for this project?

Descriptions of projects are purposely concise. For details, please see the websites and references associated with the projects.

The projects included in this compilation were identified via references supplied by NISE Network affiliates and a review of all NSF award abstracts with "nano" and "outreach" or "education" in their text. Some projects outside the "nano" field are included if they focus on the molecular or atomic level. Projects in formal K-12 education are included if they have some pertinent evaluation information available. Projects focused on undergraduates, graduates or teachers are not included in this report. All images presented with project summaries have been copied from their respective websites.

Projects are compiled in this report by type of deliverable and primary audience.[1] In order to provide project photos in the report and maintain relatively small file sizes, Part II is provided as A and B. Part IIA includes Exhibit projects. Part IIB includes Programming, Media and School-based projects. This document is Part IIB.

Programming:
- Current Science & Technology Center – Museum of Science, Boston
- Live Science Zone - At-Bristol, UK
- Materials Matter - The Franklin Institute, Penn State MRSEC
- Zoom in on Life - The Franklin Institute, Penn State MRSEC
- DeCiDe: Deliberative Citizens' Debates in European Science Centres
- NanoJury – UK
- South Carolina Citizens' School of Nanotechnology – Nanocenter, University of So. Ca.

Media:
- Earth & Sky - Earthtalk Inc.
- Nanotechnology: The Convergence – ICAN Productions
- ScienCentralNews - ScienCentral Inc.
- Molecularium℠ – Rensselaer Polytechnic Institute, Junior Museum

School-based:

Middle school:
- NanoKids™ - Rice University

Middle and High school:
- Molecular Workbench – Concord Consortium
- nanoManipulator – University of North Carolina at Chapel Hill
- Nanostructures Module – Northwestern University NSEC

High school:
- NanoLeap - Mid-continent Research for Education and Learning (McREL), Stanford Nanofabrication Facility (SNF), ASPEN Associates
- Nanoscience and nanotechnology education in the Los Angeles Unified School District – California NanoSystems Institute (CNSI), University of California, Los Angeles (UCLA)
- NanoSense - SRI International

[1] Some projects should be in this list but not enough information is available by the deadline of this report: Nanooze, an online science magazine for kids sponsored by the National Nanotechnology Infrastructure Network, see www.nanooze.org; Nanopedia, an online information source, see http://nanopedia.cwru.edu; Patterns in Nature Van, a mobile microscope laboratory to visit schools in AZ, see http://www.asu.edu/clas/csss/PINvan/.

PROGRAMMING PROJECTS

Current Science & Technology Center (CS&T)
Nanoscale Science and Engineering Center education outreach partnerships[2]

What it is: (see http://www.mos.org/nano)
The Current Science & Technology Center, located in the heart of the Museum of Science, Boston, is dedicated to engaging visitors in leading edge research in science and technology. CS&T is equipped with a high-tech stage; networked large digital displays and touchscreens; remote-control cameras and fiber optic lines to New England Cable News (NECN) studio, satellite and telecommunication links; and a desktop video production and graphics studio. The Center offers daily live presentations, weekly NECN updates on science and technology, frequent guest researcher events, exhibits, digital AV updates, a website and live links to researchers in the field. The key focus is the frequent and ever-changing live staff presentations (nano topics have included "Intro to Nanotech," "The Wonderful World of Carbon Nanotubes") and guest researcher presentations. The latter have included, for example:

- Professor Jennifer West showed how gold covered nanoshells might provide effective cancer therapy[3]
- Professor Eric Mazur on femtosecond laser research and nanowires
- Professor Mike Aziz demonstrated amorphous metals
- Fulbright scholar Derek O'Keefe presented "superhero science"

(http://www.nsec.harvard.edu/pages/education_mos.htm)

An exhibit shows off consumer products and medical applications of nanotechnology. A multimedia display offers updated stories on nano research, including profiles of researchers and video and animations of nano processes. The CS&T website posts longer versions of these stories with live links to research websites (see index at www.mos.org/nano). New England Cable News broadcasts live from CS&T every Thursday morning. The website, http://www.mos.org/cst/article/5764/, archives 3-minute clips in which MOS staff interact with news anchors and demonstrate topics in nanotechnology, such as nanotech cancer diagnostic techniques, molecular cages for hydrogen fuel storage, nano iron particles for toxic waste clean-up, nanofiber optics and nanobatteries.

Target audiences:
Museum visitors, primarily 12 years and up. New England Cable News and Internet viewers.

Goal:
To engage public and school audiences in current science and technology, stimulating further inquiry and engagement

[2] The education staff in nanoscale science and engineering are funded through outreach partnerships with NSF-funded NSECs ["Science of Nanoscale Systems and Their Device Applications" at Harvard and MIT and "Center for High-Rate Nanomanufacturing at Northeastern University and University of MA-Lowell.
[3] Image from http://www.nsec.harvard.edu/pages/education_mos.htm

Evaluation conclusions:

Formative evaluation:
The Institute for Learning Innovation (ILI) has carried out formative and summative evaluation of CS&T staff and guest researcher presentations in a variety of content areas. Alpert (2004) quotes ILI's formative evaluation of staff presentations as concluding that the presentations "seem to attract the target audience, keep the audience interested, successfully convey their messages, and are enjoyable for most visitors….The presentations in their conceptualization and their concrete implementation can be further promoted as successful models for conveying current science and technology issues to [teen and adult] audiences of a science museum or science center" (p. 248).

Summative evaluation (Storksdieck, Stein & Dancu, 2005):
The summative evaluation focuses on health science programming, reporting data from over 16 live presentations with 157 respondents. With respect to appeal, 58% rated the live presentations as "excellent" and 40% as "very good" or "good." Medical or health related shows received more "excellent" ratings than science/technology shows. Presentations are described as informative or interesting, with good speakers who are clear and organized. Presentations appeal more to adults with a higher professed interest in science and technology or to adults who did not bring children to the museum. In terms of impact:

- more than half of respondents wrote down one or more detailed facts when describing the key points of the presentation;
- 63% say they are "very likely" and 22% "likely" to pay attention to future news about the presentation subject;
- half of respondents say they are "very likely" and 30% "likely" to share what they learned with someone they know;
- 68% are "very likely" and 23% "likely" to watch another presentation on a different subject.

Contact: P.I. Carol Lynn Alpert, calpert@mos.org

References:

Alpert, C. (2004). Bridging the gap: Interpreting current research in museum settings. In D. Chittenden, G. Farmelo, & B. Lewenstein (Eds.), *Creating connections: Museums and the public understanding of current research.* Walnut Creek, CA: AltaMira Press.

Kelly, M. (2004, Sept. 10). *Museum exhibit translates nanotech for American public*. Retrieved October 1, 2005, from http://www.smalltimes.com/print_doc.cfm?doc_id=8276

Rutter, M. Patrick. Museum Studies. (2004, Fall). *Harvard Engineering and Applied Sciences Newsletter. III* (2), 16-17. Retrieved October 1, 2005, from pdf link at bottom of webpage: http://www.nsec.harvard.edu/pages/education_mos.htm

Storksdieck, M.; Stein, J.K. & Dancu, T (2005). *Summative Evaluation, Current (health) science at the Current Science & Technology Center, Museum of Science, Boston*. Technical Report. Annapolis, MD: Institute for Learning Innovation. Section on live events made available by Martin Storksdieck, Institute for Learning Innovation, November 4, 2005.

Live Science Zone at At-Bristol, UK

What it is: [4] (see http://www.at-bristol.org.uk/explore/livescience.htm)

At-Bristol is a UK science center. The Live Science zone, which opened in 2005 on the first floor of the center, has three areas presenting a changing program of events to communicate contemporary science:

1. The Studio: “Forming the hub of the zone is a state-of-the-art Studio giving you the chance to participate in exciting public shows and join in debates. You will have opportunities to meet and question guest scientists, researchers and other leading experts. In the time between shows, the area asks you to have your say on contemporary science issues and you even have the chance to appear on our super-sized, futuristic opinion wall!”
2. Exploration Stations: “For mind-boggling hands-on activities every day, head to the Exploration stations to investigate the magic of modern science! Get stuck into fun table-top experiments and exciting ’make and take’ activities.”
3. News & Views: “Highlighting the weekly science topics hitting the headlines and asking viewers to cast their votes, here you can relax, surf the web, read the news and give your views!”

Target audience:
Museum visitors

Goals:
To ask the visitor what they think about science and invite them to explore science through various interactions with people, products and processes.

Evaluation conclusions:

Front-end (Lundberg, 2005):
“The main aim of the study is to determine characteristics of what kind of techniques to use in the Live Science Zone. The objectives are to explore what has already been done at At-Bristol, and what has been done at other science centres, and to identify successful devices. The secondary aim is mapping what sorts of topics that visitors are actually interested in debating. The methods used in the study are deep qualitative interviews with professionals working within the field of science communication in Europe and North America, and questionnaires answered by visitors to At-Bristol.” (p. 5). The most popular devices to address contemporary science issues chosen by 79 At-Bristol visitors included “Film” (86%), “Lab experiments” and “Workshops” (80%).

[4] Image from http://www.at-bristol.org.uk/explore/livescience.htm

Contact: Catherine Aldridge, Education and Programmes Manager Catherine.Aldridge@at-bristol.org.uk

References:

Lundberg, K. (2005). *Citizens and contemporary science. Ways to dialogue in science centre contexts.* Master thesis in science communication, Dalarna University, Sweden. Retrieved September 18, 2005, from www.sciencecommunication.se/ master_theses/Master-Thesis_09_Lundberg.pdf

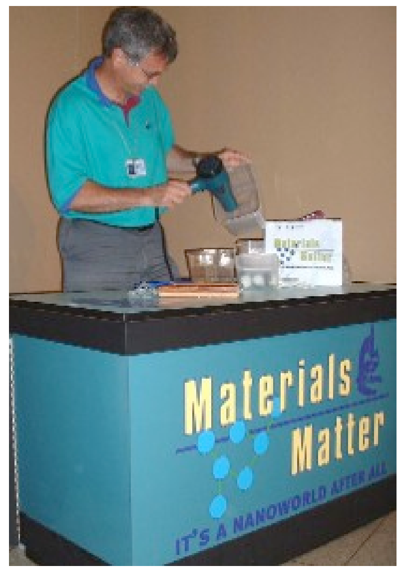
(This thesis has background and evaluation information on other live projects involving museum visitors in contemporary science including Naked Science, London; Mine Games, Vancouver. It also include in-depth interviews with museum professionals about the dialogue model as a means of engaging visitors in contemporary science.)

Materials Matter

What it is: (see http://www.mrsec.psu.edu/museum/materials/index.asp)
The Franklin Institute and Penn State Materials Research Science and Engineering Center (MRSEC) "produced the *Materials Matter* museum show, a 60 minute cart-based interactive exploration into the "micro" mechanisms behind the unusual and surprising "macro" behavior of materials such as aerogels, shape-memory alloys, polymers, electronic ink, and zeolites." Twenty-two copies of the show have been distributed to US science museums.

Demonstrations and their specific goals are listed below in the order of reported museum opinion with most favored at the top of the list (order taken from Franklin Institute, 2003, p. 5; goals taken from http://www.mrsec.psu.edu/museum/materials/index.asp):

- Gummi Worms: "The goal of this demonstration is to explore the properties of a cross-linked polymer. When a polymer is cross-linked, it can take on new properties, such as going from a liquid to a solid."
- Nitinol: [5] "Nitinol is a shape memory alloy, a mixture of two types of metal (in this case nickel and titanium) that will bend but will return to its original shape when heated."
- Mystery Mix: "Demonstrate how things on a micro scale affect your senses (how you see in this case) on a macro scale."
- Sand Hand: "To show how very common materials can do very unusual things."
- Aerogel: "The goal of this demonstration is to investigate the properties of a material, aerogel that is made mostly out of air."
- Electronic Ink: "Show things on a micro scale can effect what we see on a macro scale. Show that research is not just a result it's also a process."
- 6-pack rings: "The goal of this demonstration is to show properties of polymers. Polymers are made from long chains of molecules called "monomers." What the monomers are made from and how they are arranged can change the properties of the polymer."



- Gore-Tex: "The Gore-Tex® demonstration shows the properties of how a microporous material can allow only molecules of a certain size to pass through."
- Zeolites: "The goal of this demonstration is to show how a zeolite can work as a "cage" to trap certain molecules selectively."

Target Audience:
Wide range of museum visitors

Goals:
To explore the unique chemical and physical properties of cutting-edge materials. See specific goals for each demonstration above.

[5] Image of Nitinol demo from http://sln2.fi.edu/tfi/info/demos2.html

Evaluation conclusions:

Implementation (The Franklin Institute, 2003):
In 2003, 21 participating museums completed a use and opinion survey, concluding:

- Most popular demos as indicated by museums were Gummi Worms, Nitinol and Mysterious Mixture. "The most favorite demos were easy to do, easy to explain, appealed to a wide range of age groups and were of high interest to visitors." (The Franklin Institute, 2003, p. 5)
- Most difficult demos as indicated by museums were Gore-Tex and Zeolites.
- "Overall responses were positive. Visitors and staff enjoyed at least some of the demonstrations at all the museums." (The Franklin Institute, 2003, p. 2)
- Gummi Worms: Good hook; appeals to all age groups including children; easy to do and explain; visitors handle substances
- Nitinol: Good 'wow' factor; playing and touching springs appeals; good for all ages; wearability a problem
- Mysterious Mix: Easy to do and explain; good for small children
- Sand Hand: Attention getter; easy to do; maintenance of gloves a problem
- Aerogel: Adults like it but use of blowtorch problematic
- Electronic Ink: Problems with operation and obtaining materials
- 6-pack rings: Low appeal
- Gore-Tex: Problems with demo effectiveness and appeal
- Zeolites: Difficult to set up and explain

Beyond using the demos on the museum floor, museums used them as school outreach, at special events, and at an on-site charter school.

Contact: P.I. Steven Snyder, Franklin Institute, ssnyder@fi.edu

References:

The Franklin Institute. (2003). *Materials Matter Museum Survey*. Made available by Steven Snyder, The Franklin Institute, October 26, 2005.

See http://www.mrsec.psu.edu/museum/materials/index.asp for demo procedures and FAQs.

Zoom in on Life

What it is: (see http://www.mrsec.psu.edu/museum/biology/index.asp)
In 2005-2006, The Franklin Institute and Penn State Materials Research Science and Engineering Center (MRSEC) are distributing to museums six biology and nanoscale science demonstrations. Hands-on demonstrations and their specific goals are listed below (Franklin Institute, n.d., p. 1):

- What is "nano": "To help visitors understand what nano is."
- DNA: Building Blocks: "Visitors will learn about self-assembly"
- Membranes: The Gate Keepers: "Visitors will understand how membranes will allow some things through but keep others out"
- Antibodies: Playing Favorites: "Visitors will understand why certain molecules attach to one another but others don't"
- Retinal: The Power of Light: "Visitors will learn how outside factors like sunlight can create chemical reactions by using the chemical retinal and how we see"

Target Audience:
Wide range of museum visitors

Goals:
To show nanoscale science of the body and how scientists are using that to create new technology. See specific goals for each demonstration above.

Evaluation conclusions:
None available yet

Contact: Steven Snyder, Franklin Institute, ssnyder@fi.edu

References:
The Franklin Institute. (undated) *Demonstration description*. Made available by Steven Snyder, The Franklin Institute, October 26, 2005.

See http://www.mrsec.psu.edu/museum/biology/index.asp for demo procedures and FAQs.

DeCiDe: Deliberative Citizens' Debates in European Science Centres

What it is: (see http://www.neweconomics.org/gen/democs.aspx)
"The DECIDE project – Deliberative Citizens Debates in European Science Centres and Museums – seeks to develop and implement a way of conducting meetings in which members of the public can debate six controversial life science issues. The debates will focus on cloning, stem cell research, xenotransplantation, new drugs for HIV, brain research and nanotechnology. The project will produce a kit to facilitate structured debate. The kit will consist of cards containing information on policies, scenarios, facts and issues, along with a 'conversation guidelines' document, voting grid, feedback forms and a mapping board. An instruction booklet and background information would also be included. The kit will allow groups of citizens to carry out what DECIDE describes as a self-supporting deliberative debate on the topic of choice. The cards and mapping board will help those involved visualise the discussion and provide a way of offering feedback. The exercise should help monitor and understand public attitudes to contemporary life sciences" (European Commission, n.d., p. 1).

The DeCiDe project is built on the "Democs' card game: "Since 2001, nef [new economics foundation] has been using a debate format where groups of six to nine people can get acquainted, discuss and eventually deliberate on policy positions on a wide variety of subjects. The format is innovative: each participant takes part to the debate by literally 'putting on the table' cards that represent facts or issues related to a specific subject. This generates discussion, which allows the participants to 'cluster' their cards into themes that represent the common ground between all participants. The advantage of using visual aids in the form of cards and a mapping board means that participants can focus on the debate without getting lost in out-of-topic conversations, and at any given time they can see where the discussion is leading. When all participants have put their cards on the table, the consensus-forming phase begins. More often than not, economics, development, environmental and social issues are higher on the citizens' agenda than risk and technological assessment. During a 'Democs' session it is quite common to find people with rather diverging initial opinions agreeing on a policy, when they themselves are in charge of setting the agenda for discussion" (Ecsite newsletter, p. 14).

Nanotechnology Democs game is available for download at
http://www.neweconomics.org/gen/howtogetholdofdemocs.aspx

Target Audience:
Adults in European countries

Goals:
Project goals:

1. "To raise European citizens' awareness of deliberative methodologies
2. To develop an effective tool to conduct deliberative consultations
3. To monitor change of opinion on contemporary science issues" (Bandelli, 2005, p.10).

Evaluation conclusions:
"A comprehensive evaluation of the results of DeCiDe is the second main component of the project. One area of investigation will be the role of dialogue during and after the deliberation

process. It has been noted from the available feedback on 'Democs' that this format is in fact a catalyst for dialogue - all participants engage in active, constructive dialogue during the game, and a large majority continue talking afterwards, often spending several hours talking through issues initiated by the game event. Subjects of investigation will include: How does dialogue influence decision making? Is the stimulus to carry on the debate long lasting, or is it essentially limited to direct engagement in the game event? Given the role of the cards in the debate process, it is easy to see which arguments (represented by the facts and issues on the cards) are instrumental in creating the clusters on which participants base their deliberations. Such information is recorded during the debate process, and will be evaluated to compare results between different countries. This will allow us to see, for example, how different communities of citizens react to a deliberative consultation, and it will provide each participating institution with useful information about their audiences that can be discussed with experts and policy makers" (Ecsite newsletter, p. 15).

"Preliminary evaluation of Democs has been conducted by the Public Understanding of Environmental Change (PUEC) Group at the University College London (2004)….Two core forms of learning occur whilst playing DEMOCS. Whilst the more conventional means of gaining information through the facts on the cards did occur, the method that participants found most rewarding was through the collective knowledge and experiences around the table. This learning from other players also facilitated the development of a greater appreciation for the diversity of opinions and the complexity of the issues at hand. Most importantly, together these two types of learning contribute to generating a spark of interest that appears to foster a heightened receptivity to the topic discussed during the game, which remains present in participants' everyday lives. The process of social learning additionally appears to contribute to the establishment of a virtuous circle of knowledge and empowerment. The knowledge gained through the game appears to empower some participants to continue to educate themselves about the issues, which in turn may empower them further. Through the discursive process of deliberation, some participants were also empowered to form a more settled opinion regarding the topic addressed, and to develop the confidence to begin to consider and interrogate received expert knowledges." - PUEC report on Democs 2004
http://www.neweconomics.org/gen/democs_evaluation.aspx

Contact: Project manager Andrea Bandelli, andrea@bandelli.com

References:

Bandelli, A. (2005, September/October). Fostering Deliberative democracy: Europe's DeCiDe project. *ASTC Dimensions*, 10-11.

Ecsite Newsletter. (2005, Spring). *Focus on DeCiDE*. Issue 62, 14-15.

European Commission. (undated). *Launching public debate on science's hot topics.* Retrieved October 31, 2005, from europa.eu.int/comm/research/science-society/pdf/portfolio/governance-decide_en.pdf

NanoJury

What it is? (see www.nanojury.org)
The NanoJury is an experiment in public engagement in nanotechnology in the UK. "The NanoJury brings together twenty randomly-chosen people from different backgrounds who will hear evidence about a wide range of possible futures, and the role that nanotechnologies might play in them. Over five weeks, the jurors will hear from a variety of witnesses with widely varying perspectives, which they will draw on in coming up with a set of recommendations. These will inform how debates as to how this emerging and potentially revolutionary technology should develop. It is sponsored by the IRC in Nanotechnology at the University of Cambridge, Greenpeace UK, the Guardian and the Policy, Ethics and Life Sciences Research Centre at the University of Newcastle." Besides the randomly chosen jurors, there are witnesses who inform the jury of their particular knowledge; an oversight panel that ensures a range of perspectives are provided to the jury; facilitators to ensure that all jurors have a voice; and a science advisory panel.

The jurors met for 20 150-minute sessions, two a week for ten weeks. In April and May, 2005, the jury met over 10 sessions and discussed a topic they chose (youth crime) in order to become a working group and understand the process. In May and June, 2005, jurors met for 10 sessions to hear from witnesses and discuss potential new technologies arising from nanoscience. On Sept. 21, 2005, jurors gave their recommendations (see evaluation conclusions below). The jury's recommendations will be considered by the Nanotechnology Issues Dialogue Group, established to coordinate the UK's government response on nanotechnology.

Target Audience:
Adults, UK decision-makers and scientists

Goals:
1. "To provide a potential vehicle for people's informed views on nanotechnology to have an impact on policy
2. To facilitate a mutually educative dialogue between people with diverse perspectives and interests, including critical and constructive scrutiny of the hopes and aspirations of those working in the nanotech-related sectors by a wider group of citizens
3. To explore the potential for deliberative processes to broaden discussions about nanotechnology research policy – both in terms of the range of issues and the diversity of people who are given a say" (www.nanojury.org/aims.htm).

Evaluation conclusions:

An independent evaluation report eventually will be written by Nick Pidgeon and Tee Hayden-Rogers at the University of East Anglia. What appears below are observations from a blog of Richard Jones, Chair of the Science panel:

"Wednesday evening was spent in a general discussion about technologies and their impacts, both positive and negative, together with a very brief, scene-setting introduction to nanotechnology. The first proper witness session was held last night, on the theme of

nanotechnology in medicine. The witness was Beatrice Leigh. Bea was formerly Head of New Technology for the drug company GlaxoSmithKline; she now runs her own (somewhat smaller) drug discovery company. I thought Bea did a great job, giving a very clear picture of why nano will be important in the pharmaceutical and biomedical industries (and, on the way, not being shy about the current shortcomings and difficulties of big pharma). After her half-hour long statement, the jurors spent some time by themselves formulating what they felt were the key questions, and then Bea and I did our best to answer them. This part of the evening provided clear proof that you don't need expert knowledge to be able to ask penetrating questions."
http://www.softmachines.org/wordpress/index.php?p=121

"The citizens jury about nanotechnology that I'm involved in has now finished its third week. In week 2 the jurors heard a pair of witnesses from the skeptical side of the debate; Jim Thomas from ETC, and Charles Medawar from Social Audit, a group devoted to questioning the relationship between medicine and the pharmaceutical industry. In week 3, the jury heard from Tony Ryan, a chemistry professor (and colleague) from the University of Sheffield, and David Bott, an industrial chemist who's had senior positions in BP, Courtaulds and ICI and who now divides his time between advising the DTI, a venture capital company and a couple of nanotechnology start-ups. I went along to last night's session to see how things were going. The jury now very much has the bit between its teeth; they've found some interesting lines of argument to pursue and are assiduously comparing the different positions of the witnesses they've heard, particularly on issues like the motives and trustworthiness of industry. A surprise (to me) visitor last night was Tom Fielden, the environment correspondent of the flagship BBC radio news program "Today". He was recording some of the proceedings to use in a piece about the Nanojury that they'll run on the morning the findings are announced. It's excellent to see that this process is getting some serious interest from the mainstream media."
http://www.softmachines.org/wordpress/index.php?p=126

Recommendations:
" In full, there were twenty recommendations which attracted various degrees of support. But at the launch, four jurors attended in person, and they singled out four recommendations which they felt the whole jury felt most strongly about. After presenting these four key recommendations, they took questions from a large audience, and then the sponsors of the process gave their reactions.
The four recommendations were:
1. Health - nano-enabled medicines had big potential for reducing the time people spent in hospital. These should be developed via improved funding mechanisms and should be available without discrimination on the National Health Service.
2. The Government should support those nanotechnologies that bring jobs to the UK by investment in education, training and research.
3. Scientists should learn to communicate better - some of the jury felt sometimes patronised, they didn't like all the long words scientists used, and scientists didn't always agree with each other.
4. Products containing manufactured nanoparticles should be labelled in plain English.

The questions threw up some interesting insights. The most direct and straightforward came from the Guardian reporter - after this process, what was their general impression of nanotechnology.

All four were in agreement; if safety could be assured, they were very positive. Another journalist asked them what they felt were the most exciting applications, and again they agreed on medicine and renewable energy. A Greenpeace person asked them a rather leading question about whether they would agree with the proposition that he claimed many scientists held, that if the public only understood the science they would support it. They answered this by saying that as they learned about the science, they got excited about it and talked about it to their friends. One juror told a story about how his daughter was at school and the class was asked about nanotechnology. She said *"oh, yes, I know loads about nanotechnology"*, to which the teacher replied along the lines of *"how can you know about that, your dad's just a taxi driver"*, to which she was able to say that her father was taking part in this citizens jury and was telling her all about it.

One thing was absolutely clear - the jurors were tremendously positive about the process itself. They even managed to say some positive things about the scientists involved, despite conclusion 3. One juror rather accurately identified the problem with the upstream nature of the process - commenting that *"some of this stuff is so far ahead that even the scientists aren't sure where it is going"*. This positive view chimed well with the independent evaluation made by Nick Pidgeon, a social scientist from UEA who assessed the ill-fated GM nation project. His view was also very positive, and he noted as good features the very representative jury, the very strong multi-stakeholder oversight panel, and the direct link into government. He noted as a challenge for upstream approach precisely the problem that the juror had pointed out.

From the sponsors, Mark Welland, from the Cambridge Nanotechnology IRC, talked a lot about the importance of the integrity of the process, and pronounced himself very satisfied with this. Doug Parr, from Greenpeace, sounded a slight air of disappointment. He didn't think the recommendations reflected the richness of the discussions, he noted the importance of discussing, beyond pure technology, the wider issues of economics and the wider disconnects between science, government, industry and the public. He noted that there had been no mention of the idea of a moratorium on the new technology. I should note here, of course, that Jim Thomas, of the ETC group, which has been calling for a moratorium, was one of the witnesses and presented the case for one to the jury.

For the Government, the reaction was given by Adrian Butt, Chair of the Nanotechnology Issues Dialogue Group, the multi-department body set up to coordinate nanotechnology policy across government. He gave an explicit commitment to table the recommendations in the policy meetings of the NIDG and report back the outcome of discussions. He seemed really rather pleased with the outcome, which he took as being not far from endorsing the approach the government was taking. Nonetheless, he did exercise a certain amount of "expectations management" about how seriously the government would take this. In his words, *"the results of this kind of exercise will not by themselves directly determine policy, but will provide social intelligence on the wider environment in which policy is made"*

For nanobusiness, Barry Park, COO of Oxonica, expressed broad comfort with the balanced tone of the recommendations.

What of my personal recollections and feelings? I found it one of the most stressful things I've done in my career. I have massive admiration for Becky Willis, who chaired the oversight panel and kept the whole thing together in the face of what seemed at times overwhelming centrifugal forces (I composed one unsent resignation letter, and I suspect I wasn't the only one who came close to walking out on the whole thing). The facilitators have immense power in this kind of exercise, and I ended up with immense respect for the professional effectiveness of Tom Wakeford and his team. But Tom has his own strong political views, which as he himself conceded in his own self-critique, he doesn't always rigorously exclude from the process, and these aren't calculated to make life easy for the scientists. It would be impossible for me not to take the criticisms of scientists communication skills personally, but I honestly don't think the scientific witnesses should have done anything differently. I think the jurors got a very honest, unspun and unvarnished impression of the science, and in return I found the interactions with the jurors very rewarding.

At the end of it all, one thing that is disappointing was the very low level of press coverage - this perfunctory piece in the Guardian was the only thing in the nationals. There are some mitigating circumstances for the lack of press interest - the fact that the Guardian was the media sponsor limited the appeal for other papers, while the Guardian itself basically lost interest as a result of the decision to drop its weekly science section when the paper relaunched as a near-tabloid. But I can't help feeling that there would have been a lot more coverage if the result had been different. There were approving words in an editorial in this weeks Nature (subscription required). Its conclusion is a good place to finish: *"The results of the citizens' jury suggest that nanotechnology is not perceived as a serious threat to the values of anyone but die-hard anti-technologists."* http://www.softmachines.org/wordpress/?p=159

Greenpeace's website lists 10 recommendations that received majority support from the jury, see http://www.greenpeace.org.uk/contentlookup.cfm?CFID=1292997&CFTOKEN=81325448&ucidparam=20050926143910.

Contact and references: www.nanojury.org

See also blog of David Berube (Research Director of NanoScience and Technology Studies at U. of South Carolina) at http://nanohype.blogspot.com/2005/09/report-on-uk-nanojury.html , which describes the final public recommendation session on Sept. 25, 2005.

South Carolina Citizens' School of Nanotechnology

What it is: (see http://nsts.nano.sc.edu/outreach.html)
The South Carolina Citizens' School of Nanotechnology (SCCN) involves seven weekly sessions for adults to increase their nanoliteracy. Participants read background material for each session, attend presentations by University of South Carolina (USC) faculty and participate in two-way discussions. Additionally, participants visit two USC science labs to experience nanoscale phenomena like atomic surfaces.

Target audience:
Adults who are curious about nanotechnology and can pay $30 to cover materials duplication

Goals:
"It is thus important to build an informed public so that nonexperts can have an active and constructive voice when they participate in nanotechnology policy. Thus the USC NanoCenter hopes to nurture *nanoliteracy*, that is, a set of conditions in which members of the public:
[A] are informed about nanotechnology [including its special instruments; the basic scientific issues; the arguments about societal implications; and the diversity of voices and positions on these topics]; and,
[B] are able to pursue their own interests in nanotechnology by accessing information through various sources; and,
[C] are confident that they can participate in shaping nanotechnology policy, even if they do not necessarily possess the expert credentials of scientists or engineers.
Furthermore, the communication of information is a two-way dialogue between experts and lay persons so that lay persons can raise their own concerns." http://nsts.nano.sc.edu/organize.htm

Evaluation conclusions:

Suggestions from the manual for organizing a Citizens' School:
http://nsts.nano.sc.edu/organize.htm:

- 6-8 session once a week, always at same time
- Expert speakers need to be comfortable speaking to nonexperts. Two-way dialogue is critical
- Background materials need to be readable, at the level of *Scientific American*
- Group size limited to less than 40 so dialogue occurs
- Provide reference information – bibliography, web sites – for future learning
- Give certificates of completion
- Participants can ask questions and make comments at any time
- Use local media for publicizing at least four weeks in advance
- Parking is important

"It is worth having some measure of the success of a Citizens' School. We ask about logistics and accommodations in a one-page form with four questions. In addition, we survey participants' before-and-after knowledge with a quiz of ten simple multiple-choice questions. Finally, it would be a good idea to ask open-ended questions about how their understandings and attitudes about nanotechnology have changed" http://nsts.nano.sc.edu/organize.htm.

The quiz of ten multiple-choice questions for 16 participants in 2004-5 sessions reveals change in knowledge from pre to post school, as indicated in the table below (Toumey, 2005).

Question	Pre % Correct	Post % Correct	% Change
Why are nanoscale phenomenon invisible to optical instruments?	64%	88%	+24%
Which instrument invented in the early 1980's made it possible to produce precise images of individual atoms?	50%	94%	+44%
What is the size relation between a virus and a red blood cell?	50%	88%	+38%
In 1990, two scientists demonstrated that they could precisely manipulate individual atoms by spelling out the name of their employer in atoms. Which company's name was spelled in atoms?	36%	100%	+64%
What is the theme of Michael Crichton's *Prey*?	36%	88%	+54%
There is a molecule made of 60 atoms which is called fullerene, also known as buckyballs. What is fullerene made of?	32%	100%	+68%
Who is Eric Drexler?	28%	94%	+66%
Some people say that visions of nanotechnology were ignited by a famous 199 talk to physicists called 'There's plenty of room at the bottom." Who gave that talk?	21%	88%	+65%
What is the relation between a nanometer and an angstrom?	14%	50%	+36%
Who is the famous European leader who says that there should be a moratorium on nanotech research?	4%	13%	+9%

Contact: P.I. Chris Toumey Toumey@gwm.sc.edu

References:

Toumey, C. (2005, April). *History and ethos of the South Carolina Citizens' School of Nanotechnology.* Retrieved August 18, 2005, from http://nsts.nano.sc.edu/outreach.html.

Toumey, C. (2004, September 30). *Organizational notes for a Citizens' School of Nanotechnology.* Retrieved August 18, 2005, from http://nsts.nano.sc.edu/organize.htm.

MEDIA PROJECTS

Earth & Sky

What it is: (see www.earthsky.org)
EarthTalk, Inc. is producing 24 90-second Earth & Sky radio shows per year for three years on nanotechnology. They are partnering with Nano Science and Technology Institute (NSTI), Boston; Nanoscale Science and Technology Facility (CNF), Cornell University; and Center for Biological and Environmental Nanotechnology (CBEN), Houston to identify researchers, advisors and program ideas. Program categories are Nano 101; Innovations that could change the world; Science or science fiction; Implications and ideas; Nano and the environment; and Listener questions. The programs are supplemented by related material on Earth & Sky Online, which receives up to one million page views/month, and a composite of the nano programs onto CD mailed directly to 10,000 teachers yearly. The Earth & Sky series currently airs on 685 public and commercial radio stations nationwide. (from abstract on www.nsf.gov.)

As of November 4, 2005, on the www.earthsky.com website are 34 nano-related shows available for listening; 4 background text articles; and text interviews with 2 scientists.

Target Audience:
Radio listeners – public, commercial, satellite. Teachers.

Goal:
To increase public awareness and knowledge about the field of nanotechnology

Evaluation conclusions:
No evaluation is planned for the nanotechnology shows in particular; however, summative evaluations of the series as a whole (Flagg & Brenman, 1997; Flagg, 2005) have surveyed random samples of both public and commercial radio listeners to conclude, for example, that

- more than 8 out of 10 listeners agree that they have expanded their knowledge of science by listening to Earth & Sky;
- 8 out of 10 listeners agree that the series increases their awareness of science news topics; and
- 7 out of 10 listeners report discussing Earth & Sky topics with others.

Contact: P.I., Ryan Britton, rbritton@earthsky.org

References:
Flagg, B. N., & Brenman, A. J. (December, 1997). *Summative evaluation of "Earth & Sky" radio series in the commercial radio market*. Multimedia Research Unpublished Report No. 97-010.

Flagg, B. N. (August 9, 2005). "*Earth & Sky" summative evaluation: Study 2.* Multimedia Research Unpublished Report No. 05-009.

Nanotechnology: The Convergence

What it is: (see http://www.smartscience.org/nanotechnology_the_convergence.htm)
ICAN Productions with Oregon Public Broadcasting will produce three one-hour Fred Friendly televised seminars "conducted as live events in partnership with three museums and science centers located in various regions throughout the United States. Lawrence Hall of Science will develop a supporting web resource for the project, including moderated online forums. The American Association for the Advancement of Science will direct a community outreach initiative targeted to specific stakeholders in 7 to 15 cities throughout the U.S. and Earth & Sky will produce a series of 4-12 radio spots focused on issues raised during the Seminars. Materials for use in formal and informal educational settings include videos and video guides…. The Fred Friendly Seminars begin by painting "little pictures" – dilemmas or conflicts such as almost anyone would confront in their lives – and end with an informed and emotionally compelling exploration of the large ethical, legal and public policy questions at the heart of a well-functioning democratic society. We plan to build a series of 3 reality-constrained 'little pictures,' hypotheticals that will allow a skilled moderator to lead scientists, social, ethical, and legal scholars, policy and decision makers, business leaders, and members of the general public into thoughtful discussions about the complex tradeoffs ahead as nanotechnology moves increasingly from theory to application."
(http://www.smartscience.org/nanotechnology_the_convergence.htm)

Target Audience:
Adults

Goal:
Examine ethical, social, legal and environmental issues surrounding nanotechnology applications

Evaluation conclusions:

Front-end (*Convergence*, 2005):
Surveys about ESLE issues completed by 22 scientists and 20 individuals with experience in such issues revealed that,

- Most view nanoscale science and technology as a continuum of discovery rather than a discontinuity
- Nanoscale science is differentiated by its interdisciplinary quality
- Nanoscale discovery is proceeding faster than most anticipated

"Inverness Research Associates and Edu, Inc. will conduct both formative and summative evaluation of the project components." Retrieved from www.nsf.gov.

Contact: P.I. Cynthia Needham, Cynthia@smartscience.org

References:
Convergence: Final Technical Report: Grant no.: DE-FG02-01ER63170. (undated). Made available by Cynthia Needham, August 16, 2005.

ScienCentralNews

What it is:[6] (see www.sciencentral.com)

ScienCentral Inc. (SCI) produces two-minute science news stories for ABC and NBC television networks, who distribute them to their local news affiliates. The ABC and NBC local news shows integrate the science stories into their daily evening programs. Under an NSF award, SCI has produced several nanoscience news stories. (E. Augenbraun, personal communication, October 20, 2005)

Target Audience:
Viewers of local ABC and NBC news programs

Goal:
To reach millions with contemporary science news stories

Evaluation conclusions:
Airing of the science stories is at the discretion of the local affiliate news producers. Each broadcast of a ScienCentral story is called a "hit." The table to the right shows story categories and hits per story category for 2003 to early 2005. "…nano stories generally do not do as well as stories that have natural places to fit into the local newscast. Most news broadcasts have a health report and a report near the weather that is somehow related to weather. Nano stories have a hard time fitting in, unless we peg them to health or topical news events." (E. Augenbraun, personal communication, October 20, 2005)

Category	**Hits**
Health	36.1
Psychology	33.7
Brain Sciences	30.2
Learning	24.9
Genetics	22.2
Technology	22.1
Biology	21.7
Human Behavior	19.3
Nanotechnology	**19.3**
NOVA content	19.2
Other	16.2
Space	14.0
Oceans & Climate	13.6
Environment	4.0

Summative evaluation by Jon Miller, Northwestern University, as reported in Augenbraun's 2005 *Nature* article, concludes that 4 million US adults watch any particular local news story and 44% recall the content weeks later. This result is not specific to nanotechnology but applies to all ScienCentral aired stories.

Contact: P.I. Eliene Augenbraun, ea@sciencentral.com

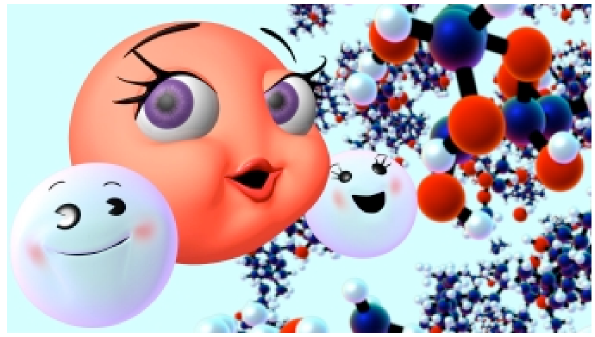
References:

Augenbraun, E. (2005, January 27). Weapon of mass attraction: Scientists should embrace, not fear television news. *Nature*, *433*, 357-358.

[6] The image shows vials of peptide amphiphiles that can act as scaffolds to support and induce the formation of blood vessels, from a story entitled "Building Blood Vessels" dated 10/21/05 at http://www.sciencentral.com/articles/view.php3?language=english&type=&article_id=218392665

Molecularium™

What it is: (see http://www.molecularium.rpi.edu/)



Riding Snowflakes is a 20 minute animated Digital dome theater show produced by Rensselaer Polytechnic Institute's NSEC.[7] "The show follows a cast of characters, based on atoms, as they move throughout the universe from the perspective of a magical ship….[which] can view matter on both the human and molecular levels. At first, a character representing an oxygen atom ("Oxy") meets two hydrogen atoms ("Hydro" and "Hydra"), and teaches them to use the ship.…The atoms, who combine to form a water molecule, descend to earth and ride snowflakes, flying around and through them. As a snowflake melts and becomes a raindrop, the [ship] voyages inside it, where the characters greet their fellow water molecules. More adventures quickly ensue: The [ship] voyages to another galaxy, returns to Earth with the steering help of a lonely carbon atom ("Carbón") seeking life forms, rides a polymer roller-coaster, and explores the objects in a kid's pocket, from a penny to a stick of gum. The adventure concludes with a "DNA ride" as the characters discover the secret of life." (Dizikes, 2004, p. 2) Hands- on activities, written materials and quizzes reinforce the show's ideas in the planetarium or classroom (Molecularium™ Resource Guide, 2005). The show is currently at the Children's Museum of Science and Technology in Troy, NY, and the Houston Museum of Science.

Target Audience:
5-10 year olds, grades K-5

Goals:

1. Children "learn that everything is made of atoms and molecules"
2. Children "learn about the three states of matter as they travel into a cloud, watch a snowflake form and count the number of water molecules in a raindrop."
3. Older children will learn about polymers. (Molecularium™ Resource Guide, 2005)

Evaluations conclusions:

Formative (http://www.molecularium.rpi.edu/teachers.html):
Troy public schools provided feedback. "When asked to draw an atom, a molecule, and a polymer, and asked about states of matter, children's understanding, based on quantitative assessment, tripled." Other information not available yet.

Contact: P.I. Linda Schadler, RPI, Schadl@rpi.edu

References:

[7] Image shows characters Oxy, Hydro, and Hydra as a water molecule, from http://www.nsf.gov/news/news_images.jsp?cntn_id=101824&org=NSF

Dizikes, P. (2004, Summer). Rensselaer's Molecularium℠ project teaches kids what "Matters". *Rennsselaer Research Quarterly*. Retrieved August 17, 2005, from http://www.rpi.edu/research/magazine/summer04/molecularium_1htm

Molecularium™ Resource Guide. (2005, March 30). Retrieved October 1, 2005, from http://www.molecularium.rpi.edu/teachers.html

SCHOOL-BASED PROJECTS

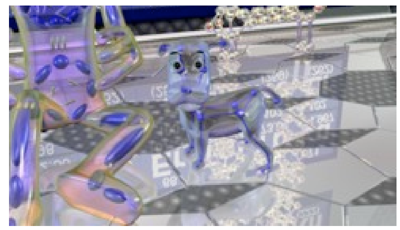
NanoKids ™

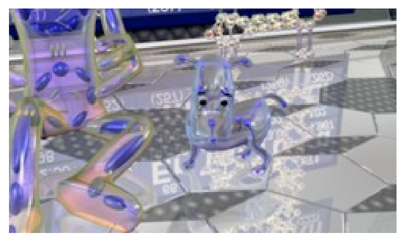
What it is: (see www.nanokids.rice.edu)

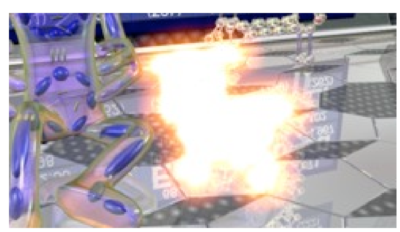
NanoKids™ is part of the educational outreach program at the Center for Nanoscale Science and Technology, Rice University, Houston, Texas. Its intent is to provide teachers and students with materials to increase understanding of science at a molecular level. The proof of concept package includes:

- A 20-minute instructional DVD with two lessons (Intro to nanoscale setting; DNA), featuring 3D computer animation of lab synthesized anthropomorphic molecules that exhibit human shapes and characteristics. The student player becomes NanoScholar who enters the NanoLoft to investigate the world of atoms and molecules at the nanometer scale along with the NanoKids.[8]
- A teachers' study guide explaining DVD, hands-on exercises and discussions, quizzes, experiments, decks of NanoCards© to teach elements names and symbols
- An interactive digital student workbook with four areas (Research Lab; NanoLoft; DNA room; Nanotechnology room) where students access science information, exercises, games, songs, sound-bites, out-of the-box imagination
- A parents guide introducing subject matter
- Website for general public and project participants

Photo 1: NanoDog is a single molecule. See the atoms in his structure? If you take one away, he will no longer be NanoDog.
Photo 2: He could be just a little different -
Photo 3: or completely different.
Photo 4: It all hinges on which atoms are changed. His personality and looks depend on how his atoms go together.







Target Audience:

Students in grades 6-8, 11-15 year olds

Goals:

1. "Generate students' interest in nanotechnology"
2. "Increase students' comprehension of chemistry, physics, biology, and materials science"
3. "Demonstrate the interdisciplinary nature of science at the nanoscale"
4. "Integrate nanoscale science and technology into existing curricula"
5. "Empower students, teachers and parents with the understanding of how nanoscale science and technology can impact their lives"

[8] Image and captioning are from http://cohesion.rice.edu/naturalsciences/nanokids/explore.cfm?doc_id=3134

6. "Provide information to the public about what is know about nanoscale science and technology" (Harris & Furuichi, 2004, p. 5)

Evaluation conclusions:

Proof of concept (Harris & Furuichi, 2004):
Beta test was implemented in 2003-2004 school year with 13 teachers from 10 middle schools and 1 high school in Houston area. Evaluation focused on usability and effectiveness of materials. [only student information about nanotechnology is summarized below]

1. Before the experience, 13% (n =214) of students agree that they "know about nanotechnology" and 77% agree that they "want to learn more about nanotechnology."
2. After the experience, 64% (n = 167) of students agree that they "want to learn more about nanotechnology." The knowledge question was not asked in post-survey.
3. The pre-survey and post-survey students were not the same so change in understanding was not assessed. However, nanotech items that showed notable differences in percentages of students answering correctly include:
    a. T/F: "Understanding the nanoscale helps me understand the real world around me." (pre, 51% correct vs. post, 73%)
    b. Multiple choice: "Which one is the correct order of scale from large to small? … Macro, Milli, Micro, Nano" (pre, 27% correct vs. post, 40%)
    c. Multiple choice: "A nanometer is …one-billionth of a meter" (pre, 41% correct vs. post, 66%)
    d. Open-ended: "List one thing scientists can do using nanotechnology" (pre, 46% gave adequate response vs. post, 89%)
4. The majority of students said the video picture and sound were clear, the speech not hard to understand, the music enjoyable and the characters likable. Multiple viewings of the DVD for understanding were reported by both students and teachers.
5. The majority of students agreed the interactive workbook was easy to navigate and the games were enjoyable.
6. Small group student discussion revealed some confusion about what was real and what was symbolic in the DVD animation (e.g., whether or not there is a wrap around molecule).
7. Students liked using computer technology to learn.

Contact: P.I. James M. Tour, tour@rice.edu

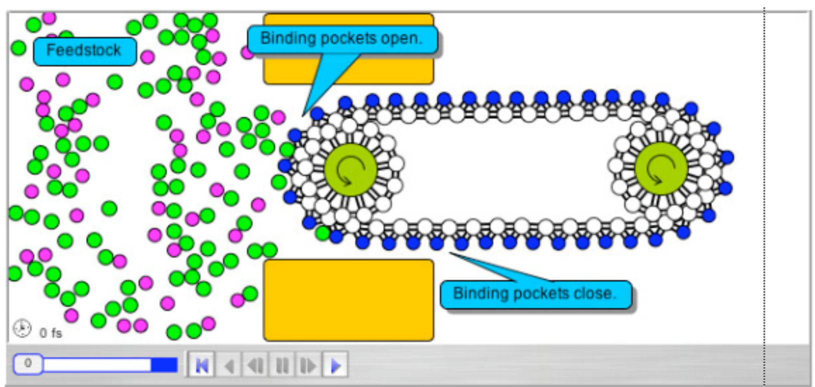
References:
Harris, C., & Furuichi, A. (March 9, 2004). *NanoKids pilot project evaluation report.* Retrieved August 17, 2005, from http://cohesion.rice.edu/naturalsciences/nanokids/index.cfm

Molecular Workbench[9]

What it is: (see http://workbench.concord.org/)
The Concord Consortium is a nonprofit educational research and development organization in Concord, MA. The Consortium offers Molecular Workbench as free modeling software, in which molecular dynamics simulations demonstrate the atomic-scale mechanisms of fundamental phenomena in physics, biology and chemistry. With Molecular Workbench, “students can visualize abstract atomic-scale phenomena, observe emergent behavior, design model-based experiments, and reason about the relationship of atomic-scale interactions to macroscopic phenomena in a structured environment. A wide range of tools is available for analyzing a model, including graphs, display options, virtual temperature and pressure probes, and more…. The software includes the easy-to-use Workbench authoring environment that supports the design of interactive activities linking atomic-level models to a broad range of core science concepts. In addition to setting the parameters of the model, the authoring environment allows the activity designer to provide instructions, scaffolding, and performance assessment instruments related to the model, including open-ended questions and multiple-choice items” (*The Molecular Workbench Software,* 2005, pp. 1-2).

See http://mw.concord.org/modeler/ for a complete description and product tour and for a collection of interactive models and activities made using Molecular Workbench, including ones about nano machinery:

- Nano differential gears
- Nano racks and pinions
- Nano machinery
- Molecular planetary gearsets
- Molecular sorter
- Hypothetical machine to operate at nanoscale
- Nano conveyor belt (shown to the right).[10]



Target audience:
Students in middle school and high school

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[9] Note that the work of the Molecular Workbench project is continued in the CC-Atoms Project (http://ccatoms.concord.org/) , Molecular Logic (http://molo.concord.org/) and the Molecular Literacy Project (http://molit.concord.org/), which are not summarized in this document.

[10] Image and text from simulation at http://mw.concord.org/modeler/. “This nanomachine looks like a conveyor belt, and it also transports stuff in a similar way. But there are a couple of significant differences: (a) Unlike macroscopic conveyor belts that the transported materials sit on top of the upper part of the belt, this nano conveyor can transport molecules in both parts of the belt (because it uses intermolecular forces to bind molecules). (b) The belt makes use of conformational changes of its molecular structure when it moves between the two driving nano wheels to bind and release molecules. Note that the "teeth" of the belt opens widely when they move into contacts with the driving wheels, whereas they close when they leave the wheels. This "open-close" mechanism of the binding pockets is responsible for transporting the green molecules from the mixture on the left compartment to the upper part of the right compartment.”

Goals:

1. To provide a rich environment that makes the atomic level familiar, predictable, and connected with the macroscopic world
2. To understand the effect of such an environment on student learning (http://workbench.concord.org)

Evaluation conclusions:

Implementation (http://workbench.concord.org/research):
Evaluation focused on one-week mini-modules for research purposes including Molecular Workbench software, macro-micro connections and hands-on activities. Mini-modules cover:

- States of matter: "focused on matter in its various states and how these reflect different arrangements and motions of the molecules. Students are asked to reason using the kinetic molecular theory."
- Aquatic solutions and our cells: "addresses essential ability of water to dissolve and transport some substances and not others, and the role of membranes in regulation concentrations of dissolved substances"
- From monomers to polymers: "explore the unity and diversity of life's building blocks, and the ways monomers can be assembled into key polymers: particularly polysaccharides and proteins."
- Shaping proteins: "explore how proteins fold into specific shapes. They also learn what causes a protein to lose its ability to function, and about molecules and diseases associated with change in structure."

Measurement included pre-post tests to assess content knowledge, student class documents, and clinical interviews to learn how students reason. The pre-post tests asked students to reason about interactions of molecules underpinning the modeled biological, chemical or physical phenomena. Post-test scores were significantly higher in most classes. No gender difference was found with pre-test as a covariate. Post-tests also showed a marked decrease in misconceptions.

The interviews focused on the extent to which student reasoning about the phenomena became more expert. "The studies indicate that middle and high school students can acquire fairly robust mental models of the state of matter, dissolving and diffusion, and protein folding through guided explorations of computational models of matter based on molecular dynamics." (See http://workbench.concord.org/research for more details on results from specific modules.) Students were also able to transfer their understanding to new situations. Interviews conducted several months after module exposure indicate retention of active mental models and accurate reasoning about atomic interactions.

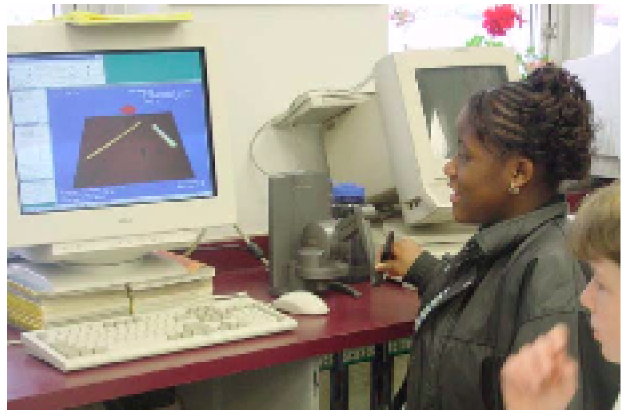
Contact: P.I. Barbara Tinker, Barbara@concord.org

References: see http://workbench.concord.org for numerous research papers

Tinker, B. (2005, November 4). *The Molecular Workbench Software*. Description made available by Barbara Tinker, Concord Consortium, Concord, MA.

nanoManipulator

What it is: [11] (see http://www.cs.unc.edu/Research/nano/cismm/nm/index.html)



A team of researchers from the departments of Computer Science and Physics and Astronomy at the University of North Carolina-Chapel Hill (UNC-CH) and Mathematics, Science and Technology Education at NCSU have developed the nanoManipulator (nM) as a natural interface to an atomic force microscope (ATM). The nM permits scientists and students to use a joystick to manipulate, and virtually see and feel, a live virus. With the nM and a force-feedback joystick device, students control the microscope probe across the sample. The haptic feedback includes sensations of hardness, elasticity, friction, morphological shape, and stickiness. Dr. Gail Jones is directing research about the use of the nM with middle school and high school students and the impact of active manipulation of viruses and the visual and haptic feedback on their learning about virus structure and function.

The instructional experience is completed in 5-6 classes. It typically involves an overview of nanotechnology, nanoscale, scientific notation, microscopy, descriptions of ATM and nM, introduction to morphology and physiology of viruses. Students then move through a series of stations every 15-25 minutes:

- Students practice with nM and stored virus images and develop a research question
- Powers of ten video from www.powersof10.com
- Relative size exercise
- Simulation of AFM
- Virus Investigation: Students use AFM and nM to explore viruses and collect data to answer question they have about virus morphology or function
- Interview university researchers about work, education, their lives
- Write newspaper article about their experiences

Target Audience:
Middle school and high school students

Goals:
1. To give students virtual hands-on experience with objects at the nanometer scale
2. To improve students' understanding of virus morphology and diversity of types

Evaluation conclusions:

Jones, M. G., Andre, T., Kubsko, D., Bokinsky, A., Tretter, T., Negishi, A., Taylor, R., & Superfine, R. (2004) "examined hands-on experiences in the context of an investigation of

[11] Image from http://www.cs.unc.edu/Research/nano/ed/index.html

viruses and explored how and why hands-on experiences may be effective. We sought to understand whether or not touching and manipulating materials and objects could lead to a deeper, more effective type of knowing than that we obtain from sight or sound alone. Four classes of high school biology students and four classes of seventh graders participated in the study that examined students' use of remote microscopy with a new scientific tool called the nanoManipulator, which enabled them to reach out and touch live viruses inside an atomic force microscope. Half of the students received full haptic (tactile and kinesthetic) feedback from a haptic joystick, whereas half of the students were able to use the haptic joystick to manipulate viruses but the tactile feedback was blocked. Results showed that there were significant gains from pre- to post instruction across treatment groups for knowledge and attitudes. Students in both treatment groups developed conceptual models of viruses that were more consistent with current scientific research, including a move from a two-dimensional to a three-dimensional understanding of virus morphology. There were significant changes in students' understandings of scale; after instruction, students were more likely to identify examples of nanosized objects and be able to describe the degree to which a human would have to be shrunk to reach the size of a virus. Students who received full-haptic feedback had significantly better attitudes suggesting that the increased sensory feedback and stimulation may have made the experience more engaging and motivating to students" (p.55).

Jones, M.G., Andre, T., Superfine, R., Taylor, R. (2003) found that a weeklong unit on viruses using the nM showed that high school "students' understandings of microscale, virus morphology, and dimensionality changed as a result of the experiences. Students' conceptions moved from a two-dimensional textbook-like image of a virus to a three-dimensional image of an adenovirus" (p. 303).

Contact: P.I. Gail Jones, gjones@email.unc.edu

References:

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Additional K-12 Instructional Materials listed at North Carolina State University: http://ced.ncsu.edu/nanoscale/materials.htm provides nanotechnology and nanoscale investigations:

1. Mystery of the Sick Puppy

"In this unique software you explore characteristics of viruses with the use of atomic force microscopy to figure out what is making a puppy ill. The program involves you in experimenting with the capsid to determine the shape of the virus, testing for DNA or RNA, and determining the size of the virus to make your diagnosis. This program is available free to educators and students for use in instructional contexts but is copywrite protected for other uses."

2. Viruses

"Learn about viruses through our new animated powerpoint presentation. Watch a phage invade a bacterium. Learn about how viruses take over a cell and multiply. Examine different virus structures and learn about the history of virology research. This program is available free to educators and students for use in instructional contexts but is copywrite protected for other uses."

Nanostructures Module for Middle and High School Classrooms, Northwestern University

What it is: (see http://www.nsec.northwestern.edu/mwm.htm)
Northwestern University's Nanoscale Science and Engineering Center is "working with the Materials World Module (MWM) program established at Northwestern University in 1993 to develop, implement, and ensure the success of a new module entitled "Functional Nanostructures." The nanostructures module is being designed to supplement existing science and math curricula. It will introduce nanoscale science through unique design challenges and a collaborative team approach, thus enabling students to make important connections between scientific theory and real-world applications. This new module will begin with a teacher demonstration to pique the interest of the students, followed by a series of activities and collaborative design projects. The module will meet goals consistent with the national standards for science education, help students develop inquiry skills, conduct a quantitative, hands-on laboratory investigation, and learn the societal impact of science and technology. To date preliminary project ideas have been developed, a pilot testing team was assembled, development and pilot testing of staging activities is completed, and alpha and beta field testing is complete. Final revisions are scheduled for September 2003, after which multimedia support resources will be developed and editing and graphic layout work of the teachers' and students' manuals will begin."

See http://www.materialsworldmodules.org/modules/m_description.htm for other Materials World Module descriptions

Target audience:
Students in middle school and high school

Goals: (goals refer to all the Materials World Modules, not nano in particular; see http://www.materialsworldmodules.org/teaching.htm)

"The major goal of the Materials World Modules is to engage students in the processes of inquiry and design.
Content goals:
- Learn scientific and mathematical principles by applying them to solve real-world problems
- Develop an understanding of the science and engineering of materials by applying knowledge from physical, life, and earth sciences to create materials for specific purposes
- Learn about the interrelationship between science and technology and their influences on local, national, and global environments
- Understand contemporary problems in society, including problems of personal and community health, natural resources, environmental quality, and human-induced hazards and appreciate the use of science and technology to meet these challenges
- View the history and nature of science as a human endeavor, producing new knowledge, supported by developing technology

Process goals:
- Ask and refine researchable, productive questions
- Plan and conduct a quantitative, hands-on laboratory investigation, using journals to guide investigation and record progress

- Work within a collaborative team to complete a design project
- Develop solutions through iterative design: challenge, problem definition comparing options, implementation, reflection, redesign
- Develop a designer's eye to analyze trade offs and decisions an engineer may encounter in creating artifacts"

Evaluation conclusions:
Field testing is being written up by Emma Tevaarwerk and is not available yet. The news report presented verbatim below refers to all Materials World Modules as well as the Nanotechnology module.

"Materials World Modules Used as Supplemental Three-week Course *written by: Emma Tevaarwerk*

Materials World Modules kits and booklets were used as part of the program for the Center for Talent Development (http://www.ctd.northwestern.edu) this past June and July. Veteran MWM high school teachers Kenneth Turner (Schaumberg HS) and Kate Heroux (Lake Forest HS) and middle school teachers Beatrise Revelins (Deerfield MS) and Charles Stempien (Deerfield MS) guided students through three week intensive courses consisting entirely of MWM modules. The Composites, Concrete, Sports Materials, Biodegradeable Materials, Food Packing, Biosensors, Polymers, and Smart Sensors modules, as well as the new Nanotechnology module were all used as part of the course.

The teachers report that the students were so excited about the modules that they arrived early to class each day, just to find out about what they would be covering a little bit sooner. The design projects were especially popular, as students were given a lot of creative room to play with. Students engaged in activities such as designing a kite with fiber re-enforced materials and making a new food packaging product. One group of students designed a way to collect of the small particles that typically settle to the bottom of a box of cereal, another an insulated delivery capsule for hot chocolate.

A female student from Winnetka, Illinois, was very excited about the Concrete module, saying "You learn the concepts better because it's hands-on…instead of just reading , you get to see and do. I was the official 'weigher' of the group, so I got to…find the mass and everything…it was pretty cool!" She went on to say that she had had a conversation with an adult about concrete at her parent's dinner party, which she related was a very rewarding experience for her."
http://www.materialsworldmodules.org/news.htm, dated 8/25/05

Contact: Emma Tevaarwerk, mwm@northwestern.edu

In addition, the National Center for Learning and Teaching in Nanoscale Science and Engineering is developing modules for middle and high school students. The first two modules, started in the spring of 2005, are entitled "Nanomaterials for Energy, Environment, and Pharmaceuticals" and "Manipulation of Light in the Nanoworld."
(contact P.I. R.P.H.Chang, r-chang@northwestern.edu)

NanoLeap

What it is: (see http://www.mcrel.org/nanoleap/index.asp)
" Mid-continent Research for Education and Learning (McREL) has partnered with the Stanford Nanofabrication Facility (SNF) and ASPEN Associates to develop and evaluate two proof of concept modules that integrate real-world nanoscale science and engineering research and where they best fit into a standards-based science, technology, engineering, and mathematics (STEM) curriculum. Two modules (NanoLeap Chemistry and NanoLeap Physical Science) will be developed that will include student activities, experiments, and assessments, to promote student learning of the interdisciplinary nanoscale core concepts of force (physics) as it relates to properties of matter (chemistry), scale (mathematics), scientific instrumentation (technology), and processes (inquiry). The standards-based proof of concept modules will serve as application and replacement units respectively with materials that can be used in one block or be inserted into the curriculum at appropriate times. Teacher guides and an online professional development will address the varied needs of the science education community and ensure effective classroom implementation." (personal communication, J. Ristvey, October 27, 2005)

Target Audience
Students and teachers in grades 9-12: Physical Science (Grade 9), Chemistry (Grades 10-12)

Goals:
Project Goals:

1. "To explore where nanoscale science, technology, engineering, and mathematics concepts can fit into high school physical science and chemistry classes in a manner that supports students in learning core science concepts."
2. "To determine a viable approach for instructional materials development in the areas of nanoscale science, technology, engineering, and mathematics" (http://www.mcrel.org/nanoleap/project_goals.asp).

"NanoLeap project expects to achieve the following:

1. Teachers who participate in training on the NanoLeap materials will be able to implement the curriculum in a manner that supports inquiry-based learning.
2. Students in classrooms where teachers fully implement the NanoLeap materials (treatment group) will demonstrate a level of understanding of core science concepts that is at least equal to, if not greater than, that of students in classrooms where the NanoLeap materials are not implemented (control group)
3. Students in classrooms where teachers fully implement the NanoLeap materials (treatment group) will demonstrate greater levels of interest and engagement in learning science than students in classrooms where the NanoLeap materials are not implemented (control group).
4. Students in classrooms where teachers fully implement the NanoLeap materials (treatment group) will demonstrate an increased understanding of nanoscale science, technology, engineering, and mathematics concepts, applications, and careers" (personal communication, J. Ristvey, October 27, 2005).

Evaluation conclusions:
Not available yet: "A formative evaluation, including pilot and field tests, will provide project staff with data to inform the development and implementation processes. The summative evaluation will assess the effectiveness of the project in achieving its articulated goals and impact on student achievement and teacher practice." (personal communication, J. Ristvey, October 27, 2005)

Contact: P.I. John Ristvey, Jristvey@mcrel.org ; Christine Morrow Co-PI nanoleap@mcrel.org

Nanoscience and nanotechnology education in the Los Angeles Unified School District

What it is: (see http://www.cnsi-uc.org/education/NanoEDU.htm)
Graduate students and postdocs at California NanoSystems Institute (CNSI) at University of California, Los Angeles, are working with 35 high school science teachers from the Los Angeles Unified School District on five different hands-on classroom experiments in nanoscience and nanotechnology. Through workshops, teachers learn the scientific background needed to understand the experiments, learn how to do the experiments with their students, and learn how they fit with state science standards. The experiment materials on the topics below include instructions, handouts, movies and images available at http://voh.chem.ucla.edu/outreach.php3 :

- Self-assembly
- Magnetic fluids
- Photolithography
- Scanning tunneling microscope
- Solar cells

"Two dozen high school science teachers were intently bent over worktables in a Geology Building classroom putting together glass "sandwiches," two small glass rectangles smeared in between with a chemical solution.[12] Ordinary office binder clips held the pieces together. Underlying this experiment that looked easy enough for a ninth grader to perform was a new realm of science that is as cutting-edge as most of these teachers had ever encountered before — nanoscience. They were using nanocrystalline titania stained with raspberry or spinach juice to absorb enough energy from the sun to create solar cells" (http://www.today.ucla.edu/2003/030812hs_nanoscience.html dated August 12, 2003)

Target audience:
High school students and teachers

Goals:
See instructions for specific experiments at http://voh.chem.ucla.edu/outreach.php3

Evaluation conclusions:
Not available

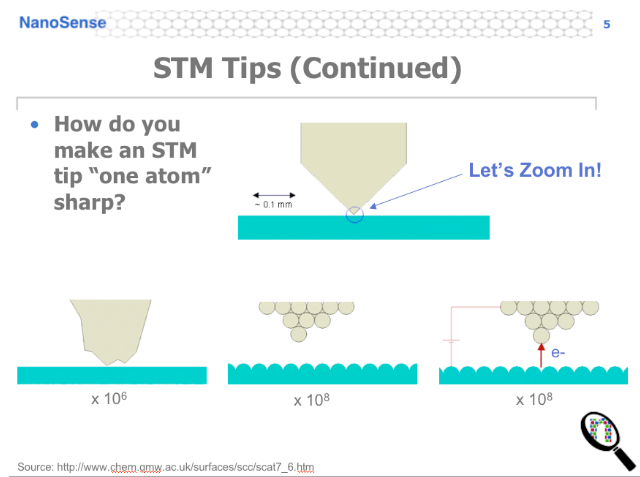
Contact: P. I. Sarah Tolbert, Tolbert@chem.ucla.edu

[12] Image from http://www.today.ucla.edu/2003/030812hs_nanoscience.html

NanoSense[13]

What it is: (see http://nanosense.org)
SRI International, Menlo Park, CA, is developing five to six high school level classroom units that focus on real-world examples of nanotechnology and the underlying scientific concepts. Units will "reflect interdisciplinary nature of nanoscience; emphasize fundamental nanoscience concepts such as size and scale and surface dominance of reactions; and explore applications of nanoscience and how they could affect society, policy, and students' lives. Each unit will include professional development materials for the teacher, activities and instructional materials for students, and embedded formative and summative assessments. Most units will span two to four class periods, and some may include multiple components from which the teachers can select….Current and planned units include the following:"

- Size Matters: Introduction to Nanoscience (pilot-tested in May-June 2005)[14]
- Clear Sunscreen
- Nanofiltration
- Quantum Dots
- Carbon Nanotubes
- Catalysis/Clean Energy



Target Audience
Students in grades 9-12

Goals:
1. "Help students visualize physical, chemical, and biological principles that govern the behavior of particles on the nanoscopic scale"
2. "Help students understand underlying principles, applications, and implications of nanoscale science" (http://nanosense.org)

See Schank, Stanford, Rosenquist, & Wise, 2005, for more detail on enduring understandings, essential questions, key knowledge and skills.

Evaluation conclusions:

Front-end (Sabelli, Schank, Rosenquist, Standford, Patton, Cormia, & Hurst, 2005; Schank et al. 2005; Wise, Schank, Stanford, Rosenquist, submitted):
A March, 2005, workshop of educational researchers, science educators, nanoscientists, informal learning experts and workforce development staff concluded that

- challenges of understanding nanoscience are conceptual and practical: "objects and concepts at the nanoscale are hard to visualize, difficult to describe, abstract, and their relationships to the observable world can be counterintuitive. This suggests the need to conceptualize a

[13] Much of the NanoSense reference material that is not summarized here discusses school, student and teacher issues that are not relevant to the informal settings and volunteer audiences of the NISE Network projects.
[14] Image from Teacher's PowerPoint (SM_SPMSlides.ppt) in Size Matters: Lesson 4: Tools of the Nanosciences http://nanosense.org/activities/sizematters/index.html

continuum of scales that can represent the non-observable phenomena in nature to help students integrate their views of matter at all scales" (Wise et al., submitted, p. 6).

- "some central epistemological ideas …can lead to better understanding of why science at the nanoscale requires a different educational approach. Two examples of such ideas are (1) small quantitative changes in some property can aggregate towards large *qualitative* differences and (2) all matter can be considered as either individual particles, as small groups of particles, or as large group of particles, each entailing different scientific models and theories" (Wise et al, submitted, p. 6).
- "a discussion of the social implications of nanotechnology as part of nanoscience education is important to give students tools to help them put in perspective the significant hype, positive as well as negative, found in most public discussions of the topic" (Wise et al, submitted, p. 7).

"Many nanoscale education projects emphasize size as the lone characteristic of the nanoscale …. The group agreed that a unified approach to nanotechnology education, independent of audience or subject depth, requires addressing simultaneously four aspects of the physical world. These aspects are size, force, properties, and time. As sizes decrease, forces, properties, and time may also change" (Sabelli et al., p. 3, 17).

The group identified foundational concepts to teach high school students:

- "Surfaces (e.g., surface chemistry, surface physics, interfaces)
- Unique properties at the nanoscale (e.g., electromagnetic, mechanical, optical)
- Self-assembly (e.g., bionanotechnology, crystal structures)
- Quantum principles and probability (e.g., quantized energy, quantum numbers)
- Scale (e.g., size, number, forces, properties, time)
- Energy (e.g., role in interparticle interactions, scale of energy and power)
- Nanostructures (e.g., nanotubes, colloids, thin films, quantum dots)
- Fabrication (e.g., tools, processes, metrology)" (Schank et al, 2005, p. 28).

Formative evaluation (Schank et al, 2005):
The piloted *Size Matters* six-lesson unit uses readings, Power Point presentations, worksheets and lab activities to introduce concepts related to size and scale, unusual properties of nanoscale and example applications. Goals for this unit include

1. "The study of unique phenomena at the nanoscale could vastly change our understanding of matter and lead to new questions and answers in many areas, including health care, the environment, and technology."
2. "There are enormous scale differences in our universe, and at different scales, different forces dominate and different models better explain phenomena."
3. "Nanosized particles of any given substance exhibit different properties than larger particles of the same substance."
4. "New tools for observing and manipulating matter increase our ability to investigate and innovate." (http://nanosense.org)

Teachers reviewed early materials across several revisions. Teachers also gathered feedback from students to revise a science fiction story illustrating future influence of nanotechnology on everyday life. EDC evaluator Ellen Mandinach and principal designers observed use of *Size Matters* pilot materials in AP chemistry classes for a full week of activities in spring of 2005:

- Card sort activity worked well. This activity involves placing cards representing different items (e.g., height of a basketball player or diameter of a gold atom) at appropriate places on a number line of 10^1 to 10^{-10} meter (see http://www.nanosense.org/activities/sizematters/sizeandscale/SM_Lesson2Teacher.pdf)
- Observations concluded that students "were unclear about how general physical and chemical principles could apply to these [nanoscale] objects; how and why smaller objects had different properties was confusing to them. While students were able to correctly state that things 'work differently' at the nanoscale level, with a lack of alternative scheme for understanding, they continued to draw on their macroscale-level knowledge to try and explain specific phenomenon" (Schank et al, 2005, p. 32). The chemistry teacher revealed a similar difficulty.
- "An understanding of the tools and methods for studying nanoparticles is one that students could benefit from greatly" (Schank et al, 2005, p. 37).

Contact: P.I. Patricia Schank, Patricia.schank@sri.com
nanosense-contact@chemsense.org

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